

July 1, 1998
American Society Of Mechanical Engineers
SEC III NCA A98
1998 ADDENDA SUMMARY OF CHANGES

Page xxvii

Changes given below are identified on the pages by a margin note, **98**, placed next to the affected area.

Page	Location	Change
3	NCA-1100	Title revised
	NCA-1110	(1) Title revised (2) Revised in its entirety
17	NCA-3125	Last sentence of subparagraph (a) corrected by Errata
23	NCA-3370	Title revised
24	NCA-3420	Subparagraphs (c) and (e) corrected by Errata
26	NCA-3520	Subparagraph (o) added by Errata
31	NCA-3841	Subparagraph (f) revised
32	NCA-3842.2	Subparagraph (d) revised
36	NCA-3856.3	Subparagraph (d) revised
52	NCA-5220	Subparagraph (g) corrected by Errata
54, 55	NCA-5290	(1) Title revised (2) Subparagraphs (a), (b), and (c) revised
59	NCA-8120	Subparagraphs (d), (e), and (f) revised
63	NCA-8162	Deleted
	NCA-8163	Redesignated as new NCA-8162
65	NCA-8310	Subparagraph (c) revised
72	NCA-9200	Definition of <i>Modification</i> deleted

NOTE: Volume 42 of the Interpretations to Section III, Divisions 1 and 2, of the ASME Boiler and Pressure Vessel Code follows the last page of this Edition.

July 1, 1998
American Society Of Mechanical Engineers
SEC III NCA INTRODUCTION
Introduction

**1998 ASME
BOILER &
PRESSURE VESSEL CODE
AN INTERNATIONAL CODE**

III

Subsection NCA

General

Requirements

for Division 1

and Division 2

RULES FOR

CONSTRUCTION

OF NUCLEAR

POWER PLANT

COMPONENTS

[ASME logo] The American Society of
Mechanical Engineers

ACI STANDARD 359-98



LOGOS

AN AMERICAN NATIONAL STANDARD

IMPORTANT INFORMATION ON THE 1998 BOILER AND PRESSURE VESSEL CODE ADDENDA DISTRIBUTION SCHEDULE

There is a change in the way the Addenda to the 1998 Edition of the ASME Boiler and Pressure Vessel Code are distributed. The 1998 Edition, published July 1, 1998, incorporates the 1998 Addenda revisions, additions, or deletions. There will be no separate 1998 Addenda issued in a replacement page format. Two additional Addenda to the 1998 Edition, in the form of replacement pages, will be issued on July 1, 1999 and July 1, 2000.

The Summary of Changes published with the 1998 Edition lists and describes the revisions that are part of the 1998 Addenda. These changes are identified with a margin note, **98**, denoting the affected area.

The Addenda for 1999 and 2000 will also have a Summary of Changes and identifiers printed on the replacement pages. The revisions, additions, or deletions will be incorporated directly into the affected pages. It is advisable to retain the title sheets and all replaced pages for reference.

The effective dates for Code Editions and Addenda are described in the Foreword.

ASME BOILER AND PRESSURE VESSEL CODE

AN INTERNATIONAL CODE

(ACI STANDARD 359-98)

RULES FOR

CONSTRUCTION OF

**NUCLEAR POWER
PLANT COMPONENTS**

III

Subsection NCA

General

**Requirements
for
Division 1
and
Division 2**

1998 Edition

July 1, 1998

**ASME BOILER AND
PRESSURE VESSEL
COMMITTEE
SUBCOMMITTEE ON
NUCLEAR POWER**

**ACI-ASME JOINT
TECHNICAL
COMMITTEE**

**THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
NEW YORK, NEW YORK**

Date of Issue - July 1, 1998

(Includes all Addenda dated December 1997 and earlier)

This code or standard was developed under procedures accredited as meeting the criteria for American National Standards. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment which provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not "approve," "rate," or "endorse" any item, construction, proprietary device, or activity.

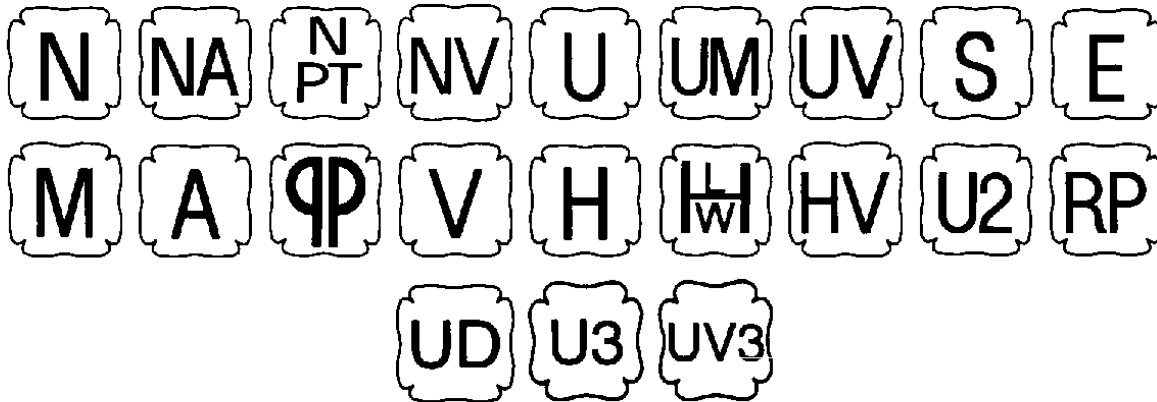
ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of any applicable Letters Patent, nor assume any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations issued in accordance with governing ASME procedures and policies which preclude the issuance of interpretations by individual volunteers.

The footnotes in this document are part of this American National Standard.

[ASME logo] ASME collective membership mark



LOGOS

The above ASME symbols are registered in the U.S. Patent Office.

"ASME" is the trademark of the American Society of Mechanical Engineers.

No part of this document may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Library of Congress Catalog Card Number: 56-3934

Printed in the United States of America

Adopted by the Council of the American Society of Mechanical Engineers, 1914.

Revised 1940, 1941, 1943, 1946, 1949, 1952, 1953, 1956, 1959, 1962, 1965, 1968, 1971, 1974, 1977, 1980, 1983, 1986, 1989, 1992, 1995, 1998

The American Society of Mechanical Engineers
Three Park Avenue, New York, NY 10016-5990

Copyright © 1998 by
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
All Rights Reserved

1998 ASME

BOILER AND PRESSURE VESSEL CODE

SECTIONS

I Rules for Construction of Power Boilers

II Materials

Part A - Ferrous Material Specifications

Part B - Nonferrous Material Specifications

Part C - Specifications for Welding Rods, Electrodes, and Filler Metals

Part D - Properties

III Subsection NCA - General Requirements for Division 1 and Division 2

III Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

III Division 2 - Code for Concrete Reactor Vessels and Containments

III Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

IV Rules for Construction of Heating Boilers

V Nondestructive Examination

VI Recommended Rules for the Care and Operation of Heating Boilers

VII Recommended Guidelines for the Care of Power Boilers

VIII Rules for Construction of Pressure Vessels

Division 1

Division 2 - Alternative Rules

Division 3 - Alternative Rules for Construction of High Pressure Vessels

IX Welding and Brazing Qualifications

X Fiber-Reinforced Plastic Pressure Vessels

XI Rules for Inservice Inspection of Nuclear Power Plant Components

ADDENDA

Colored-sheet Addenda, which include additions and revisions to individual Sections of the Code, are published annually and will be sent automatically to purchasers of the applicable Sections up to the publication of the 2001 Code. The 1998 Code is available only in the loose-leaf format; accordingly, the Addenda will be issued in the loose-leaf, replacement-page format.

INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code. The Interpretations for each individual Section will be published separately and will be included as part of the update service to that Section. They will be issued semiannually (July and December) up to the publication of the 2001 Code. Interpretations of Section III, Divisions 1 and 2, will be included with the update service to Subsection NCA.

CODE CASES

The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 1998

FOREWORD

The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety governing the design, fabrication, and inspection during construction of boilers and pressure vessels, and to interpret these rules when questions arise regarding their intent. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property and to provide a margin for deterioration in service so as to give a reasonably long, safe period of usefulness. Advancements in design and material and the evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction,¹ and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

¹ Construction, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are responsible for the application of these programs to their design.

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practice as determined by the engineer.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Boiler and Pressure Vessel Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Mandatory Appendix covering preparation of technical inquiries). Proposed revisions to the Code resulting from inquiries will be presented to the Main Committee for appropriate action. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by ASME.

Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute and published in *Mechanical Engineering*

to invite comments from all interested persons. After the allotted time for public review and final approval by ASME,

revisions are published annually in Addenda to the Code.

Code Cases may be used in the construction of components to be stamped with the ASME Code symbol beginning with the date of their approval by ASME.

Code Editions may be used on or after the date of issue shown in the Edition. After Code revisions are approved by ASME, they may be used beginning with the date of issue shown on the Addenda. Revisions to material specifications are originated by the American Society for Testing and Materials (ASTM) and other recognized national or international organizations, and are usually adopted by ASME. However, those revisions may or may not have any effect on the suitability of material, produced to earlier editions of specifications, for use in ASME construction. ASME material specifications approved for use in each construction Code are listed in the Appendices of Section II, Parts A and B. These Appendices list, for each specification, the latest edition adopted by ASME, and earlier and later editions considered by ASME to be identical for ASME construction.

Owners of nuclear power plants are cautioned that Code Editions, Addenda, and Cases to be used in construction shall be acceptable to the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

Each state and municipality in the United States and each province in Canada that adopts or accepts one or more Sections of the Boiler and Pressure Vessel Code is invited to appoint a representative to act on the Conference Committee to the Boiler and Pressure Vessel Committee. Since the members of the Conference Committee are in active contact with the administration and enforcement of the rules, the requirements for inspection in this Code correspond with those in effect in their respective jurisdictions. The required qualifications for an Authorized Inspector under these rules may be obtained from the administrative authority of any state, municipality, or province which has adopted these rules.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, method of fabrication, inspection, and safety devices. Permission may be granted to regulatory bodies and organizations publishing safety standards to use a complete Section of the Code by reference. If usage of a Section, such as Section IX, involves exceptions, omissions, or changes in provisions, the intent of the Code might not be attained.

Where a state or other regulatory body, in the printing of any Section of the Boiler and Pressure Vessel Code, makes additions or omissions, it is recommended that such changes be clearly indicated.

The National Board of Boiler and Pressure Vessel Inspectors is composed of chief inspectors of states and municipalities in the United States and of provinces in Canada that have adopted the Boiler and Pressure Vessel Code. This Board, since its organization in 1919, has functioned to uniformly administer and enforce the rules of the Boiler and Pressure Vessel Code. The cooperation of that organization with the Boiler and Pressure Vessel Committee has been extremely helpful.

The Code Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The Scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Code for vessels or components not considered to be within its Scope or may establish additions or deletions in that Scope. Accordingly, inquiries regarding such laws or regulations are to be directed to the issuing enforcement or regulatory body.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the ASME Boiler and Pressure Vessel Committee. ASME is to be notified should questions arise concerning improper use of an ASME Code symbol.

The specifications for materials given in Section II are identical with or similar to those of specifications published by ASTM, AWS, and other recognized national or international organizations. When reference is made in an ASME material specification to a non-ASME specification for which a companion ASME specification exists, the reference shall be interpreted as applying to the ASME material specification. Not all materials included in the material specifications in Section II have been adopted for use in this Section. Usage is limited to those materials and grades listed in at least one of the tables of Section II, Part D, Subpart 1, identified as applicable to this Section. All materials allowed by this Section and used for construction within the scope of these rules shall be furnished in accordance with material specifications

contained in Section II or referenced in Appendices A of Section II, Parts A and B except where otherwise provided in Code Cases or in this Section of the Code. Materials covered by these specifications are acceptable for use in items covered by the Code Sections only to the degree indicated in the applicable Section. Materials for Code use should preferably be ordered, produced, and documented on this basis. Material produced to an acceptable specification with requirements different from the requirements of the corresponding specification listed in Appendix A of Part A or Part B may also be used in accordance with the above, provided the material manufacturer or vessel manufacturer certifies with evidence acceptable to the Authorized Inspector that the corresponding ASME specification requirements of specifications listed in Appendix A of Part A or Part B have been met. Material produced to an acceptable material specification is not limited as to country of origin.

When required by context in this Section, the singular shall be interpreted as the plural, and vice-versa; and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

Publication of the SI (Metric) Edition of the ASME Boiler and Pressure Vessel Code was discontinued with the 1986 Edition. Effective October 1, 1986, the SI Edition was withdrawn as an ASME Boiler and Pressure Vessel Code document.

STATEMENT OF POLICY ON THE USE OF CODE SYMBOLS AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use Code Symbols for marking items or constructions which have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the symbols, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications which might so indicate. An organization holding a Code Symbol and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code."

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified items will carry the symbol. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

The ASME logo, which is the cloverleaf with the letters ASME within, shall not be used by any organization other than ASME.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Code Symbol Stamp described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the various Code Symbols shall not be used on any item which is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME which tend to imply that

all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

Page xiii

PERSONNEL ASME Boiler and Pressure Vessel Committee Subcommittees, Subgroups, and Working Groups

As of December 31, 1997

MAIN COMMITTEE

D. A. Canonico, *Chair*
G. G. Karcher, *Vice Chair*
J. S. Brzuszkiewicz, *Secretary*
R. W. Barnes
F. P. Barton
D. L. Berger
M. D. Bernstein
M. N. Bressler
W. J. Carter
T. M. Cullen
J. R. Farr
R. E. Feigel
J. G. Feldstein
M. Gold
O. F. Hedden
A. J. Justin
D. F. Landers
W. M. Lundy
J. R. MacKay
T. J. Mawson
T. G. McCarty
G. C. Millman
R. A. Moen
C. C. Neely
C. J. Pieper
R. F. Reedy
B. W. Roberts
F. J. Schaaf, Jr.
A. Selz
K. K. Tam
D. E. Tanner

EXECUTIVE COMMITTEE (MAIN COMMITTEE)

G. G. Karcher, *Chair*
D. A. Canonico, *Vice Chair*
J. S. Brzuszkiewicz, *Secretary*
F. P. Barton
J. R. Farr

J. G. Feldstein
M. Gold
O. F. Hedden
A. J. Justin
J. R. MacKay
T. G. McCarty
T. P. Pastor
T. E. Quaka
R. F. Reedy
A. J. Spencer

HONORARY MEMBERS (MAIN COMMITTEE)

R. D. Bonner
R. J. Bosnak
H. M. Canavan
L. J. Chockie
J. S. Clarke
W. E. Cooper
W. D. Doty
R. C. Griffin
E. J. Hemzy
E. C. Kistner, Jr.
J. E. Lattan
J. LeCoff
F. N. Moschini
C. E. Rawlins
W. E. Somers
L. P. Zick, Jr.

HONORS AND AWARDS COMMITTEE

J. R. MacKay, *Chair*
A. J. Spencer, *Vice Chair*
F. R. Lyons, *Secretary*
F. P. Barton
W. J. Carter
J. G. Feldstein
M. Gold
F. E. Gregor
E. C. Kistner, Jr.
T. P. Pastor
R. F. Reedy

MARINE CONFERENCE GROUP

J. Tiratto, *Chair*
C. F. Banks
L. W. Douthwaite
J. L. Jones
G. F. Wright

CONFERENCE COMMITTEE

D. E. Tanner - Tennessee (*Chair*)
R. D. Reetz - North Dakota (*Vice Chair*)
A. J. Justin - National Board of Boiler and Pressure Vessel Inspectors (*Secretary*)
R. J. Aben, Jr. - Michigan
J. S. Aclaro - Los Angeles, California
E. A. Anderson - Chicago, Illinois
J. Anderson - South Dakota
R. Barkdoll - Washington
F. P. Barton - Virginia
C. Castle - Nova Scotia, Canada
R. R. Cate - Louisiana
L. Chase - Northwest Territories, Canada
R. A. Coomes - Kentucky
J. Corcoran - Connecticut
M. H. Diehl, Jr. - Maryland
D. A. Douin - Illinois
D. Eastman - Newfoundland and Labrador, Canada
G. L. Ebeyer - New Orleans, Louisiana
F. Ellis - New Hampshire
E. Everett - Georgia
P. C. Hackford - Utah
D. Hanrath - North Carolina
J. B. Harlan - Delaware
K. Hynes - Prince Edward Island, Canada
D. T. Jagger - Ohio
D. J. Jenkins - Kansas
M. Kotb - Quebec, Canada
J. P. Larson - Minnesota
K. T. Lau - Alberta, Canada
J. Lemire - California
G. A. Lundberg - Florida
W. C. Lundine - Oregon
M. A. Malek - Maine
I. W. Mault - Manitoba, Canada
H. T. McEwen - Mississippi
A. W. Meiring - Indiana
R. Mile - Ontario, Canada
T. J. Monroe - Oklahoma
Y. Nagpaul - Hawaii
J. D. Payton - Pennsylvania
D. K. Peetz - Missouri
D. C. Price - Yukon Territory, Canada
R. S. Pucek - Wisconsin
T. E. Rennie - Arizona
L. Roussinos - British Columbia, Canada

M. Shuff - West Virginia
R. Snyder - New Jersey
N. Surtees - Saskatchewan, Canada
M. J. Verhagen - Wisconsin
R. B. West - Iowa
M. J. Wheel - Vermont
K. A. White - Nevada
R. K. White - New York
T. F. Wickham - Rhode Island
C. S. Withers - Colorado

SUBCOMMITTEE ON POWER BOILERS (SC I)

J. R. MacKay, *Chair*
M. D. Bernstein, *Vice Chair*
P. D. Stumpf, *Secretary*
D. L. Berger
E. Everett
D. N. French
F. R. Gerety
J. Hainsworth
T. E. Hansen
J. S. Hunter
W. L. Lowry
T. C. McGough
P. A. Molvie
D. K. Parrish
J. T. Pillow
R. G. Presnak
B. W. Roberts
R. D. Schueler, Jr.
R. V. Wielgoszinski
R. L. Williams

Page xiv

Subgroup on Design (SC I)

M. D. Bernstein, *Chair*
R. D. Schueler, Jr., *Vice Chair*
P. A. Molvie, *Secretary*
M. A. Farrugia
J. D. Fishburn
C. F. Jeerings
K. C. Morrison
A. Nassif
N. Surtees
R. V. Wielgoszinski

Subgroup on Fabrication and Examination (SC I)

D. L. Berger, *Chair*

R. E. McLaughlin, *Secretary*
R. W. Boyce
D. N. French
J. Hainsworth
T. E. Hansen
M. H. Iken
J. M. Lyons
J. T. Pillow
M. E. Reese
R. D. Schueler, Jr.
R. F. Slack, Sr.
R. V. Wielgoszinski

Subgroup on General Requirements (SC I)

T. C. McGough, *Chair*
M. D. Bernstein, *Vice Chair*
W. L. Lowry, *Secretary*
D. L. Berger
E. Everett
F. R. Gerety
J. Hainsworth
C. F. Jeerings
J. M. Lyons
R. E. McLaughlin
D. K. Parrish
J. T. Pillow
W. E. Somers
R. L. Williams

Subgroup on Materials (SC I)

B. W. Roberts, *Chair*
C. E. Spaeder, Jr., *Chair*
J. S. Hunter, *Secretary*
T. M. Cullen
D. N. French
J. F. Henry
J. P. Libbrecht
F. Masuyama
J. M. Tanzosh

Subgroup on Piping (SC I)

T. E. Hansen, *Chair*
D. L. Berger
M. D. Bernstein
P. D. Edwards
W. L. Lowry
T. C. McGough
R. G. Presnak

E. Whittle
P. L. Ziegler

SUBCOMMITTEE ON MATERIALS (SC II)

M. Gold, *Chair*
T. M. Cullen, *Vice Chair*
F. R. Lyons, *Secretary*
A. P. Ahrendt
M. N. Bressler
A. Cohen
R. Dirscherl
W. D. Doty
W. D. Edsall
D. Gandy
M. H. Gilkey
J. J. Heger
J. F. Henry
G. C. Hsu
F. Masuyama
E. Michalopoulos
R. A. Moen
R. K. Nanstad
E. G. Nisbett
J. T. Parsons
D. W. Rahoi
B. W. Roberts
E. Shapiro
C. E. Spaeder, Jr.
R. W. Swindeman
J. M. Tanzosh
B. E. Thurgood
A. W. Zeuthen

Subgroup on External Pressure (SC II)

R. W. Mikitka, *Chair*
D. J. Green
D. S. Griffin
E. Michalopoulos
B. R. Morelock
D. Nadel
C. E. Spaeder, Jr.
C. H. Sturgeon

Subgroup on Ferrous Specifications (SC II)

E. G. Nisbett, *Chair*
B. M. Dingman
W. D. Edsall
T. Graham
W. N. Holliday

W. N. Holliday
E. A. Jonas
D. C. Krouse
J. F. Longenecker
W. C. Mack
A. S. Melilli
J. T. Parsons
E. J. Rozic, Jr.
E. Upitis
A. W. Zeuthen
R. H. Zong

Subgroup on International Material Specifications (SC II)

J. T. Parsons, *Chair*
D. C. Agarwal
J. Cameron
R. Dirscherl
W. D. Doty
D. M. Fryer
M. Gold
M. H. Iken
W. M. Lundy
H. Masahisa
T. F. Miskell
F. Osweiler
A. P. Povilonis
R. D. Schueler, Jr.
R. R. Seeley
E. A. Steen
E. Upitis
E. O. Woolridge

Subgroup on Nonferrous Alloys (SC II)

D. W. Rahoi, *Chair*
D. C. Agarwal, *Secretary*
W. R. Apblett
L. G. Coffee
A. Cohen
R. Dirscherl
M. H. Gilkey
G. C. Hsu
M. Katcher
E. Shapiro
L. E. Shoemaker
R. C. Sutherlin

Subgroup on Strength, Ferrous Alloys (SC II)

B. W. Roberts, *Chair*
J. M. Tanzosh, *Secretary*

A. P. Ahrendt
W. R. Apblett
T. M. Cullen
M. Gold
J. J. Heger
C. L. Hoffmann
A. Iseda
F. Masuyama
R. A. Moen
D. W. Rahoi
C. E. Spaeder, Jr.
R. W. Swindeman
B. E. Thurgood

Subgroup on Strength of Weldments (SC II & SC IX)

C. E. Spaeder, Jr., *Chair*
W. D. Doty
D. W. Rahoi
B. W. Roberts
C. Robino
W. J. Sperko
J. M. Tanzosh
B. E. Thurgood

Subgroup on Toughness (SC II)

J. M. Barsom
D. A. Hansen
A. Selz
R. S. Vecchio
S. Yukawa
R. Zawierucha

Page xv

SUBCOMMITTEE ON NUCLEAR POWER (SC III)

C. J. Pieper, *Chair*
R. M. Jessee, *Vice Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
Y. Asada
R. W. Barnes
J. N. Baysden
W. H. Borter
E. B. Branch
M. N. Bressler
F. C. Cherny
G. D. Cooper
R. P. Deubler
W. D. Doty

F. R. Drahos
K. Ennis
B. A. Erler
D. Hanrath
C. L. Hoffmann
K.-H. Hsu
D. F. Landers
W. C. LaRochelle
T. J. Mawson
W. N. McLean
R. A. Moen
D. B. Nickerson
R. F. Perrin
R. F. Reedy
M. W. Smith
J. D. Stevenson
R. E. Tome
K. R. Wichman

Subgroup on Containment Systems for Spent Fuel and High-Level Waste Transport Packagings (SC III)

J. D. Stevenson, *Chair*
H. H. Chung
R. R. Doggart
E. L. Farrow
K. Goldmann
R. H. Jones
W. H. Lake
R. W. Lambert
H. W. Lee
P. McConnell
R. E. Nickell
D. J. Nolan
D. T. Raske
T. Saegusa
R. H. Smith
K. B. Sorenson
P. Turula
N. Urabe
C. R. Witt
S. Yukawa

Subgroup on Design (SC III)

R. W. Barnes, *Chair*
E. B. Branch, *Vice Chair*
R. S. Hill III, *Secretary*
Y. Asada
M. N. Bressler
C. W. Bruny

C. W. Bruny
J. R. Cole
G. D. Cooper
R. P. Deubler
N. W. Edwards
R. E. Gimple
D. Hanrath
R. W. Haupt
T. Iida
B. Jarman
D. F. Landers
W. N. McLean
D. B. Nickerson
E. C. Rodabaugh
J. R. Santangelo
G. C. Slagis
J. D. Stevenson
J. H. Wawrzeniak
K. R. Wichman
R. Wray

Working Group on Administration (SG-D) (SC III)

E. B. Branch, *Chair*
R. W. Barnes, *Vice Chair*
R. S. Hill III, *Secretary*
C. W. Bruny
G. D. Cooper
R. P. Deubler
J. T. Land
D. F. Landers
W. N. McLean
D. B. Nickerson
J. R. Santangelo
R. Wray

Working Group on Core Support Structures (SG-D) (SC III)

J. T. Land, *Chair*
R. H. Hansen
K. B. Larsen
J. F. Mullooly
B. L. Silverblatt

Working Group on Dynamic and Extreme Load Conditions (SG-D) (SC III)

R. Wray, *Chair*
A. E. Meligi, *Secretary*
P. L. Anderson
M. K. Au-Yang
R. D. Blevins
G. J. Bohm

D. L. Caldwell
P.-Y. Chen
A. Hadjian
M. Hartzman
W. S. LaPay
H. Lockert
P. R. Olson
R. F. Perry
J. Wallach

Working Group on Piping (SG-D) (SC III)

D. F. Landers, *Chair*
R. S. Hill III, *Vice Chair*
P. Hirschberg, *Secretary*
T. M. Adams
G. A. Antaki
J. R. Cole
A. B. Glickstein
R. W. Haupt
J. C. Hennart
R. D. Hookway
R. B. Jenkins
K. A. Manoly
J. C. Minichiello
S. E. Moore
A. N. Nguyen
D. B. Nickerson
O. O. Oyamada
R. D. Patel
E. C. Rodabaugh
J. R. Santangelo
M. S. Sills
G. C. Slagis
E. A. Wais

Working Group on Pumps (SG-D) (SC III)

D. B. Nickerson, *Chair*
H. L. Brammer
P. Burchett
R. E. Cornman, Jr.
A. A. Fraser
M. Higuchi
G. R. Jones
J. W. Leavitt
J. E. Livingston
R. A. Schussler
H. Tafarrodi

G. K. Vaghasia

Working Group on Supports (SG-D) (SC III)

R. P. Deubler, *Chair*

R. M. Dulin, Jr., *Secretary*

U. S. Bandyopadhyay

F. J. Birch

M. N. Bressler

J. R. Cole

J. C. Finneran, Jr.

R. W. Haupt

J. C. Hennart

A. S. Laurenson

A. Lee

R. J. Masterson

A. E. Meligi

A. N. Nguyen

J. R. Stinson

Working Group on Valves (SG-D) (SC III)

W. N. McLean, *Chair*

E. A. Bake

R. R. Brodin

W. G. Knecht

R. Koester

J. J. McGavin

S. N. Shields

H. R. Sonderegger

J. C. Tsacoyeanes

R. G. Visalli

J. R. Zahorsky

Working Group on Vessels (SG-D) (SC III)

C. W. Bruny, *Chair*

T. K. Burr, Sr.

G. D. Cooper

G. A. Deaver

N. W. Edwards

D. Hanrath

W. J. Heilker

B. Jarman

T. M. Khan

O. Maekawa

K. A. Manoly

A. Merend

G. K. Miller

W. Z. Novak

E. Pelling

H. S. Thornton

Special Working Group on Environmental Effects (SG-D) (SC III)

R. S. Hill III, *Chair*
Y. Asada
W. J. Heilker
C. L. Hoffmann
R. A. Moen
W. Z. Novak
S. Yukawa

Special Working Group on Seismic Piping Rules (SG-D) (SC III)

E. B. Branch, *Chair*
T. M. Adams
G. A. Antaki
R. D. Hookway
J. C. Minichiello
M. S. Sills
E. A. Wais

Subgroup on General Requirements (SC III & SC 3C)

W. C. LaRochelle, *Chair*
K. Ennis, *Secretary*
A. Appleton
J. R. Barbee
J. N. Baysden
L. M. Beason
B. H. Berg
R. E. Kelley
G. S. Korin
A. S. Laurenson
C. Lizotte
M. J. Meyer
M. R. Minick
L. C. Oakes
R. F. Perrin
U. Potapovs
B. B. Scott
D. E. Tanner
D. V. Walshe

Subgroup on Materials, Fabrication, and Examination (SC III)

C. L. Hoffmann, *Chair*
G. P. Milley, *Secretary*
C. W. Allison
D. Doyle
F. R. Drahos
G. M. Foster

G. B. Georgiev
J. E. Harris
R. W. Jackson
R. M. Jessee
C. C. Kim
R. A. Moen
C. J. Pieper
R. R. Seeley
N. M. Simpson
R. C. Soin
W. J. Sperko
K. B. Stuckey
S. Yukawa

Subgroup on Pressure Relief (SC III)

F. C. Cherny, *Chair*
S. F. Harrison, Jr.
E. M. Petrosky
M. W. Smith
A. L. Szeglin
B. S. York
J. R. Zahorsky

Special Working Group on Editing and Review (SC III)

R. F. Reedy, *Chair*
W. H. Borter
M. N. Bressler
R. P. Deubler
B. A. Erler
W. C. LaRochelle
M. W. Smith
J. D. Stevenson
E. O. Woolridge

JOINT ACI-ASME COMMITTEE ON CONCRETE COMPONENTS FOR NUCLEAR SERVICE (SC 3C)

B. A. Erler, *Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
R. M. Attar
A. C. Eberhardt
J. Gutierrez
D. J. Haavik
M. F. Hessheimer
T. E. Johnson
G. R. Murphy
S. F. Putman
B. B. Scott
R. E. Shewmaker
J. D. Stevenson

A. Y. Wong

Subgroup on Design (SC 3C)

D. G. Adams

A. C. Eberhardt

T. E. Johnson

S. F. Putman

R. E. Shewmaker

J. D. Stevenson

A. Y. Wong

Subgroup on Materials, Construction, and Examination (SC 3C)

D. J. Haavik, *Chair*

J. F. Artuso

R. M. Attar

B. A. Erler

J. Gutierrez

SUBCOMMITTEE ON HEATING BOILERS (SC IV)

F. P. Barton, *Chair*

P. A. Molvie, *Vice Chair*

B. P. Feder, *Secretary*

R. B. Duggan

W. L. Haag, Jr.

W. M. Hiddleston

J. D. Hoh

K. M. McTague

R. I. Mullican

E. A. Nordstrom

J. L. Seigle

D. E. Tanner

S. V. Voorhees

R. H. Weigel

R. V. Wielgoszinski

J. I. Woodworth

T. L. Bedeaux, *Alternate*

Subgroup on Care and Operation of Heating Boilers (SC IV)

J. I. Woodworth, *Chair*

B. P. Feder, *Secretary*

K. J. Hoey

J. D. Hoh

F. M. Lucas

K. M. McTague

P. A. Molvie

R. I. Mullican

R. H. Weigel

T. F. Wickham

T. L. Bedeaux, Alternate

Subgroup on Cast Iron Boilers (SC IV)

K. M. McTague, *Chair*

R. B. Duggan

R. H. Weigel

T. F. Wickham

J. I. Woodworth

T. L. Bedeaux, Alternate

Subgroup on Water Heaters (SC IV)

W. L. Haag, Jr., *Chair*

T. D. Gantt

W. M. Hiddleston

F. M. Lucas

K. M. McTague

R. I. Mullican

D. Smith

D. E. Tanner

M. A. Taylor

Subgroup on Welded Boilers (SC IV)

P. A. Molvie, *Chair*

T. L. Bedeaux

D. H. Mapes

E. A. Nordstrom

J. L. Seigle

R. F. Slack, Sr.

R. P. Sullivan

D. E. Tanner

R. V. Wielgoszinski

SUBCOMMITTEE ON NONDESTRUCTIVE EXAMINATION (SC V)

T. G. McCarty, *Chair*

J. E. Batey, *Vice Chair*

F. S. Fitzgerald, *Secretary*

A. S. Birks

B. H. Clark, Jr.

W. T. Clayton

R. A. Coomes

N. Y. Faransso

H. C. Graber

O. F. Hedden

G. W. Hembree

F. B. Kovacs

J. F. Manning

W. C. McGaughey

R. D. McGuire

Subgroup on General Requirements/Personnel Qualifications and Inquiries (SC V)

R D. McGuire, *Chair*

J. E. Batey

W. T. Clayton

N. Y. Faransso

H. C. Graber

G. W. Hembree

J. R. MacKay

J. P. Swezy

Subgroup on Surface Examination Methods (SC V)

H. C. Graber, *Chair*

S. J. Akrin

T. Alexander

A. S. Birks

B. H. Clark

R. A. Coomes

G. W. Hembree

Subgroup on Volumetric Methods (SC V)

J. E. Batey, *Chair*

S. J. Akrin

W. T. Clayton

N. Y. Faransso

H. C. Graber

G. W. Hembree

B. Kellerhall

E. K. Kietzman

F. B. Kovacs

R. W. Kruzic

J. F. Manning

W. C. McGaughey

J. R. Mitchell

Working Group on Acoustic Emissions (SG-VM) (SC V)

B. H. Clark, Jr.

P. M. Horrigan

J. F. Manning

J. R. Mitchell

Working Group on Radiography (SG-VM) (SC V)

G. W. Hembree, *Chair*

S. J. Akrin

T. Alexander

J. E. Batey

N. Y. Faransso

H. C. Graber

F. B. Kovacs

Working Group on Ultrasonics (SG-VM) (SC V)

W. T. Clayton, *Chair*
O. F. Hedden
B. Kellerhall
E. K. Kietzman
J. F. Manning
W. C. McGaughey
R. Paillaman
F. J. Sattler
M. L. Shakinovsky

SUBCOMMITTEE ON PRESSURE VESSELS (SC VIII)

T. P. Pastor, *Chair*
K. Mokhtarian, *Vice Chair*
A. J. Roby, *Secretary*
A. P. Ahrendt
V. Bogosian
S. M. Caldwell
W. J. Carter
S. C. Cyr
R. Dirscherl
R. M. Elliott
J. R. Farr
R. E. Feigel
J. G. Feldstein
G. L. Hollinger
M. J. Houle
W. S. Jacobs
G. G. Karcher
G. B. Komora
K. T. Lau
R. W. Mikitka
U. R. Miller
C. C. Neely
K. J. Schneider
A. Selz
J. R. Sims, Jr.
A. J. Spencer
E. A. Steen
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Design (SC VIII)

U. R. Miller, *Chair*
R. E. Knoblock, *Secretary*
M. R. Bauman
M. R. Breach
S. M. Caldwell

N. W. Edwards
J. R. Farr
J. A. Hayward
G. L. Hollinger
W. S. Jacobs
G. G. Karcher
G. B. Komora
R. W. Mikitka
K. Mokhtarian
T. P. Pastor
M. D. Rana
A. Selz
S. C. Shah
J. W. Stokes
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Fabrication and Inspection (SC VIII)

E. A. Steen, *Chair*
K. Mokhtarian, *Vice Chair*
W. J. Bees
R. W. Boyce
S. C. Cyr
R. E. Feigel
H. E. Gordon
M. J. Houle
W. S. Jacobs
R. A. Johnson
A. S. Lester III
F. C. Ouyang
M. J. Rice
W. P. Webb

Subgroup on General Requirements (SC VIII)

R. M. Elliott, *Chair*
A. P. Ahrendt
V. Bogosian
W. J. Carter
W. P. Crow
J. P. Glaspie
C. R. Good
D. B. Kadakia
J. C. Keenan
W. E. Laveck, Jr.
A. S. Mann
C. C. Neely
A. S. Olivares
K. J. Schneider

A. J. Spencer

Subgroup on Materials (SC VIII)

R. Dirscherl, *Chair*

D. C. Agarwal

A. P. Ahrendt

J. Cameron

W. D. Doty

W. D. Edsall

M. Katcher

W. M. Lundy

E. E. Morgenegg

E. G. Nisbett

J. T. Parsons

D. W. Rahoi

K. K. Tam

B. K. Thakur

Special Working Group on Heat Transfer Equipment (SC VIII)

G. B. Komora, *Chair*

R. P. Zoldak, *Secretary*

C. F. Andreone

D. E. Bolt

S. M. Caldwell

T. K. Haldas

M. J. Holtz

W. G. Jandrasits

R. Mahadeen

U. R. Miller

F. Osweiller

J. E. Soehrens

A. I. Soler

W. A. Treff

S. Yokell

Page xviii

Special Working Group on High-Pressure Vessels (SC VIII)

J. R. Sims, Jr., *Chair*

P. A. Reddington, *Secretary*

L. P. Antalffy

J. E. Baxter

R. C. Biel

T. B. Boyd

D. J. Burns

P. N. Chaku

E. L. Danfelt

R. E. Feigel

D. M. Fryer

J. L. Heck, Jr.
A. H. Honza
V. T. Hwang
M. M. James
P. Jansson
J. A. Kapp
D. P. Kendall
A. K. Khare
S. C. Mordre
G. J. Mraz
E. H. Perez
L. M. Picqueur
E. D. Roll
W. L. Stewart
J. F. Sullivan
F. W. Tatar

Special Working Group on Toughness (SC VIII)

W. S. Jacobs, *Chair*
J. Cameron
W. D. Doty
D. A. Hansen
G. G. Karcher
G. B. Komora
K. Mokhtarian
J. L. Mooney
C. C. Neely
M. D. Rana
J. W. Stokes

SUBCOMMITTEE ON WELDING (SC IX)

J. G. Feldstein, *Chair*
W. J. Sperko, *Vice Chair*
J. Labrador, *Secretary*
R. Barkdoll
D. A. Bowers
M. L. Carpenter
W. D. Doty
P. D. Flenner
M. J. Houle
R. A. Johnson
W. M. Lundy
R. D. McGuire
J. J. Meyer
A. H. Miller
B. R. Newmark
P. P. Norris

S. D. Reynolds, Jr.
W. K. Scattergood
G. W. Spohn III
M. J. Stanko
J. M. Tanzosh
R. R. Young

Subgroup on Brazing (SC IX)

M. J. Houle, *Chair*
A. S. Artayet
M. L. Carpenter
C. F. Jeerings
A. H. Miller
C. Robino

Subgroup on General Requirements (SC IX)

B. R. Newmark, *Chair*
R. Barkdoll
P. R. Evans
P. C. Filean
R. M. Jessee
D. W. Mann
A. S. Olivares
C. E. Wainwright
R. A. Weiss
K. R. Willens

Subgroup on Materials (SC IX)

M. L. Carpenter, *Chair*
L. P. Connor
P. D. Flenner
R. M. Jessee
A. H. Miller
H. A. Sadler
C. E. Sainz
C. E. Spaeder, Jr.
W. J. Sperko
M. J. Stanko
R. R. Young

Subgroup on Performance Qualification (SC IX)

J. J. Meyer, *Chair*
V. A. Bell
D. A. Bowers
L. P. Connor
R. A. Coomes
P. D. Flenner
G. Herrmann
M. J. Houle

W. M. Lundy
R. D. McGuire
S. R. Nordman
P. P. Norris
W. K. Scattergood
G. W. Spohn III

Subgroup on Procedure Qualification (SC IX)

J. J. Meyer, *Chair*
R. K. Brown, Jr.
R. A. Johnson
A. H. Miller
P. P. Norris
A. S. Olivares
F. C. Ouyang
S. D. Reynolds, Jr.
M. J. Rice
W. K. Scattergood
W. J. Sperko
T. C. Wiesner

SUBCOMMITTEE ON FIBER-REINFORCED PLASTIC PRESSURE VESSELS (SC X)

P. J. Conlisk, *Chair*
D. Eisberg, *Vice Chair*
A. J. Roby, *Secretary*
K. M. Agrawal
F. L. Brown
J. L. Bustillos
T. W. Cowley
T. J. Fowler
S. V. Hoa
L. E. Hunt
J. C. Murphy
A. L. Newberry
D. J. Painter
J. A. Rolston
B. F. Shelley
P. R. Wilt

SUBCOMMITTEE ON NUCLEAR INSERVICE INSPECTION (SC XI)

O. F. Hedden, *Chair*
T. J. Mawson, *Vice Chair*
G. L. Fechter, *Secretary*
C. W. Allison
W. H. Bamford, Jr.
R. L. Beverly
J. M. Bloom
R. W. Boyce

C. D. Cowfer
D. D. Davis
R. L. Dyle
T. N. Epps III
R. E. Gimple
F. E. Gregor
L. B. Gross
K. Iida
C. A. Ireland
R. D. Kerr
D. F. Landers
T. F. Lentz
J. T. Lindberg
G. C. Millman
C. R. Osman
P. C. Riccardella
L. Sage
F. J. Schaaf, Jr.
J. E. Staffiera
R. P. Sullivan
R. W. Swayne
R. J. Tamminga
J. C. Tobin
R. A. Yonekawa

Honorary Members (SC XI)

S. H. Bush
L. J. Chockie
J. P. Houstrup
L. R. Katz
R. R. MacCary

Page xix

Subgroup on Evaluation Standards (SC XI)

W. H. Bamford, Jr., *Chair*
M. Kupinski, *Secretary*
J. M. Bloom
R. C. Cipolla
R. M. Gamble
T. J. Griesbach
P. J. Hijeck
K. Iida
Y. Imamura
J. G. Merkle
S. Ranganath
P. C. Riccardella
D. A. Scarth
W. L. Server

C. A. Tomes
W. A. Van Der Sluys
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa

Working Group on Flaw Evaluation (SG-ES) (SC XI)

R. C. Cipolla, *Chair*
W. H. Bamford, Jr.
M. Basol
J. M. Bloom
E. Friedman
T. J. Griesbach
F. D. Hayes
D. N. Hopkins
K. Iida
Y. Imamura
M. Kupinski
H. S. Mehta
J. G. Merkle
J. S. Panesar
R. K. Qashu
S. Ranganath
D. A. Scarth
T. S. Schurman
W. L. Server
F. A. Simonen
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Working Group on Operating Plant Criteria (SG-ES) (SC XI)

T. J. Griesbach, *Chair*
W. H. Bamford, Jr.
H. Behnke
B. A. Bishop
W. F. Brady
E. Friedman
S. R. Gosselin
E. M. Hackett
P. J. Hijeck
S. D. Leshnoff
P. Manbeck
J. S. Panesar

W. E. Pennell
J. H. Phillips
S. Ranganath
S. T. Rosinski
W. L. Server
E. A. Siegel
F. A. Simonen
T. D. Spry
K. K. Yoon
S. Yukawa

Working Group on Pipe Flaw Evaluation (SG-ES) (SC XI)

D. A. Scarth, *Chair*
G. M. Wilkowski, *Secretary*
W. H. Bamford, Jr.
J. M. Bloom
R. C. Cipolla
N. G. Cofie
S. K. Daftuar
G. H. De Boo
E. Friedman
D. N. Hopkins
K. Iida
H. S. Mehta
J. G. Merkle
J. S. Panesar
D. Quinones
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Subgroup on Liquid-Metal-Cooled Systems (SC XI)

C. G. McCargar, *Chair*
W. L. Chase
S. Hattori
R. Hundal
W. Kwant
J. C. Tobin

Working Group on Liquid-Metal Reactor Covers (SG-LMCS) (SC XI)

W. L. Chase, *Chair*
S. Hattori
R. Hundal
W. Kwant

Subgroup on Nondestructive Examination (SC XI)

R. L. Beverly, *Chair*

N. R. Bentley, *Secretary*
D. C. Adamonis
F. L. Becker
F. T. Carr
C. B. Cheezem
W. T. Clayton
C. D. Cowfer
F. J. Dodd
T. N. Epps III
D. O. Henry
M. R. Hum
S. N. Liu
R. D. McGuire
M. C. Modes
C. R. Osman
F. J. Schaaf, Jr.
J. C. Spanner, Jr.
C. J. Wirtz

Working Group on Personnel Qualification and Surface Visual and Eddy Current Examination (SG-NDE) (SC XI)

C. J. Wirtz, *Secretary*
B. L. Curtis
N. Economos
H. B. Garland
D. O. Henry
H. E. Houser
J. J. McArdle III
R. D. McGuire
S. A. Redner
M. F. Sherwin
A. L. Smith
D. Spake
J. C. Spanner, Sr.
J. C. Spanner, Jr.
T. V. Tran

Working Group on Pressure Testing (SG-NDE) (SC XI)

G. P. Alexander
T. M. Anselmi
T. B. Basso
J. Boughman
T. R. Bugelhol
R. J. Cimoch
C. E. Jensen
W. N. Keisler
D. Lamond
F. J. Schaaf, Jr.
D. Terao

Working Group on Procedure Qualification and Volumetric Examination (SG-NDE) (SC XI)

C. D. Cowfer, *Chair*
C. E. Larsen, *Secretary*
D. C. Adamonis
F. L. Becker
N. R. Bentley
B. Bevins
F. T. Carr
C. B. Cheezem
W. T. Clayton
S. R. Doctor
F. J. Dodd
T. N. Epps III
B. Kellerhall
G. A. Lofthus
J. K. McClanahan
M. C. Modes
M. Saporito
T. T. Taylor
S. M. Walker

Subgroup on Repairs, Replacements, and Modifications (SC XI)

R. E. Gimple, *Chair*
W. C. Holston, *Secretary*
R. W. Boyce
M. N. Bressler
S. B. Brown
C. E. Hartz
R. A. Hermann
C. A. Ireland
R. D. Kerr
D. F. Landers
R. S. Lewis
T. J. Mawson
M. S. McDonald
R. R. Stevenson
R. P. Sullivan
R. W. Swayne
R. E. Tome
D. E. Waskey
R. A. Yonekawa

Page xx

Working Group on Design Reconciliation (SG-RR&M) (SC XI)

W. C. Holston, *Chair*
J. T. Conner, *Secretary*
R. W. Boyce

S. B. Brown
J. E. Charnley
T. E. Hiss
E. V. Imbro
D. N. Irvine, Jr.
D. F. Landers
R. W. Swayne
F. Tehranchi
H. J. Thailer
R. E. Tome

Working Group on Responsibilities and Program Requirements (SG-RR&M) (SC XI)

R. A. Yonekawa, *Chair*
R. R. Stevenson, *Secretary*
S. K. Fisher
G. M. Foster
C. E. Hartz
R. S. Lewis
M. S. McDonald
U. Potapovs
S. M. Swilley
A. J. Walcutt
J. Ghergurovich, *Alternate*

Working Group on Welding and Special Repair Processes (SG-RR&M) (SC XI)

D. E. Waskey, *Chair*
R. E. Cantrell, *Secretary*
D. A. Delsignore
A. L. Finney
P. D. Fisher
A. J. Giannuzzi
R. A. Hermann
R. P. Indap
R. D. Kerr
B. R. Newton
P. P. Norris
J. E. O'Sullivan
J. H. Sodergren
K. R. Willens

Subgroup on Water-Cooled Systems (SC XI)

T. F. Lentz, *Chair*
K. Christian, *Secretary*
C. W. Allison
W. J. Briggs
T. R. Bugelholz
D. D. Davis
A. F. Deardorff

R. L. Dyle
L. B. Gross
T. C. Hinkle
S. D. Kulat
M. P. Lintz
J. E. Staffiera
C. W. Tahnk
R. J. Tamminga
D. Terao
S. M. Walker
R. A. West

Working Group on Concrete Containment (SG-WCS) (SC XI)

W. J. Briggs, *Chair*
B. Talmadge, *Secretary*
H. G. Ashar
K. K. N. Chao
M. J. Ferlisi
H. T. Hill
R. D. Hough
C. N. Krishnaswamy
D. Naus
S. C. Petitgout
C. G. Ranganath

Working Group on Implementation of Risk-Based Examination (SG-WCS) (SC XI)

T. J. Mawson, *Chair*
A. McNeill III, *Secretary*
J. Agold
S. A. Ali
B. A. Bishop
J. W. Connor
A. F. Deardorff
H. Q. Do
R. Fougrousse
S. R. Gosselin
J. T. Lindberg
I. Mach
R. K. Mattu
P. J. O'Regan
J. H. Phillips
F. A. Simonen
T. V. Vo
R. A. West

Working Group on Inspection of Systems and Components (SG-WCS) (SC XI)

R. L. Dyle, *Chair*
G. C. Park, *Secretary*
G. L. Belew

T. W. Brombach
R. Fougerousse
T. C. Hinkle
M. R. Hum
S. D. Kulat
J. T. Lindberg
M. P. Lintz
T. K. McLellan
C. Pendleton
C. M. Ross
C. W. Tahnk
K. B. Thomas
E. Throckmorton
R. A. West
J. Whitman

Working Group on Metal Containment (SG-WCS) (SC XI)

J. E. Staffiera, *Chair*
W. E. Norris, *Secretary*
W. J. Briggs
K. K. N. Chao
M. J. Ferlisi
R. W. Hammelmann
M. P. Lintz
S. C. Petitgout
C. G. Ranganath
G. W. Robin
R. T. Zak

Special Working Group on Low-Temperature Heavy Water Reactors (SG-WCS) (SC XI)

C. D. Cowfer, *Chair*
J. M. Morrison, *Secretary*
B. Awadalla
K. F. Schmidt
P. R. Vormelker
S. H. Zaidi

Working Group on General Requirements (SC XI)

A. T. Roberts III, *Chair*
R. G. Edl, *Secretary*
D. A. Graham
L. B. Gross
C. A. Ireland
D. A. Jackson
R. K. Mattu
L. Sage
R. J. Scott
J. C. Shropshire

R. J. Tamminga

Special Working Group on Editing and Review (SC XI)

R. W. Swayne, *Chair*

R. L. Beverly

L. B. Gross

M. P. Lintz

J. E. Staffiera

C. J. Wirtz

Special Working Group on Plant Life Extension (SC XI)

F. E. Gregor, *Chair*

L. B. Gross, *Secretary*

D. D. Davis

D. A. Graham

D. L. Harrison

M. P. Lintz

P. Manbeck

H. W. Massie, Jr.

D. W. Peltola

D. A. Piccione

C. M. Regan

V. N. Shah

R. J. Tamminga

SUBCOMMITTEE ON TRANSPORT TANKS (SC XII)

A. Selz, *Chair*

P. D. Stumpf, *Secretary*

A. N. Antoniou

S. C. Cyr

K. Ennis

M. Hennemand

C. H. Hochman

G. G. Karcher

P. P. Laluc

G. McRae

M. R. Minick

T. P. Pastor

M. D. Rana

C. M. Serratella

G. R. Stoeckinger

N. Surtees

J. P. Swezy

A. P. Varghese

S. V. Voorhees

W. L. White

Subgroup on Design and Materials (SC XII)

M. D. Rana, *Chair*
D. A. Canonico
W. D. Doty
G. G. Karcher
P. P. Laluc
T. P. Pastor
T. A. Rogers
C. M. Serratella
A. P. Varghese
E. Whittle

Subgroup on Fabrication and Inspection (SC XII)

S. V. Voorhees, *Chair*
D. A. Canonico
M. L. Coats
M. Hennemand
D. J. Kreft
G. McRae
M. R. Minick
N. Surtees
J. P. Swezy

Subgroup on General Requirements (SC XII)

C. H. Hochman, *Chair*
T. Alexander
A. N. Antoniou
D. Carter
K. Ennis
M. A. Garrett
J. C. Keenan
F. A. Licari
G. R. Stoeckinger
W. L. White

SUBCOMMITTEE ON BOILER AND PRESSURE VESSEL ACCREDITATION (SC-BPVA)

A. J. Spencer, *Chair*
A. J. Justin, *Vice Chair*
K. I. Baron, *Secretary*
M. B. Doherty
D. A. Douin
P. D. Edwards
R. M. Elliott
C. E. Ford
J. J. Greene
R. C. Howard
B. B. MacDonald
M. L. Sisk
B. C. Turczynski

R. V. Wielgoszinski
R. L. Williams
V. A. Bell, Alternate
V. Bogosian, Alternate
M. A. De Vries, Alternate
J. R. Farr, Alternate
R. G. Friend, Alternate
W. C. LaRochelle, Alternate
A. S. Lester III, Alternate
K. M. McTague, Alternate
G. P. Milley, Alternate
R. E. Muise, Alternate
P. G. Scheckermann, Alternate
N. Surtees, Alternate

SUBCOMMITTEE ON NUCLEAR ACCREDITATION (SC-NA)

T. E. Quaka, *Chair*
R. R. Stevenson, *Vice Chair*
S. Griffin, *Secretary*
C. W. Allison
M. N. Bressler
G. Deily
F. R. Drahos
J. E. Harris
M. Kotb
W. C. LaRochelle
U. Potapovs
H. B. Prasse
A. J. Spencer
G. M. Tolson
L. M. Beason, Alternate
R. W. Boyce, Alternate
S. Dasgupta, Alternate
P. D. Edwards, Alternate
J. P. Ellenberger, Alternate
R. E. Feigel, Alternate
D. Hanrath, Alternate
K. A. Huber, Alternate
A. J. Justin, Alternate
N. C. Kist, Alternate
A. A. Lotfi, Alternate
R. P. McIntyre, Alternate
O. E. Trapp, Staff Representative

SUBCOMMITTEE ON DESIGN (SC-D)

W. J. Carter, *Chair*
F. S. Fitzgerald, *Secretary*
R. W. Barnes

R. W. Barnes
C. Becht IV
O. F. Hedden
R. W. Mikitka
K. Mokhtarian
W. J. O'Donnell
R. D. Schueler, Jr.
M. P. Schwartz
A. Selz

Subgroup on Design Analysis (SC-D)

T. P. Pastor, *Secretary*
P. J. Conlisk
A. G. Eggers
J. L. Hechmer
G. L. Hollinger
D. P. Jones
A. Kalnins
W. J. Koves
T. H. Liu
O. Maekawa
A. Merend
T. V. Narayanan
E. L. Thomas, Jr.

Subgroup on Elevated Temperature Design (SC-D)

C. Becht IV, *Chair*
J. M. Corum, *Secretary*
C. R. Brinkman
R. D. Campbell
D. S. Griffin
R. I. Jetter
C. Lawton
W. J. O'Donnell
D. A. Osage
C. C. Schultz, Jr.
L. K. Severud
D. F. Shaw
A. L. Snow
B. E. Thurgood

Subgroup on Fatigue Strength (SC-D)

C. R. Brinkman
P. R. Donavin
J. A. Hayward
J. L. Hechmer
D. P. Jones
G. Kharshafdjian
C. Lawton

A. Merend
H. H. Ziada

Subgroup on Openings (SC-D)

M. P. Schwartz, *Chair*
R. W. Mikitka, *Secretary*
M. R. Breach
V. T. Hwang
S. C. Lou
R. B. Luney
J. P. Madden
K. C. Morrison
D. R. Palmer
M. D. Rana
E. C. Rodabaugh

Special Working Group on Bolted Flanged Joints (SC-D)

R. W. Mikitka, *Chair*
G. D. Bibel
G. Kharshafdjian
D. L. Kurle
E. Michalopoulos
S. N. Pagay
J. R. Payne
R. W. Schneider
R. D. Schueler, Jr.
A. Selz

SUBCOMMITTEE ON SAFETY VALVE REQUIREMENTS (SC-SVR)

E. C. Kistner, Jr., *Chair*
M. D. Bernstein, *Vice Chair*
U. D'Urso, *Secretary*
J. F. Ball
J. A. Cox
R. D. Danzy
R. J. Doelling
D. A. Douin
R. G. Friend
H. I. Gregg
S. F. Harrison, Jr.
C. F. Laitner
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson
D. J. Scallan
C. M. Schroepfer
A. J. Spencer

J. C. Standfast
E. A. Steen
L. L. Thompson
J. A. West
T. J. Ferrigan, Alternate

Page xxii

Subgroup on Design (SC-SVR)

R. G. Friend, *Chair*
J. Cahoon, Jr.
R. D. Danzy
D. B. DeMichael
R. J. Doelling
H. I. Gregg
S. R. Irvin
C. F. Laitner
P. R. Sievert
A. J. Spencer
E. A. Steen
T. R. Tarbay
J. A. West

Subgroup on General Requirements (SC-SVR)

M. D. Bernstein, *Chair*
J. F. Ball
V. M. Deluca
D. A. Douin
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson
J. C. Standfast
L. L. Thompson

Subgroup on Testing (SC-SVR)

S. F. Harrison, Jr., *Chair*
S. Cammeresi
J. A. Cox
W. F. Hart
D. M. Papa
D. J. Scallan
C. M. Schroepfer
D. E. Snyder

Page xxiii

ORGANIZATION OF SECTION III

1. GENERAL

Section III consists of Division 1, Division 2, and Division 3. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter "N" for Division 1, by the letter "C" for Division 2, and by the letter "W" for Division 3. The following eleven books make up the three Divisions.

Subsection NCA - General Requirements for Division 1 and Division 2

Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

Division 2 - Code for Concrete Reactor Vessels and Containments

Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

The Division 2 book includes Subsection CC - Concrete Containments and Division 2 Appendices.

The Division 3 book includes Subsections WA and WB for General Requirements and Class TP (Type B) Containment, respectively.

2. SUBSECTIONS

Subsections are divided into Articles, Subarticles, paragraphs, and, where necessary, subparagraphs and subsubparagraphs.

3. ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections followed by Arabic numbers, such as NB-1000. Where possible, Articles dealing with the same topics are given the same number in each Subsection in accordance with the following general scheme:

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination
6000	Testing
7000	Overpressure Protection
8000	Nameplates, Stamping, and Reports

The numbering of Articles and the material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the rules have been prepared with some gaps in the numbering.

4. SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

5. SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as NB-2130, and generally have no text. When a number such as NB-1110 is followed by text, it is considered a paragraph.

6. PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

7. SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as NB-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

8. SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

Page xxiv

9. REFERENCES

References used within Section III generally fall into one of the following four categories.

A. References to Other Portions of Section III

When a reference is made to another Article, Subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to NB-3000 includes all material in Article NB-3000; reference to NB-3200 includes all material in Subarticle NB-3200; reference to NB-3230 includes all paragraphs NB-3231 through NB-3236.

B. References to Other Sections

Other Sections referred to in Section III are:

Section II, Materials. When a requirement for a material, or for the examination or testing of a material, is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II. These references begin with the letter "S."

Section V, Nondestructive Examination. Section V references begin with the letter "T" and relate to the nondestructive examination of material or welds.

Section IX, Welding and Brazing Qualifications. Section IX references begin with the letter "Q" and relate to welding and brazing requirements.

Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components. When a reference is made to inservice inspection, the rules of Section XI shall apply.

C. Reference to Specifications and Standards Other Than Published in Code Sections

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials. At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E 71-64 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

2The American National Standards Institute (ANSI) was formerly known as the American Standards Association. Standards approved by the Association were designated by the prefix "ASA" followed by the number of the standard and the year of publication. More recently, the American National Standards Institute was known as the United States of America Standards Institute. Standards were designated by the prefix "USAS" followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the numbers of the standards have remained unchanged.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by the American Society of Mechanical Engineers and approved by the American National Standards Institute.² When a product is to conform to such a standard, for example ANSI B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NB-3132-1, for example ANSI B16.5-1977. Standards published by the American Society of Mechanical Engineers are available from ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-6, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, 127 Park Street, N.E., Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NB-3132-1, for example MSS SP-6-1963.

(4) Specifications for welding and brazing materials are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33135. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix "SF," for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-620 and API-2000. When documents so designated are referred to in Section III, they are standards published by the American Petroleum Institute.

D. References to Appendices

Two types of Appendices are used in Section III and are designated Mandatory and Nonmandatory.

(1) Mandatory Appendices contain requirements which must be followed in construction; such references are designated by a Roman numeral followed by Arabic numerals. References to II-1100 or XI-3212, for example, relate to the Mandatory Appendices.

(2) Nonmandatory Appendices provide information or guidance for the use of Section III; such references are designated by a capital letter followed by Arabic numerals. A reference to D-1100, for example, relates to a Nonmandatory Appendix.

July 1, 1998

American Society Of Mechanical Engineers

SEC III NCA ACI

THE AMERICAN CONCRETE INSTITUTE

Page xxv

The American Concrete Institute was organized in 1905 to provide industry standards in the field of concrete usage. The organization, which was formed as a result of meetings begun during the Engineering Congress at the Louisiana Purchase Exposition in St. Louis in 1904, was initially entitled the National Association of Cement Users. In 1913, the name of the Society was changed to the American Concrete Institute to better fit the actual scope of its activities and aims, which are to further engineering education, scientific investigation, and scientific research by organizing the efforts of its members for a nonprofit, public service in gathering, correlating, and disseminating information for the improvement of the design, construction, manufacture, use, and maintenance of concrete products and structures.

The day-to-day operation of ACI is administered by an Executive Director, under general supervision of its 18-member Board of Direction, which assigns a part of its administrative duties to standing committees, the ACI Standards Board, and various technical committees.

ACI - TECHNICAL ACTIVITIES COMMITTEE

The Technical Activities Committee, which is appointed by the Board of Direction, is responsible for Institute technical publications, review of standards, the technical program at conventions, and continuing studies of technical committees, from

publications, review of standards, the technical program at conventions, and continuing studies of technical committees, from which arise recommendations for the activities, and the formation or discharge of these groups. TAC members are selected by the ACI Board to represent ACI's varied interests.

ACI - STANDARDS BOARD

The Standards Board, also appointed by the Board of Direction, is responsible for matters of policy, procedure, and appeal pertaining to ACI Standards. All proposed new standards or revisions to existing standards, including minority reports from sponsoring technical committees, are forwarded to the Standards Board through the Technical Activities Committee. On release by the Standards Board, these are published, and after ratification by letter ballot of the ACI membership at large are then available for public use. The primary functions of the Standards Board are to verify that proper standardization procedures have been followed and to rule on matters of policy as related to standards.

ACI - TECHNICAL AND EDUCATIONAL COMMITTEES

Much of the important work of the American Concrete Institute is performed by technical committees that prepare committee reports and standards. Technical committees, composed of volunteer personnel, develop ACI recommendations in their respective fields. Their work, subject to review and approval by the Board of Direction through the Technical Activities Committee and the Standards Board, forms the basis for Institute Standards.

Educational committees, also composed of volunteer personnel, develop seminars, workshops, curriculum guides, and student manuals to further ACI's involvement in education. Their work, subject to review and approval by the ACI Educational Activities Committee, forms the basis for Institute manuals and training programs.

July 1, 1998

American Society Of Mechanical Engineers

SEC III NCA-1000

ARTICLE NCA-1000 SCOPE OF SECTION III

Page 1

[98]

NCA-1100GENERAL

[98]

NCA-1110SCOPE¹

The rules of this Section constitute requirements for the design, construction, stamping, and overpressure protection of:

(a) items (such as vessels, concrete reactor vessels and concrete containments, storage tanks, piping systems, pumps, valves, core support structures, and supports) for use in nuclear power plants²;

(b) spent fuel storage canisters; and

(c) nuclear spent fuel transport containments (see Division 3, Subsection WA).

Section XI contains rules for inservice inspections of items used in nuclear power plants.

[98]

NCA-1120 DEFINITIONS

Definitions of key terms used in Subsection NCA are included in NCA-9000.

¹ Refer to NCA-9000 for definitions of the terms construction, nuclear power plant, and items.

² Specifically excluded from consideration in this Section are tubes or other forms of sheathing used only for cladding nuclear fuel or neutron control material.

NCA-1130 LIMITS OF THESE RULES

(a) The rules of this Section provide requirements for new construction and include consideration of mechanical and thermal stresses due to cyclic operation. They do not cover deterioration which may occur in service as a result of radiation effects, corrosion, erosion, or instability of the material. These effects shall be taken into account with a view to realizing the design or the specified life of the components and supports. The changes in properties of materials subjected to neutron radiation can be checked periodically by means of material surveillance programs. These rules provide requirements for new construction of concrete reactor vessels and containments. They are applicable only to those components that are designed to provide a pressure retaining or containing barrier. They are not applicable to other concrete structures in the plant, as for example to concrete shield and support structures, except as they directly affect the components.

(b) The rules are not intended to be applicable to valve operators, controllers, position indicators, pump impellers, pump drivers, or other accessories and devices, unless they are pressure retaining parts or act as core support structures or supports. If such items are in a support load path, the provisions of NF-1100 apply.

(c) The rules of this Section do not apply to instruments, or permanently sealed fluid filled tubing systems furnished with instruments, but do apply to instrument, control, and sampling piping when specified in Design Specifications.

(d) Auxiliary systems for concrete reactor vessels or containments that are required to assure functional adequacy of the vessels in accordance with the requirements of the Design Specification, including but not limited to concrete cooling systems, thermal insulation, corrosion protection, leakage monitors, and strain monitoring systems, must be delineated fully by appropriate performance, reliability, and test requirements. These rules are not intended to otherwise be applicable to auxiliary systems.

NCA-1140 USE OF CODE EDITIONS, ADDENDA, AND CASES

(a) (1) Under the rules of this Section, the Owner or his designee shall establish the Code Edition and Addenda to be included in the Design Specifications. All items of a nuclear power plant may be constructed to a single Code Edition and Addenda, or each item may be constructed to individually specified Code Editions and Addenda.

Page 4

(2) In no case shall the Code Edition and Addenda dates established in the Design Specifications be earlier than 3 years prior to the date that the nuclear power plant construction permit application is docketed.

(b) Except as permitted in (e) below for materials, Code Editions and Addenda later than those established by (a) above may be used by mutual consent of the Owner or his designee and Certificate Holder. For Division 2 design and construction, the consent of the Designer shall also be obtained. Specific provisions within an Edition or Addenda later than those established in the Design Specifications may be used, provided that all related requirements are met.

(c) Code Cases are permissible and may be used beginning with the date of approval by the ASME Council (and the American Concrete Institute for Division 2 design and construction). Only Code Cases that are specifically identified as being applicable to this Section may be used.

(d) Code Cases may be used by mutual consent of the Owner or his designee, and the Certificate Holder on or after the date permitted by (c) above. For Division 2 design and construction, the consent of the Designer shall also be obtained.

(e) Materials produced and certified in accordance with Code Editions and Addenda other than the one specified for construction of an item may be used, provided all of the following requirements are satisfied.

(1) The material (NCA-1220) meets the applicable requirements of a material specification permitted by paragraph 2121 of the applicable Subsection of the Section III Edition and Addenda specified for construction.

(2) The material meets all the requirements of Article 2000 of the applicable Subsection of the Section III Edition and Addenda specified for construction.

(3) The material was produced under the provisions of a Quality System Program which had been accepted by the Society or qualified by a party other than the Society (NCA-3820), in accordance with the requirements of the latest Section III Edition and Addenda issued at the time the material was produced. Material exempted from portions of the provisions of NCA-3800 by paragraph 2610 of the applicable Subsection of Section III may be used, provided the

requirements of (1) and (2) above are met.

(f) Code Editions, Addenda [including the use of specific provisions of Editions or Addenda permitted by (b) and (e) above], and Cases used shall be reviewed by the Owner or his designee for acceptability to the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

NCA-1200 GENERAL REQUIREMENTS FOR ITEMS AND INSTALLATION

NCA-1210 COMPONENTS

Each component of a nuclear power plant shall require a Design Specification (NCA-3250), Design Report (NCA-3350, NCA-3550), and other design documents specified in NCA-3000. Data Reports and stamping shall be as required in NCA-8000.

NCA-1220 MATERIALS

NCA-1221 Metallic Materials

Metallic materials shall be manufactured to an SA, SB, or SFA Specification,³ or any other material specification permitted by this Section. Such material shall be manufactured, identified, and certified in accordance with the requirements of this Section. Tubular products and fittings welded with filler metal require NPT symbol stamping but do not require nameplates.

NCA-1221.1 Metallic Material, ASTM Specification.

Metallic materials produced under an ASTM designation may be accepted as complying with the corresponding ASME Specification, provided the ASME Specification is designated as being identical with the ASTM Specification for the grade, class, or type produced and provided that the material is confirmed as complying with the ASTM Specification by a Certified Material Test Report or Certificate of Compliance from the Material Organization. When a material does not have a corresponding ASME Specification, it may be accepted for Section III, Division 2 construction if it is specified in the Design Documents, provided all materials comply with all of the requirements of CB-2000 for concrete reactor vessels or CC-2000 for concrete containments, as applicable.

NCA-1221.2 Welding Material, AWS Specification.

Welding material produced under an AWS designation may be accepted as complying with the corresponding ASME Specification, provided the latter Specification is indicated to be identical with the AWS Specification and provided the welding material is confirmed as complying with the AWS Specification by a Certified Material Test Report or Certification from the Material Organization.

³ SA or SB Specifications listed under the heading Bars, Rods, Shapes, Forgings may be used as material for any of these product forms even though not all product forms are listed in the SA or SB Specification.

NCA-1222 Nonmetallic Materials - Division 2

NCA-1222.1 Concrete and Grout.

Plastic concrete and grout shall be manufactured to material specifications permitted by this Section. Plastic concrete and grout shall be manufactured and identified in accordance with the requirements of this Section.

NCA-1222.2 Concrete and Grout Constituents.

The constituents of plastic concrete and grout shall be manufactured to material specifications permitted by this Section. Constituents shall be manufactured and identified in accordance with the requirements of this Section.

NCA-1230 PARTS, PIPING SUBASSEMBLIES, AND SUPPORTS

NCA-1231 Parts

The Design Specifications (NCA-3250) and Design Report, Load Capacity Data Sheet, or Design Report Summary (NCA-3350, NCA-3550) for components and supports shall apply to the parts of such components and supports. Data Reports and stamping shall be as required in NCA-8000.

NCA-1232 Piping Subassemblies

The Design Specifications (NCA-3250) and Design Report (NCA-3551.1) for the piping system shall apply to the piping subassemblies of that system. Data Reports and stamping shall be as required in NCA-8000.

NCA-1233 Supports

The Design Conditions for supports shall be included in either the component or piping Design Specifications (NCA-3250) or in a separate Design Specification. A Design Report, Load Capacity Data Sheet, or Design Report Summary (NCA-3551) for each support or group of supports shall be furnished. Data Reports and stamping shall be as required by NCA-8000.

NCA-1260 APPURTENANCES

The design conditions for appurtenances shall be included in either the component Design Specification (NCA-3250) or in a separate Design Specification. A Design Report (NCA-3553) for each appurtenance or group of identical appurtenances for each component shall be furnished, if not included in the component Design Report. The Owner, directly or through his designee, shall be responsible for the overall correlation of the component and appurtenance Design Reports (NCA-3260). Data Reports and stamping shall be as required by NCA-8000.

NCA-1270 MISCELLANEOUS ITEMS

NCA-1271 Control Rod Drive Housings

Control rod drive housings attached to a reactor vessel shall be considered in the Design Specification as a part, appurtenance, or as a separate vessel. The rules of Subsection NB shall apply to those portions of the housings forming a pressure retaining boundary.

NCA-1272 Heater Elements

That portion of heater elements forming a pressure retaining boundary of a nuclear power system shall be considered in the Design Specification either as a part or an appurtenance.

NCA-1273 Fluid Conditioner and Flow Control Devices Other Than Valves

That portion of fluid conditioners or flow control devices, such as filters, demineralizers, traps, strainers, flow nozzles, flow restrictors, venturis, orifice plates [except orifice plates or flow restrictions not exceeding $\frac{1}{2}$ in. (13 mm) nominal thickness which are clamped between flanges], eductors, and similar devices which form the pressure boundary, shall be considered as a piping subassembly, part, appurtenance, component, or material in accordance with the rules of this Section.

NCA-1274 Penetration Assemblies

Penetration assemblies shall be considered in the Design Specification to be either parts or appurtenances.

NCA-1275 Rupture Disk Devices

The portion of the rupture disk holder which forms the pressure boundary shall be considered as material, a part, or an appurtenance. The rupture disks are not required to be Code material.

NCA-1280 INSTALLATION

NCA-1281 Activities and Requirements

The requirements pertaining to installation governing materials, fabrication, examination, testing, inspection,

Page 6

stamping, and reporting shall be in accordance with the rules applicable to the classification and type of component involved. When joining components of different classifications, the more restrictive requirements shall govern, except that connections between piping and other components shall be considered part of the piping. Data Reports and stamping shall be as required in NCA-8000.

NCA-1282 Support Installation

Installation of supports consists of those activities required to attach supports to the building structure and join parts and materials by welding or mechanical means. The requirements pertaining to installation governing materials, fabrication, examination, inspection, stamping, and reporting shall be in accordance with the rules applicable to the classification and type of support involved.

NCA-1283 Services

Services such as handling, rigging, setting, and temporary bolting and temporary aligning may be performed by organizations who are non-Certificate Holders as provided for in NCA-3125.

July 1, 1998

American Society Of Mechanical Engineers

SEC III NCA-2000

ARTICLE NCA-2000 CLASSIFICATION OF COMPONENTS AND SUPPORTS

Page 7

NCA-2100 GENERAL REQUIREMENTS

NCA-2110 SCOPE

(a) Division 1 specifies rules for:

- (1) nuclear power system metal components, parts, and appurtenances
- (2) metal containment vessels
- (3) supports

(b) Division 2 specifies rules for:

- (1) concrete reactor vessels
- (2) concrete containments

(c) While providing for several classes of construction (NCA-2120, NCA-2130), this Section does not provide guidance in the selection of a specific classification to fit a component in a given system. Such guidance is derived from systems safety criteria for specific types of nuclear power systems, such as pressurized water reactors, boiling water reactors, or high temperature gas cooled reactors, and may be found in engineering standards or in the requirements of regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

(d) The Owner of a nuclear power plant shall be responsible for applying system safety criteria to classify the equipment in the nuclear power plant to be constructed in accordance with the rules of this Section (NCA-2120 and NCA-2130). Classification shall be included in the Design Specification.

NCA-2120 PURPOSE OF CLASSIFYING ITEMS OF A NUCLEAR POWER PLANT

Construction rules are specified for items which are designated Code Classes 1, 2, 3, CS, MC, CB, and CC. These Code classes are intended to be applied to the classification of items of a nuclear power system and containment system. Within these systems the Code recognizes the different levels of importance associated with the function of each item as related to the safe operation of the nuclear power plant. The Code classes allow a choice of rules that provide assurance of structural integrity and quality commensurate with the relative importance assigned to the individual items of the nuclear power plant.

NCA-2130 CLASSIFICATIONS AND RULES OF THIS SECTION

NCA-2131 Code Classes and Rules of Division 1

(a) Division 1 provides rules for the construction of items in the following Code classes:

Class 1 - items constructed in accordance with the rules of Subsection NB

Class 2 - items constructed in accordance with the rules of Subsection NC

Class 3 - items constructed in accordance with the rules of Subsection ND

Class MC - metal containment vessels constructed in accordance with the rules of Subsection NE

Class CS - core support structures constructed in accordance with the rules of Subsection NG

(b) Division 1 also provides rules for:

(1) supports constructed in accordance with the rules of Subsection NF

(2) internal structures constructed in accordance with the rules of Subsection NG

NCA-2132 Rules of Division 2

Division 2 of this Section provides rules for:

(a) concrete reactor vessels designed and constructed in accordance with the rules of Subsection CB; and

(b) concrete containments designed and constructed in accordance with the rules of Subsection CC.

NCA-2133 Multiple Code Class Components

(a) Compartments in components consisting of multiple compartments such as heat exchangers may be

Page 10

assigned different Code classes, provided any interactions between compartments produced by service conditions are taken into account and these conditions are specified in the Design Specifications.

(b) Supports for multiple Code class components shall be constructed in accordance with the rules of Subsection NF for the more restrictive class.

NCA-2134 Optional Use of Code Classes

(a) Items classified as Class 2 in their Design Specifications may be constructed and stamped in accordance with the rules of Subsection NB.

(b) Items classified as Class 3 in their Design Specifications may be constructed and stamped in accordance with the rules of Subsection NB or NC.

(c) Containment vessels classified as Class MC in their Design Specification may be constructed and stamped in accordance with the rules of Subsection NB, provided the rules of NE-7000 are applied in lieu of the rules of NB-7000 for protection against overpressure.

(d) When an item is optionally classified to a higher class, the Design Specifications shall identify the minimum required class as well as the optionally selected higher class.

(e) Those items designated as parts (Division 1) or appurtenances (Division 1) when used in a Division 2 component, if stamped as parts (Division 1), may be used without further stamping under Division 2 requirements, provided:

(1) the Designer identifies the parts to be stamped under Division 1 requirements in the Construction Specification;

(2) the Designer separately establishes that the use of such parts satisfies the requirements of the Design Specification, the Construction Specifications, and the Design Drawings.

NCA-2135 Code Cases for Division 2 Parts

Parts specified to meet the requirements of Division 1 for material, design, fabrication, and examination may be stamped CB or CC in accordance with Division 2 when used in a Division 2 component (CB-1000, CC-1000). For these parts, Division 1 Code Cases which are applicable for material, design, fabrication, and examination may be used for Division 2 construction in accordance with NCA-1140.

NCA-2140 DESIGN BASIS

NCA-2141 Consideration of Plant and System Operating and Test Conditions¹

(a) Components and supports of a nuclear power system (NCA-1110) may be subjected to plant and system operating and test conditions which are required to be considered in the design and overpressure protection of the components and the design of supports in order to satisfy applicable systems safety criteria. The significance of plant and system operating and test conditions upon design may vary from item to item within a system for a specific operating or test condition experienced by the plant or system. The temperatures, pressures, and mechanical loads to which components and supports are subjected in consequence of plant or system operating and test conditions are referred to in this Section as component or support Design, Service, or Test Loadings.

(b) The definition of plant and system operating and test conditions, and the determination of their significance to the design and operability of components and supports of a nuclear power system, are beyond the scope of this Section. Appropriate guidance for the selection of plant or system operating and test conditions, which may be determined to be of significance in the selection of component or support Design, Service, or Test Loadings, the combinations thereof, and the corresponding acceptable Limits, may be derived from systems safety criteria documents for specific types of nuclear power systems and may be found in the requirements of regulatory and enforcement authorities having jurisdiction at the site.

NCA-2142 Establishment of Design, Service, and Test Loadings and Limits

In the Design Specification, the Owner or his designee shall identify the loadings and combinations of loadings and establish the appropriate Design, Service, and Test Limits for each component or support.

¹ Plant and system operating conditions are commonly referred to as normal, upset, emergency, and faulted.

(a) *Loadings.* The Design, Service, and Test Loadings shall be identified considering all plant or system operating and test conditions anticipated or postulated to occur during the intended service life of the component or support. Service Loadings are not required to be identified for Class 2 and 3 components, Class 2 and 3 component supports, and Class MC supports, when the Design Pressure and Design Mechanical Loads result in stresses of greater magnitude, relative to

Page 11

the allowable stress or stress intensity at the Design Temperature, than would the Service Loadings relative to the allowables for the appropriate Service Level. When this is not the case, and for piping and its supports, Service Loadings shall be identified in the Design Specification. For the Class MC containment vessel, loadings associated with the containment function shall be identified as Design Loadings, except as provided in NE-3000.

(b) *Limits.* The selection of Design, Service, and Test Limits for each item shall be established in accordance with NCA-2142.4. The rules of this Section do not assure operability of components in which mechanical motion is required. The selection of limits for Design, Service, or Test Loadings to assure operability is beyond the scope of this Section.

However, the rules of this Section do require operability of pressure relief valves. When assurance of operability is required, it is the responsibility of the Owner to define the appropriate limiting parameters by referring to documents which specify the requirements for operability. Such parameters are outside the scope of this Section [NCA-1130, NCA-2160, and NCA-5210(b)].

NCA-2142.1 Design Loadings.

Design Loadings for components and supports shall be in accordance with (a), (b), and (c) below and the additional requirements of the applicable Subsections of this Section.

(a) *Design Pressure.* The specified internal and external Design Pressure shall not be less than the maximum difference in pressure between the inside and outside of the item, or between any two chambers of a combination unit, which exists under the most severe loadings for which the Level A Service Limits are applicable. The Design Pressure shall include allowances for pressure surges, control system error, and system configuration effects such as static pressure heads.

(b) *Design Temperature.* The specified Design Temperature shall not be less than the expected maximum mean metal temperature through the thickness of the part considered for which Level A Service Limits are specified. Where a component is heated by trace heating, such as induction coils, jacketing, or by internal heat generation, the effect of such heat input shall be considered in establishing the Design Temperature. The Design Temperature shall consider control system error and system configuration effects.

(c) *Design Mechanical Loads.* The specified Design Mechanical Loads shall be selected so that when combined with the effects of Design Pressure, they produce the highest primary stresses of any coincident combination of loadings for which Level A Service Limits are designated in the Design Specification.

NCA-2142.2 Service Loadings.

When the Design Specification or applicable Subsection of this Section requires computations to demonstrate compliance with specified Service Limits, the Design Specification shall provide information from which Service Loadings can be identified (pressure, temperature, mechanical loads, cycles, or transients). The Design Specification shall designate the appropriate Service Limit (NCA-2142.4) to be associated with each Service Loading or combination of Loadings.

NCA-2142.3 Test Loadings

(a) Test Loadings include pressure tests required by this Section.

(b) Loads due to other types of tests as may be required by the Owner shall be included in the Design Specification.

NCA-2142.4 Design, Service, and Test Limits

(a) *Design Limits.* The limits for Design Loadings shall meet the requirements of the appropriate Subsection of this Section.

(b) *Service Limits.* The Design Specification may designate Service Limits as defined in (1) through (4) below.

(1) *Level A Service Limits.* Level A Service Limits are those sets of limits which must be satisfied for all Level A Service loadings identified in the Design Specifications to which the component or support may be subjected in the performance of its specified service function.

(2) *Level B Service Limits.* Level B Service Limits are those sets of limits which must be satisfied for all Level B Service loadings identified in the Design Specifications for which these Service Limits are designated. The component or support must withstand these loadings without damage requiring repair.

(3) *Level C Service Limits.* Level C Service Limits are those sets of limits which must be satisfied for all Level C Service loadings identified in the Design Specifications for which these Service Limits are designated. These sets of limits permit large deformations in areas of structural discontinuity which may necessitate the removal of the component or support from service for inspection or repair of damage to the component or support. Therefore, the selection of this limit shall be reviewed by the Owner for compatibility with established system safety criteria (

NCA-2141).

(4) *Level D Service Limits.* Level D Service Limits are those sets of limits which must be satisfied for all Level D Service loadings identified in the Design Specifications for which these Service Limits are designated. These sets of limits permit gross general deformations with some consequent loss of dimensional stability

Page 12

and damage requiring repair, which may require removal of the component or support from service. Therefore the selection of this limit shall be reviewed by the Owner for compatibility with established system safety criteria (NCA-2141).

(c) *Alternative Service Limits.* Components or supports may be alternatively designed using more restrictive Service Limits than specified in the Design Specification. For example, Level B Service Limits may be used where Level C Service Limits have been specified.

(d) *Test Limits*

(1) The limits for Test Loadings shall meet the requirements of the appropriate Subsection of this Section.

(2) The selection of Limits for other tests defined by the Owner [NCA-2142.3(b)] shall be included in the Design Specification.

NCA-2143 Acceptance Criteria

(a) Components and supports shall comply with the design rules established for Design, Service, and Test Loadings in the appropriate Subsections.

(b) It is the responsibility of the Owner to define acceptance criteria for the Service Level Loading for which acceptance criteria are not contained in this Section.

(c) Design documentation shall be completed in accordance with the requirements of the Subsection applicable to the component or support.

NCA-2144 Concrete Reactor Vessels and Concrete Containments

NCA-2144.1 Concrete Reactor Vessels.

Concrete reactor vessels, in addition to satisfying the structure design allowables (CB-3400), shall be evaluated for load categories in CB-3220.

NCA-2144.2 Concrete Containments.

Concrete containments, in addition to satisfying the structure design allowables (CC-3400), shall be evaluated for load categories in CC-3200.

NCA-2160 SPECIAL REQUIREMENTS APPLIED TO CODE CLASSES

Contractual arrangements between the Owner and Certificate Holder which specify requirements in addition to or more restrictive than those specified by the rules of this Section for the applicable class of an item may be applied, provided such requirements do not negate any rules of this Section. Such special contractual requirements are beyond the scope of this Section and shall not apply as conditional requirements for Code construction of items.

July 1, 1998

American Society Of Mechanical Engineers

SEC III NCA-3000

ARTICLE NCA-3000 RESPONSIBILITIES AND DUTIES

Page 13

NCA-3100 GENERAL

NCA-3110 RESPONSIBILITIES VS. LEGAL LIABILITIES

The various parties involved in the construction of a nuclear power plant or items which come under the jurisdiction of this Section have specific responsibilities for complying with these requirements. The responsibilities set forth herein relate only to Code compliance and are not to be construed as involving contractual or legal liabilities.

NCA-3120 ACCREDITATION

NCA-3121 Types of Certificates

Table NCA-8100-1 lists the types of certificates issued by the Society and indicates the responsibilities assumed by each Certificate Holder. Further details of these responsibilities are contained in this Article.

[98]

NCA-3125 Subcontracted Services

(a) Services may be subcontracted which are both within and beyond the scope of this Section. There are no requirements for the subcontracting of services beyond the scope of this Section. Services covered by this Section may either be of a type for which the Society issues Certificates, or may be of the type for which the Society does not issue a Certificate. Subcontracts for activities for which Certificates are required shall be made only to Certificate Holders. A Certificate Holder may subcontract to another organization the surveying and auditing of his subcontractors and Material Organizations, but must retain the responsibility for these activities and for the qualification of these subcontractors and Material Organizations.

(b) It is the right of an N Certificate Holder to subcontract stress analysis or complete design of all or a portion of a component. However, the N Certificate Holder is responsible for the design of the component and for the Design Output Documents.

(c) The Quality Assurance Manual shall describe the manner in which the Certificate Holder controls and accepts the responsibility for the subcontracted activities.

[98]

NCA-3130 WELDING¹ AND SUBCONTRACTING DURING CONSTRUCTION

NCA-3131 Welding During Construction

For Divisions 1 and 2, it is required that all shop and field welding during Code construction be done only by a Certificate Holder holding a certificate appropriate to the scope of welding to be performed. A Certificate Holder may engage individuals by contract for their services as welders or welding operators at the site location shown on the Certificate, provided conditions of (a) through (g) below are met. This is an acceptable method of complying with Section IX requirements concerning responsibility for welding.

(a) The work to be done by such welders and welding operators is within the scope of the Certificate.

(b) The use of such welders and welding operators is contained in the Quality Assurance Program of the Certificate Holder. The Quality Assurance Program (NCA-3462, NCA-3562, NCA-3662, or NCA-3762) shall include a requirement for direct supervision and direct technical control of the welders and welding operators by the Certificate Holder during such welding operations, and this program shall be acceptable to the Certificate Holder's Authorized Inspection Agency (NCA-5121) performing the inspections.

(c) The welding procedures have been properly qualified by the Certificate Holder, and Code responsibility for such procedures is retained by the Certificate Holder.

- (d) The welders and welding operators are qualified by the Certificate Holder to perform such procedures.
- (e) The Certificate Holder shall have contractual control of the welding operation, including authority to assign or remove welders and welding operators at his discretion.
- (f) The Certificate Holder shall be responsible for Code compliance of the completed item or installation including Code Symbol stamping and providing the completed appropriate Data Report Form.
- (g) Exceptions to the requirements of this paragraph for furnace brazing operations are specified in NCA-3561(c), NCA-3661(b), and NCA-3761(b).

NCA-3132 Subcontracted Construction Services - Division 2

A Certificate Holder may engage individuals or organizations not holding a Certificate to provide subcontracted construction services other than welding at the site location shown on the Certificate, provided all of the following conditions are met.

- (a) The activities, such as placement of concrete or reinforcing steel, to be performed by subcontracted individuals or organizations are included within the Scope of the Certificate of the Certificate Holder, and a description of the subcontracted activities is contained in the Certificate Holder's Quality Assurance Program.
- (b) The Quality Assurance Program (NCA-3462, NCA-3662) shall include requirements for direct technical control of such individuals or organizations. Technical control by the Certificate Holder includes controlling the performance of all Code required examinations, inspections, and tests including documentation and record retention. The Quality Assurance Program shall be acceptable to the Society (NCA-8120) and to the Authorized Nuclear Inspector Supervisor (NCA-5122).
- (c) The construction procedures have been approved by the Certificate Holder, and Code responsibility for such procedures is retained by the Certificate Holder.
- (d) Splicers for sleeve filler metal splices or mechanical reinforcing bar splices are qualified as required by this Section, provided their qualifications are reviewed and approved by the Certificate Holder.
- (e) The Certificate Holder shall have contractual control of the construction operation, including authority to assign or remove individuals or organizations at his discretion.
- (f) The Certificate Holder shall be responsible for Code compliance of the completed item including Code Symbol stamping and providing the completed, applicable Data Report Form.
- (g) Provisions shall be made by the Certificate Holder for the Authorized Inspector to have access to all areas and functions required to perform his duties, including those of procedure development and qualification performed by a subcontractor for the Certificate Holder.

NCA-3200 OWNER'S RESPONSIBILITIES

NCA-3220 CATEGORIES OF THE OWNER'S RESPONSIBILITIES

The responsibilities of the Owner include the requirements of (a) through (u) below:

- (a) obtaining an Owner's Certificate (NCA-3230);
- (b) documenting a Quality Assurance Program (NCA-8140);
- (c) obtaining a written agreement with an Authorized Inspection Agency (NCA-3230 and NCA-8130);
- (d) certifying and filing of Owner's Data Report (NCA-3280);
- (e) establishing the Code Editions, Addenda, and Code Cases to be used in Design Specifications, and determining that they are acceptable to the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site (NCA-1140)

NCA-1140);

(f) verifying through a review of the required documentation that the Code Editions, Addenda, and Code Cases used for completed components and supports, and materials satisfy NCA-1140 and are acceptable to the regulatory and enforcement authorities;

(g) classifying equipment (NCA-2110 and NCA-3253);

(h) designating the Designer, Constructor, and Fabricators for Division 2 construction and verifying through a review of the required documentation that the Designer has fulfilled his responsibilities for Division 2 construction;

(i) providing adequate structures, foundations, and auxiliary systems for the items covered by both Divisions of this Section (NCA-3240);

(j) providing and correlating Design Specifications, including establishment of component and system boundaries (NCA-3252);

(k) certifying Design Specifications (NCA-3255);

(l) reviewing Design Reports (NCA-3260);

(m) designating the overpressure protection requirements for each component or system, including the Class of overpressure protection rules assigned to each component or system and the location of the overpressure protection devices;²

² As explained in NB-, NC-, ND-, and NE-7000, an overpressure protection device or devices may be provided to protect one or more components, portions of the nuclear power system, or portions of components, provided they are so designed and located so that the overpressure protection requirements of all protected components and systems are fully complied with and that the safety relieving devices cannot be isolated from any component or system protected by them while the component or system is operating.

Page 19

**TABLE NCA-3200-1
DOCUMENT DISTRIBUTION FOR DIVISION 2 CONSTRUCTION¹**

Document	Prepared by	Reviewed by	Certified by	Approved by	Provided to [Note (2)]	Available on Request
Design Specification (NCA-3250)	O	O	O	...	D, C, I, J	...
Construction Specification (NCA-3340)	D	O	D	O	O, C, F, M	I, J
Design Drawings (NCA-3340)	D	O	D	O	O, C, F, M	I, J
Design Report (NCA-3350)	D	O	D	O	O	I, J
Construction Procedures [Note (2)] (NCA-3451)	C, F	D	...	D	D, O	I, J
Certified Material Test Reports or Certificates of Compliance [Note (2)] (CB-2130, CC-2130)	M	C, F	M	...	C, F, O	I, J, D
Shop and Field Drawings [Note (2)] (NCA-3452)	C, F	D	...	D	C, F	I
Construction Report (NCA-3454)	C	D	D, I	O	D, O, J	I, J
Data Report C-1 (NCA-8410)	C	...	D, C, I	...	O	I, J
Data Report N-2 (NCA-8410)	F	...	F, I	...	C	I, J
Data Report N-3 (NCA-8420)	O	...	O, I	...	J	...

NOTES:

(1) Symbols: O — Owner or his designee
D — Designer
C — Constructor
F — Fabricator
M — Material Manufacturer
I — Inspector
J — Enforcement Authority

(2) Information provided to the indicated participants when required to satisfy their designated responsibilities under this Section. Other information provided only by specific arrangement with the Owner. Participants are required to furnish only such information as is necessary to permit the recipient to perform his duties in conformance with this Section. Other information may be furnished at the discretion of the responsible parties.

TABLE NCA-3200-1 DOCUMENT DISTRIBUTION FOR DIVISION 2 CONSTRUCTION¹

- (n) providing and filing the Overpressure Protection Report (NCA-3270) required for the nuclear power system;
- (o) reviewing and approving the Construction Specification, Design Drawings, and Construction Report for Division 2 construction (Table NCA-3200-1);
- (p) making available to the Inspector the documents specified by this Section and those requested by the Inspector to ensure compliance with Code requirements (NCA-5242);
- (q) designating Designer's responsibilities with respect to construction surveillance for Division 2 construction (NCA-3252);
- (r) providing for the design and arrangement of components to permit accessibility in accordance with Section XI;
- (s) designating the preservice inspection requirements [NCA-3252(c)];
- (t) designating records to be maintained and providing for their maintenance (NCA-3290);
- (u) performing other duties as defined throughout this Section.

The activities necessary to provide compliance with responsibilities assigned to the Owner by (e) through (u) above may be performed on the Owner's behalf by a designee; however, the responsibility for compliance remains with the Owner.

NCA-3230 OWNER'S CERTIFICATE

The Owner, after receipt of notification from the regulatory authority that an application for a Construction Permit for a specific plant has been docketed, shall obtain an Owner's Certificate from the Society for unit(s) docketed concurrently for each site prior to beginning field installation. The information to be supplied by the Owner when making applications is given in forms issued by the Society. A written agreement with an Authorized Inspection Agency (NCA-8130) is required prior to application.

Page 20

NCA-3240 PROVISION OF ADEQUATE SUPPORTING STRUCTURES

It is the responsibility of the Owner to assure that intervening elements, foundations, and building structures adequate to support the items covered by this Section are provided and to assure that jurisdictional boundary interfaces for Code items are defined and compatible. Loads imposed upon structures outside the scope of this Section by items covered by this Section shall be defined in the Design Specification. Concrete reactor vessels or concrete containments bearing on soil or rock or on caissons or piles require an allowable bearing pressure or allowable load per caisson or pile to be determined by the Owner and furnished to the Designer.

NCA-3250 PROVISION OF DESIGN SPECIFICATIONS

NCA-3251 Provision and Correlation

It is the responsibility of the Owner to provide, or cause to be provided, Design Specifications for components, supports, and appurtenances. The Owner, either directly or through his designee, shall be responsible for the proper correlation of all Design Specifications. Separate Design Specifications are not required for parts, piping subassemblies, appurtenances, or supports when they are included in the Design Specification for a component (NCA-1210). However, the applicable data from the component Design Specification (Division 1) or the Construction Specification and Design Drawings (Division 2) shall be provided in sufficient documented detail to form the basis for fabrication in accordance with this Section.

NCA-3252 Contents of Design Specifications³

(a) The Design Specifications shall contain sufficient detail to provide a complete basis for Division 1 construction or Division 2 design in accordance with this Section. Such requirements shall not result in construction which fails to conform with the rules of this Section. All Design Specifications shall include (1) through (7) below:

(1) the functions and boundaries of the items covered (NCA-3254);

3 See Appendix B, except that for core support structures see Appendix J.

(2) the design requirements [NCA-2110(a) and (b) and NCA-2140] including all required overpressure protection requirements [NCA-3220(m)];

(3) the environmental conditions, including radiation;

(4) the Code classification of the items covered (NCA-2000);

(5) material requirements including impact test requirements;

(6) when operability of a component is a requirement, the Design Specification shall make reference to other appropriate documents which specify the operating requirements;

(7) the effective Code Edition, Addenda, and Code Cases to be used for construction.

(b) A Design Specification shall be provided for each concrete reactor vessel or concrete containment serving in a single power generating unit or for multiple concrete reactor vessels or concrete containments at the same site. In addition to the requirements of (a) above, the Design Specifications for Division 2 items shall also include (1) through (7) below:

(1) design life;

(2) corrosion effects;

(3) structural acceptance testing requirements (CB-6000 and CC-6000);

(4) shielding requirements;

(5) construction surveillance required by the Designer;

(6) foundation type and allowable loading, if applicable (NCA-3240);

(7) loads from internal structures (NCA-2132).

(c) The Design Specification shall identify those components and/or parts that require a preservice examination and shall include the following:

(1) Examination

(a) Edition and Addenda of Section XI to be used;

(b) category and method; and

(c) qualifications of personnel, procedures, and equipment.

(2) Welds

(a) surface conditioning requirements; and

(b) identification/markings system to be used.

NCA-3253 Classification of Components, Parts, and Appurtenances

The Owner, either directly or through his designee, shall establish the Code classification of the items which comprise the nuclear power plant.

Page 21

NCA-3254 Boundaries of Jurisdiction

In order to define the boundaries of components with respect to adjacent components, intervening elements, and other structures, the Design Specifications shall include:

(a)

- (a) the locations of each such boundary;
- (b) the forces, moments, strains, or displacements which are imposed at each such boundary;
- (c) the structural characteristics of the attached components or structures, whether or not they are within this Section's jurisdiction when such components or structures provide constraints to the movement of components or appurtenances;
- (d) when the foundation support is constructed as an integral part of the concrete reactor vessel or concrete containment, it shall be included within this Section's Division 2 jurisdiction to the extent required by NCA-2132.

NCA-3254.1 Definition of Division 1 Boundaries

- (a) The boundaries for Class 1 components are given in NB-1130.
- (b) The boundaries for Class 2 components are given in NC-1130.
- (c) The boundaries for Class 3 components are given in ND-1130.
- (d) The boundaries for Metal Containment Vessels are given in NE-1132.
- (e) The boundaries for Supports are given in NF-1130.
- (f) The boundaries for Core Support Structures are given in NG-1130.

NCA-3254.2 Definition of Division 2 Boundaries.

The Design Specification shall define the boundaries of Division 2 in accordance with the limits defined in NCA-1120; it shall also show the external boundaries of the component with respect to its supporting structures. Where the support is constructed as an integral part of the concrete vessel or the concrete containment, it shall be included within the jurisdiction of Division 2 to the extent required by NCA-1120. The Design Specification shall include the specific dimensional location of each boundary, including the boundaries for parts and appurtenances designated to meet the requirements of Division 1.

NCA-3255 Certification of the Design Specifications

The Design Specifications shall be certified to be correct and complete and to be in compliance with the requirements of NCA-3250 by one or more Registered Professional Engineers, competent in the applicable field of design and related nuclear power plant requirements and qualified in accordance with the requirements of Appendix XXIII of Section III Appendices. These Registered Professional Engineers are not required to be independent of the organization preparing the Design Specifications. Document distribution for Division 2 construction is shown in Table NCA-3200-1.

NCA-3256 Filing of Design Specifications

(a) The Design Specifications in their entirety shall become a principal document governing design and construction of items. A copy of the Design Specification shall be made available to the Inspector at the manufacturing site before fabrication begins, and a copy shall be filed at the location of the installation and made available to the enforcement authorities having jurisdiction over the plant installation before components or appurtenances are placed in service. In the case of parts, piping subassemblies, appurtenances, and supports, the Design Specifications need not be made available to the Inspector at the fabrication site (NCA-3251). However, the applicable data from the Design Specifications which form the basis for fabrication shall be made available to the Inspector at the fabrication site. Document distribution for Division 2 construction is shown in Table NCA-3200-1.

(b) For pumps and valves 4 in. nominal pipe size (DN 100) and less, for linear supports used as mechanical snubbers, and for standard supports, the Certificate Holder may provide his own Design Specification in accordance with NCA-3252 as a basis for construction. Prior to installation, the Owner or his designee shall be responsible for reconciling the Certificate Holder's Design Specification with his own Design Specification.

NCA-3260 REVIEW OF DESIGN REPORT

- (a) The Design Report which the Certificate Holder or the Designer provides shall be reviewed by the Owner or his

designee to determine that all the Design and Service Loadings as stated in the Design Specification have been evaluated, and that the acceptance criteria explicitly provided for in this Section, or additional acceptance criteria permitted by this Section when established in the Design Specification, associated with the specified Design and Service Conditions, have been considered. The responsibility for the method of analysis and the accuracy of the Design Report remains with the Certificate Holder or the Designer.

Page 22

(b) Except as provided for in NCA-3260(c) below, documentation shall be provided by the Owner or his designee to indicate that the review required by NCA-3260(a) above has been conducted. Prior to the stamping of the component, a copy of this documentation shall be attached to the copy of the Design Report which is made available to the Inspector. A copy of this documentation shall be included with the Design Report, which is filed at the location of the installation in accordance with NCA-4134.17 and made available to the regulatory and enforcement authorities having jurisdiction at the site of the nuclear power plant installation. Document distribution for Division 2 construction is shown in Table NCA-3200-1.

(c) When a Certified Design Report Summary (NCA-3551.3) is furnished in lieu of a Design Report (NCA-3551.1), for standard supports, documentation shall be provided by the Owner or the Owner's designee to indicate that the Certified Design Report Summary has been reviewed in accordance with NCA-3260(a) above. Prior to stamping of the component, including piping systems, a copy of this documentation shall be attached to the Certified Design Report Summary which is made available to the Inspector. A copy of this documentation and the Certified Design Report Summary shall be filed at the location of the installation in accordance with NCA-4134.17 and made available to the regulatory and enforcement authorities having jurisdiction at the site of the nuclear power plant.

NCA-3270 OVERPRESSURE PROTECTION REPORT

NCA-3271 Responsibility and Content

It is the responsibility of the Owner to provide, or cause to be provided, an Overpressure Protection Report for each component or system (NB-7200, NC-7200, ND-7200, NE-7200, or CB-7200).

NCA-3272 Certification of Report

The Report shall be certified as specified in NB-7230, NC-7230, ND-7230, NE-7230, or CB-7230.

NCA-3273 Filing of Report

The Report shall be filed as specified in NB-7250, NC-7250, ND-7250, NE-7250, or CB-7240.

NCA-3280 OWNER'S DATA REPORT AND FILING

The Owner or his designee shall prepare the Form N-3 (Appendix V).

NCA-3290 OWNER'S RESPONSIBILITY FOR RECORDS

The Owner shall be responsible for designating the records to be maintained (NCA-4134.17). The Owner shall also be responsible for continued maintenance of the records required by this Section and Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, at the power plant site, the Certificate Holder's plant, or other locations determined by the Owner. The Owner shall advise the Enforcement Authority in writing regarding the location of the records.

NCA-3300 RESPONSIBILITIES OF A DESIGNER - DIVISION 2

NCA-3320 CATEGORIES OF THE DESIGNER'S RESPONSIBILITY

The Designer has the following categories of responsibility:

(a) prepare structural design of the component in conformance with this Section and the Design Specification (NCA-3250);

- (b) prepare the Design Drawings and Construction Specification (NCA-3340);
 - (c) prepare and submit the Design Report (NCA-3350);
 - (d) surveillance of construction to the extent designated by the Owner in the Design Specification (NCA-3220);
 - (e) review of construction documents (NCA-3450) as specified in the Construction Specification;
 - (f) establish and maintain a Quality Assurance Program (NCA-4134);
 - (g) modifications of Design Drawings and Construction Specification (NCA-3370);
 - (h) certification of the Construction Report (NCA-3380);
 - (i) document distribution as shown in Table NCA-3200-1.
-

NCA-3340 DESIGN DRAWINGS AND CONSTRUCTION SPECIFICATION

NCA-3341 Design Drawings

The Design Drawings shall contain the following:

- (a) concrete and steel liner thickness;
- (b) size and location of reinforcing steel;
- (c) size and location of prestressing tendons;
- (d) size and location of penetrations;
- (e) all other details necessary to construct the item in accordance with the requirements of the Design Specification, the Construction Specification, and this Section.

NCA-3342 Construction Specification

The Construction Specification shall contain the following:

- (a) material specifications;
- (b) material shipping, handling, and storage requirements;
- (c) inspection requirements;
- (d) appropriate Code references;
- (e) requirements for personnel or equipment qualification;
- (f) material or part examination and testing requirements;
- (g) acceptance testing requirements;
- (h) leak testing requirements;
- (i) requirements for shop drawings;
- (j) requirements for batching, mixing, placing, and curing concrete;
- (k) requirements for the fabrication and installation of the prestressing system, reinforcing steel, embedments, and all other parts;
- (l) identification of parts requiring a Code stamp;
- (m) design life for parts and materials where necessary to establish compliance with the Design Specification;
- (n) construction surveillance to be performed by the Designer as required by the Design Specification;

(o) construction documents which require review by the Designer and those which require both review and approval by the Designer - as a minimum, these will include the requirements of Table NCA-3200-1.

NCA-3350 DESIGN REPORT

The Designer shall prepare a Design Report in sufficient detail to show that the applicable stress limitations are satisfied when the component is subject to the loading conditions specified in the Design Specification and this Section. The Design Report prepared by the Designer shall contain calculations and sketches substantiating that the design is in accordance with the Design Specification and this Section. Distribution of the Design Report is shown in Table NCA-3200-1.

NCA-3360 CERTIFICATION OF THE CONSTRUCTION SPECIFICATION, DESIGN DRAWINGS, AND DESIGN REPORT

(a) The Construction Specification, Design Drawings, and Design Report shall be reviewed and certified to be correct and in accordance with the Design Specification and this Section by one or more Registered Professional Engineers competent in the field of design of concrete components and qualified in accordance with the requirements of Appendix XXIII of Section III Appendices. These Registered Professional Engineers are not required to be independent of the organization designing the component. Distribution of Construction Specification, Design Drawings, and the Design Report is shown in Table NCA-3200-1.

(b) In order for the Designer to certify the Construction Specification and Design Drawings, it is necessary that the Design Specification has been certified. For the Constructor or Fabricator to do work in accordance with Construction Specifications and Design Drawings, it is necessary that these documents have been certified.

[98]

NCA-3370 REVISION OF DESIGN DRAWINGS AND CONSTRUCTION SPECIFICATION

Design Documents issued for use in construction shall be revised to reflect any change in the Design. Changes to Design Documents shall be reviewed and certified in accordance with NCA-3360.

NCA-3380 CERTIFICATION OF CONSTRUCTION REPORT

The Construction Report shall be evaluated by the Designer, who shall certify that the Construction Report conforms to the requirements of Division 2 and the Design Specification. He shall also provide any supplemental analysis needed to substantiate this evaluation. Prior to certification, he shall review the file of as-built, design, shop, and field drawings to establish that the list provided by the Constructor in the Construction Report corresponds to the as-built, design, shop, and field drawings which will be maintained as a file by

Page 24

the Owner. Distribution of the Construction Report is shown in Table NCA-3200-1.

NCA-3400 RESPONSIBILITIES OF AN N CERTIFICATE HOLDER - DIVISION 2

[98]

NCA-3420 CATEGORIES OF THE N CERTIFICATE HOLDER'S RESPONSIBILITIES

The N Certificate Holder is responsible for:

- (a) obtaining an N Certificate (NCA-3430);
- (b) constructing the components and parts in accordance with the Design Drawings and Construction Specification(s) and in accordance with this Section;
- (c) qualification of Metallic Material Organizations (NCA-3800);
- (d) qualification of Manufacturers of nonmetallic material (NCA-3900);
- (e) establishing and maintaining a Quality Assurance Program (NCA-3460);

- (f) documenting a Quality Assurance Program (NCA-3462);
- (g) filing the Quality Assurance Manual (NCA-3463);
- (h) preparing construction procedures (NCA-3451);
- (i) preparing shop and field drawings (NCA-3452);
- (j) preparing the Construction Report (NCA-3454);
- (k) obtaining agreement with an Authorized Inspection Agency (NCA-8130);
- (l) Data Reports (NCA-3455);
- (m) document distribution as shown in Table NCA-3200-1;
- (n) structural integrity testing (CB-6000, CC-6000);
- (o) making available to the Inspector the documents specified by this Section and those requested by him to assure compliance with Code requirements;
- (p) review of Certified Material Test Reports and Certificates of Compliance for materials (NCA-1220) used by him;
- (q) preparation, accumulation, control, and protection of required records while in his custody (Table NCA-3200-1);
- (r) documentation of review and approval of material used by him as permitted by NCA-1140(e).

[98]

NCA-3430 OBTAINING A CERTIFICATE

An N Certificate (NCA-8100) shall be obtained for the construction of any concrete reactor vessel or containment intended to be in compliance with the requirements of this Section and to be stamped with an N Code Symbol.

NCA-3440 COMPLIANCE WITH THIS SECTION

The N Certificate Holder has the responsibility for constructing the concrete reactor vessel or concrete containment in accordance with the Design Drawings and Construction Specification and in accordance with this Section. For Division 2 construction, the N Certificate Holder's responsibilities do not include design of the component.

NCA-3450 CONSTRUCTION DOCUMENTS

NCA-3451 Construction Procedures

Construction Procedures give sufficient detailed information about the methods of construction and fabrication to enable those reviewing the procedures to determine whether the requirements of the Design Specification, the Construction Specification, and the Design Drawings will be satisfied. Construction procedures will include test procedures to be performed by the Certificate Holder that are needed to establish conformance with the requirements of the documents listed in this Article. Distribution of procedures is shown in Table NCA-3200-1.

NCA-3452 Shop and Field Drawings

The Certificate Holder shall provide Shop and Field Drawings. Distribution of Shop and Field Drawings is shown in Table NCA-3200-1.

NCA-3453 Material Documentation

The N Certificate Holder shall assemble records to verify that materials comply with the requirements of this Section and the Construction Specification.

NCA-3454 Contents of the Construction Report

The N Certificate Holder shall provide a Construction Report. The Report shall include the following:

- (a) a summary of construction progress showing key dates of major construction activities;
- (b) a complete and detailed record of all reactor vessel or containment acceptance testing;
- (c) a summary of quality control records for components and parts;

Page 25

- (d) a list of as-built, design, field, and shop drawings showing the latest revision used for construction and date;
- (e) a summary of deviations (nonconformances) giving a brief description of the nature of the deviations (nonconformances) and the corrective actions and the date when the corrective actions were taken;
- (f) distribution and approvals as shown in Table NCA-3200-1.

NCA-3455 Data Report

The N Certificate Holder shall certify by signing Form C-1, Appendix V, Division 2 that all details of materials, construction, and workmanship of the component conform to this Section and the Construction Specification. Distribution of the Data Reports is shown in Table NCA-3200-1.

NCA-3460 RESPONSIBILITY FOR QUALITY ASSURANCE

NCA-3461 Scope of Responsibilities for Quality Assurance

(a) The N Certificate Holder shall be responsible for surveying, qualifying, and auditing suppliers of subcontracted services (NCA-3125), including nondestructive examination contractors and Material Organizations. Material Organizations holding a Quality System Certificate (Materials) and Certificate Holders whose scope includes supply or manufacture and supply of material need not be surveyed nor audited for work or material covered by the scope of their Certificate. Subcontractors holding an appropriate Certificate need not be surveyed nor audited for work within the scope of the subcontractor's certificate.

(b) An N Certificate Holder may qualify vendors of subcontracted services other than those requiring a Certificate, such as Material Organization, for another Certificate Holder doing work for that N Certificate Holder. The qualification documentation shall be supplied to the other Certificate Holder prior to their use of the subcontracted service or Material Organization.

NCA-3462 Documentation of Quality Assurance Program

The N Certificate Holder shall be responsible for documenting its Quality Assurance Program (NCA-4134).

NCA-3463 Filing of Quality Assurance Manual

The N Certificate Holder shall file with the Authorized Inspection Agency (NCA-5121) copies of the Quality Assurance Manual. The N Certificate Holder shall keep a copy on file available to the Inspector (NCA-5122).

NCA-3500 RESPONSIBILITIES OF AN N CERTIFICATE HOLDER - DIVISION 1

[98]

NCA-3520 CATEGORIES OF THE N CERTIFICATE HOLDER'S RESPONSIBILITIES

The N Certificate Holder's responsibilities include the following:

- (a) obtaining an N Certificate (NCA-3530);
- (b) compliance with this Section (NCA-3540);
- (c) achievement of structural integrity (NCA-3540);

- (d) provision of a Design Report (NCA-3550) when one is required including:
 - (1) stress analysis of parts (NCA-3552);
 - (2) stress analysis of appurtenances (NCA-3553);
 - (3) reconciliation of Design Drawing changes with Design Report (NCA-3554);
 - (4) certification of Design Report (NCA-3555);
 - (5) availability of Design Report and its documentation of review to Inspector (NCA-3557);
 - (6) provision of Design Report to Owner or his designees for review, and documentation of review (NCA-3556);
 - (7) filing at the site of installation the Design Report or Certified Design Report Summary.
 - (e) qualification of Material Organizations and suppliers of subcontracted services (NCA-3561);
 - (f) establishing and maintaining a Quality Assurance Program (NCA-3560 and NCA-3562);
 - (g) documenting a Quality Assurance Program (NCA-3562);
 - (h) filing the Quality Assurance Manual (NCA-3563);
 - (i) Data Reports (NCA-3570);
 - (j) obtaining an agreement with an Authorized Inspection Agency (NCA-8130);
 - (k) making available to the Inspector the documents specified by this Section and those requested by him to assure compliance with Code requirements;
 - (l) review of Certified Material Test Reports and Certificates of Compliance for materials (NCA-1220) used by him;
 - (m) preparation, accumulation, control, and protection of required records while in his custody (NCA-4134.17);
-

Page 26

- (n) documentation of review and approval of material used by him as permitted by NCA-1140(e);
 - (o) subcontracting (NCA-3125) for materials, design, fabrication, installation, examination, testing, and inspection. The N Certificate Holder shall retain overall responsibility, including certification and stamping.
- [98]

NCA-3530 OBTAINING A CERTIFICATE

An N Certificate (NCA-8100) shall be obtained for the construction of any item intended to be in compliance with the requirements of this Section and to be stamped with an N Code Symbol. An N Certificate Holder may do all of the work of an NPT or NA Certificate Holder at the location shown on his Certificate, provided that the scope of work is included in this Certificate.

NCA-3540 COMPLIANCE WITH THIS SECTION

The N Certificate Holder has the responsibility for the structural integrity using the Design Specification as a basis of design, complying with this Section, and furnishing a Design Report if required.

NCA-3550 REQUIREMENTS FOR DESIGN OUTPUT DOCUMENTS

NCA-3551 General

The drawings used for construction shall comply with the Design Specifications and the rules of this Section and shall be in agreement with the other Design Output Documents.

⁴ See Appendix C of Division 1.

NCA-3551.1 Design Report.⁴

The drawings used for construction shall be in agreement with the Design Report before it is certified and shall be identified and described in the Design Report. It is the responsibility of the N Certificate Holder to furnish a Design Report for each component and support, except as provided in NCA-3551.2 and NCA-3551.3. The Design Report shall be certified by a Registered Professional Engineer when it is for Class 1 components and supports, Class CS core support structures, Class MC vessels and supports, Class 2 vessels designed to NC-3200 (NC-3131.1), or Class 2 or Class 3 components designed to Service Loadings greater than Design Loadings. A Class 2 Design Report shall be prepared for Class 1 piping 1 in. nominal pipe size (DN 25) or smaller which is designed in accordance with the rules of Subsection NC.

NCA-3551.2 Load Capacity Data Sheet.

The Load Capacity Data Sheet shall state the load capacity of the support and identify the tests and calculations used to establish the load capacity. The Load Capacity Data Sheet shall adequately identify the support. The Load Capacity Data Sheet for supports for Class 1 components, Class MC vessels, and Class 2 vessels designed to NC-3200 shall be certified by a Registered Professional Engineer qualified in accordance with the requirements of Appendix XXIII of Section III Appendices. The Load Capacity Data Sheet shall specify the organization responsible for retaining the data substantiating the stated load capacity. Such data shall be on file and available for review.

NCA-3551.3 Certified Design Report Summary.

For standard supports designed by analysis, a Certified Design Report Summary may be furnished in lieu of a Design Report when the manufacturer of the standard support provides his own Design Specification [NCA-3256(b)]. The Design Report used to justify the Certified Design Report Summary shall be certified by a Registered Professional Engineer. The Certified Design Report Summary shall include NCA-3551.3(a) through NCA-3551.3(g) below.

- (a) A description or sketch of the Standard Support including the manufacturer's catalog item number or identification number.
- (b) Identification and location of the Standard Support manufacturer's applicable Design Specification.
- (c) Identification and location of the Standard Support manufacturer's applicable Design Report.
- (d) The classification (Class 1, 2, 3, or MC or combination) of the Standard Support.
- (e) A summary of allowable loads, temperatures, and associated Service Level Limits which the designer of the piping system or other component may use in his design.
- (f) Applicable Code Edition and Addenda.
- (g) Date of Certification.

NCA-3552 Design Output Documents for Parts

When the N Certificate Holder purchases parts from an NPT Certificate Holder, it is the responsibility of the N Certificate Holder to provide or cause to be provided the calculations for the parts and to incorporate them into the Design Output Documents.

Page 27

NCA-3553 Design Output Documents for Appurtenances

The Design Output Documents for each appurtenance which is to be attached to a completed component shall be provided unless they are already included in the component Design Output Documents.

NCA-3554 Modification of Documents and Reconciliation With Design Report

Any modification of any document used for construction, from the corresponding document used for design analysis,

shall be reconciled with the Design Report by the person or organization responsible for the design. A revision or addenda to the Design Report shall be prepared and (if required by NCA-3551.1) certified to indicate the basis on which this has been accomplished. All such revised documentation shall be filed with the completed Design Report.

NCA-3555 Certification of Design Report

(a) The Design Report for Class 1 components and supports, Class CS core support structures, Class MC vessels and supports, Class 2 vessels designed to NC-3200 (NC-3131.1), or Class 2 or Class 3 components designed to Service Loadings shall be certified by one or more Registered Professional Engineers competent in the applicable field of design and qualified in accordance with the requirements of Appendix XXIII of Section III Appendices. The Design Report shall be certified only after all design requirements of this Section have been met. Such Registered Professional Engineers shall be other than the individuals certifying the Design Specifications (NCA-3255) but are not required by these rules to be independent of the organization holding the Certificate.

(b) It is the intent of this Section that the certification of the Design Report shall in no way relieve the N Certificate Holder of the responsibility for the structural integrity of the completed item for the conditions stated in the Design Specifications.

NCA-3556 Submittal of Design Report for Owner Review

The N Certificate Holder shall submit to the Owner or his designee a copy of the completed Design Report or all components and supports for review and documentation of review to the extent required by NCA-3260.

NCA-3557 Availability of Design Report

The N Certificate Holder shall make a copy of the completed Design Report, Load Capacity Data Sheets, Certified Design Report Summaries, and the drawings used for construction available to the Inspector.

NCA-3560 RESPONSIBILITY FOR QUALITY ASSURANCE

NCA-3561 Scope of Responsibilities

(a) The N Certificate Holder shall be responsible for surveying, qualifying, and auditing suppliers of subcontracted services (NCA-3125), including nondestructive examination contractors and Material Organizations. Material Organizations holding Quality System Certificates (Materials), and Certificate Holders whose scope includes supply or manufacture of materials, need not be surveyed nor audited for work or material covered by the scope of their Certificate. Subcontractors holding an appropriate Certificate of Authorization need not be surveyed nor audited for work within the scope of the subcontractor's Certificate. N or NV Certificate Holders may supply replacement material without material supply being shown in the scope of their Certificate provided supply of replacement material is included in their Quality Assurance Program, the replacement material conforms to all applicable requirements of this Section, and are exclusively for incorporation into items originally manufactured or fabricated and furnished by the N or NV Certificate Holders under their Certificate.

(b) An N Certificate Holder may qualify vendors of subcontracted services (NCA-3125) other than those requiring a Certificate of Authorization, such as Material Organization, for another Certificate Holder doing work for that N Certificate Holder. The qualification documentation shall be supplied to the other Certificate Holder prior to their use of the subcontracted service or Material Organization.

(c) An N Certificate Holder may subcontract furnace brazing operations involving uniform heating to an organization not holding a Certificate, provided:

(1) the work performed is within the scope of activities of the N Certificate Holder's Certificate;

(2) the N Certificate Holder's Quality Assurance Program shall provide for the subcontracting of furnace brazing operations, including Authorized Inspection, and these provisions shall be acceptable to the N Certificate Holder's Authorized Inspection Agency;

(3) the N Certificate Holder's Quality Assurance Program provides for surveillance by the N Certificate

Holder at his subcontractor's facility during the brazing operation;

(4) the N Certificate Holder shall be responsible for surveying and accepting the Quality System Programs of the subcontractor;

(5) the N Certificate Holder shall assure that the subcontractor uses written procedures and brazing operators that have been qualified as required by the Code;

(6) the N Certificate Holder shall be responsible for controlling the quality and for assuring that all materials and parts which are submitted to the Inspector for acceptance, including those brazed by subcontractors, conform to all applicable requirements of this Section.

NCA-3562 Documentation of Quality Assurance Program

The N Certificate Holder shall be responsible for documenting its Quality Assurance Program (NCA-4134).

NCA-3563 Filing of Quality Assurance Manual

The N Certificate Holder shall file with the Authorized Inspection Agency (NCA-5121) copies of the Quality Assurance Manual. The N Certificate Holder shall keep a copy on file available to the Inspector (NCA-5122).

NCA-3570 DATA REPORT

The N Certificate Holder shall certify compliance with this Section by signing the appropriate Data Report including stamping (NCA-8000).

NCA-3600 RESPONSIBILITIES OF AN NPT CERTIFICATE HOLDER

NCA-3620 CATEGORIES OF THE NPT CERTIFICATE HOLDER'S RESPONSIBILITIES

The responsibilities of an NPT Certificate Holder include the following:

- (a) obtaining an NPT Certificate (NCA-3630);
- (b) compliance with this Section (NCA-3640);
- (c) qualification of Material Organizations and suppliers of subcontracted services (NCA-3661);
- (d) establishing and maintaining a Quality Assurance Program (NCA-3660);
- (e) documenting a Quality Assurance Program (NCA-3662);
- (f) filing the Quality Assurance Manual (NCA-3663);
- (g) Data Reports (NCA-3670);
- (h) contributing information to the Constructor needed for the preparation of the Construction Report for Division 2 construction (NCA-3454);
- (i) obtaining agreement with an Authorized Inspection Agency (NCA-8130);
- (j) fabricating parts assigned to him in accordance with the Design Drawings, Construction Specification(s), and in accordance with this Section;
- (k) preparing construction procedures and shop and field drawings;
- (l) distribution of documents for Division 2 construction as shown in Table NCA-3200-1;
- (m) making available to the Inspector the documents specified by this Section and those requested by him to assure compliance with Code requirements;
- (n) review of Certified Material Test Reports and Certificates of Compliance for materials (NCA-1220) used by him;

- (o) preparation, accumulation, control, and protection of required records while in his custody (NCA-4134.17);
- (p) documentation of review and approval of material used by him as permitted by NCA-1140(e);
- (q) provision of Design Report (NCA-3650) for appurtenances when not included in the component Design Report.

NCA-3630 OBTAINING A CERTIFICATE

An NPT Certificate (NCA-8100) shall be obtained for the construction of any item intended to be in compliance with the requirements of this Section and to be stamped with an NPT Code Symbol.

NCA-3640 COMPLIANCE WITH THIS SECTION

The NPT Certificate Holder shall have all work performed in accordance with the applicable requirements of this Section.

NCA-3650 DESIGN DOCUMENTS FOR APPURTENANCES

The Design Documents for each appurtenance which is to be attached to a completed component shall be provided unless they are already included in the component Design Documents.

Page 29

NCA-3660 RESPONSIBILITY FOR QUALITY ASSURANCE

NCA-3661 Scope of Responsibilities

(a) The NPT Certificate Holder shall be responsible for surveying, qualifying, and auditing the Quality System Programs of suppliers of subcontracted services (NCA-3125), including nondestructive examination contractors and Material Organizations. Material Organizations holding a Quality System Certificate (Materials), and Certificate Holders whose scope includes supply or manufacture and supply of materials need not be surveyed nor audited for work or material covered by the scope of their Certificate. Subcontractors holding an appropriate Certificate need not be surveyed nor audited by the NPT Certificate Holder for work within the scope of the subcontractor's Certificate.

(b) An NPT Certificate Holder may subcontract furnace brazing operations involving uniform heating to an organization not holding a Certificate, provided:

(1) the work performed is within the scope of activities of the NPT Certificate Holder's Certificate;

(2) the NPT Certificate Holder's Quality Assurance Program shall provide for the subcontracting of furnace brazing operations, including Authorized Inspection, and these provisions shall be acceptable to the NPT Certificate Holder's Authorized Inspection Agency;

(3) the NPT Certificate Holder's Quality Assurance Program provides for surveillance by the NPT Certificate Holder at his subcontractor's facility during the brazing operation;

(4) the NPT Certificate Holder shall be responsible for surveying and accepting the Quality System Programs of the subcontractor;

(5) the NPT Certificate Holder shall assure that the subcontractor uses written procedures and brazing operators that have been qualified as required by the Code;

(6) the NPT Certificate Holder shall be responsible for controlling the quality and for assuring that all materials and parts which are submitted to the Inspector for acceptance, including those brazed by subcontractors, conform to all applicable requirements of this Section.

NCA-3662 Documentation of Quality Assurance Program

The NPT Certificate Holder shall be responsible for documenting its Quality Assurance Program (NCA-4134).

NCA-3663 Filing of Quality Assurance Program

The NPT Certificate Holder shall file with the Authorized Inspection Agency (NCA-5121) copies of the Quality Assurance Manual. The NPT Certificate Holder shall keep a copy on file available to the Inspector (NCA-5122).

NCA-3670 DATA REPORT

The NPT Certificate Holder shall certify compliance with this Section by signing the appropriate Data Report Form and applying the appropriate stamping (NCA-8000).

NCA-3700 RESPONSIBILITIES OF AN NA CERTIFICATE HOLDER

NCA-3720 CATEGORIES OF THE NA CERTIFICATE HOLDER'S RESPONSIBILITIES

The NA Certificate Holder's responsibilities include the following:

- (a) obtaining an NA Certificate (NCA-3730);
- (b) compliance with this Section (NCA-3740);
- (c) qualification of Material Organizations and suppliers of subcontracted services (NCA-3761);
- (d) establishing and maintaining a Quality Assurance Program (NCA-3760);
- (e) documenting the Quality Assurance Manual (NCA-3762);
- (f) filing the Quality Assurance Manual (NCA-3763);
- (g) Data Reports (NCA-3770);
- (h) obtaining an agreement with an Authorized Inspection Agency (NCA-8130);
- (i) making available to the Inspector the documents specified by this Section and those requested by him to assure compliance with Code requirements;
- (j) review of Certified Material Test Reports and Certificates of Compliance for materials (NCA-1220) used by him;
- (k) preparation, accumulation, control, and protection of required records while in his custody (NCA-4134.17);
- (l) documentation of review and approval of material used by him as permitted by NCA-1140(e).

NCA-3730 OBTAINING A CERTIFICATE

An NA Certificate (NCA-8100) shall be obtained for the installation of any item intended to be in compliance

Page 30

with the requirements of this Section and to be stamped with the NA Code Symbol.

NCA-3740 RESPONSIBILITY FOR COMPLIANCE WITH THIS SECTION

The NA Certificate Holder has responsibility for those activities required to place and attach components to their support structures or join items in accordance with the applicable requirements of this Section.

NCA-3760 RESPONSIBILITY FOR QUALITY ASSURANCE

NCA-3761 Scope of Responsibilities

(a) The NA Certificate Holder shall be responsible for surveying, qualifying, and auditing suppliers of subcontracted services (NCA-3125), including nondestructive examination contractors and Material Organizations. Material Organizations holding a Quality System Certificate (Materials), and Certificate Holders whose scope includes supply or manufacture and supply of materials, need not be surveyed nor audited for work or material covered by the scope of their Certificate. Subcontractors holding an appropriate N, NPT, or NA Certificate need not be surveyed nor audited by the NA Certificate Holder for work within the scope of the subcontractor's Certificate.

(b) An NA Certificate Holder may subcontract furnace brazing operations involving uniform heating to an organization not holding a Certificate, provided:

- (1) the work performed is within the scope of activities of the NA Certificate Holder's Certificate;
- (2) the NA Certificate Holder's Quality Assurance Program shall provide for the subcontracting of furnace brazing operations, including Authorized Inspection, and these provisions shall be acceptable to the Authorized Inspection Agency;
- (3) the NA Certificate Holder's Quality Assurance Program provides for surveillance by the NA Certificate Holder at his subcontractor's facility during the brazing operation;
- (4) the NA Certificate Holder shall be responsible for surveying and accepting the Quality System Programs of the subcontractor;
- (5) the NA Certificate Holder shall assure that the subcontractor uses written procedures and brazing operators that have been qualified as required by the Code;
- (6) the NA Certificate Holder shall be responsible for controlling the quality and for assuring that all materials and parts which are submitted to the Inspector for acceptance, including those brazed by subcontractors, conform to all applicable requirements of this Section.

NCA-3762 Documentation of Quality Assurance Program

The NA Certificate Holder shall be responsible for documenting his Quality Assurance Program (NCA-4134).

NCA-3763 Filing of Quality Assurance Manual

The NA Certificate Holder shall file with his Authorized Inspection Agency (NCA-5121) copies of the Quality Assurance Manual. The NA Certificate Holder shall keep a copy on file available to the Inspector (NCA-5122).

NCA-3770 DATA REPORT

The NA Certificate Holder shall certify compliance with this Section by signing the appropriate Data Report Forms and applying the appropriate stamping (NCA-8000).

NCA-3800 METALLIC MATERIAL ORGANIZATION'S QUALITY SYSTEM PROGRAM

NCA-3810 EXCLUSIONS

Material falling within the small products exclusion of NB-/NC-/ND-/NE-/NF-/ NG-2610 or material which is allowed by this Section to be furnished with a Certificate of Compliance, is exempted from the requirements of NCA-3800, except:

- (a) Certified Material Test Reports or Certificates of Compliance shall meet the requirements of NCA-3862.1.
- (b) For Class 1 construction only, material identification and marking shall meet the requirements of NCA-3856.3.

NCA-3820 ACCREDITATION OR QUALIFICATION OF MATERIAL ORGANIZATIONS

(a) A Material Organization shall be accredited by obtaining a Quality System Certificate issued by the Society verifying the adequacy of the Material Organization's Quality System Program.

Page 31

(b) Alternatively, the Certificate Holder (NCA-3461, NCA-3561, NCA-3661, or NCA-3761) or, when included in its scope of activities, the accredited Material Organization [NCA-3820(a)] may qualify Material Organizations not accredited by the Society by evaluation of the organization's Quality System Program in accordance with the requirements of NCA-3842.

(c) A Certificate Holder may furnish material when stated in the scope of its Certificate. In this case, a Quality System Certificate is not required, nor is the user of the material required to survey, qualify, or audit such a Certificate Holder.

NCA-3830 RESPONSIBILITIES OF MATERIAL ORGANIZATIONS

The Material Organization shall be responsible for establishing, documenting, implementing, and maintaining a Quality System Program in accordance with the requirements of NCA-3850, and as applicable to its scope of activities:

- (a) establishing and maintaining measures for the traceability of material or source material while under its control (NCA-3856);
- (b) controlling quality during manufacture, including control of testing, examination, repair, and treatment of the material or source material (NCA-3857, NCA-3858);
- (c) evaluating, qualifying, and auditing Material Organizations (NCA-3842), as provided by NCA-3820(b), except when the party holds a Quality System Certificate which covers the operations performed;
- (d) approving and controlling operations performed by suppliers of source material and subcontracted services (NCA-3855);
- (e) preparing Certified Material Test Reports and Certificates of Compliance (NCA-3860).

NCA-3840 EVALUATION OF THE PROGRAM

[98]

NCA-3841 Evaluation by the Society

(a) The Society, when requested by the applicant on forms issued by the Society, will arrange for a survey of the Material Organization's Quality System Program for the scope of activities on the application. The Program will be evaluated on the basis of its compliance with the applicable material requirements of this Section and the requirements of this Subarticle. The Quality System Certificate, which is issued for a three year period, will describe and specify the scope and limits of work for which the accredited Material Organization is qualified and will be subject to a planned audit program by the Society. Not later than six months prior to the expiration of the Certificate, the accredited Material Organization shall apply for a renewal evaluation and for issuance of a new Certificate.

(b) The applicant shall supply all information required by forms provided by the Society.

(c) The applicant's Quality System Program shall be accepted by the Society prior to the issuance of a Certificate.

(d) A controlled copy of the accredited Material Organization's Quality System Manual shall be filed with the Society. The Manual shall be the Society's guide for surveying and auditing the accredited Material Organization's continued compliance with the accepted Quality System Program.

(e) The accredited Material Organization shall make available for on-site review by the Society any procedures, process sheets, or drawings as are necessary to understand the Program. Detailed technical procedures will not be approved by the Society. The accredited Material Organization shall keep a controlled copy of the Manual on file and in a place and manner readily available to the Society's audit team.

(f) The accredited Material Organization shall obtain the Society's review and acceptance of proposed revisions to the Quality System Manual prior to implementation.

(g) When the applicant requests that the scope of the Quality System Certificate include qualification of non-accredited Material Organizations (NCA-3842), this activity shall be included in the Manual, and will be reviewed by the Society.

(h) When the applicant requests that the scope of the Quality System Certificate include implementation of NCA-3855.5, Utilization of Unqualified Source Material, this activity shall be included in the Manual and will be reviewed by the Society.

(i) When the applicant requests that the scope of the Quality System Certificate include approval and control of suppliers (NCA-3855.3), this activity shall be included in the Manual and will be reviewed by the Society.

[98]

NCA-3842

NCA-3842 Evaluation by Parties Other Than the Society

NCA-3842.1 Qualification of Material Organizations

(a) The qualification of Material Organizations by parties other than the Society shall be limited to the furnishing of source material, material, or subcontracted services to the accredited Material Organization or Certificate Holder performing the evaluation, or their designee.

Page 32

(b) When a Material Organization has been qualified by an accredited Material Organization or Certificate Holder, it is not necessary for another party to requalify that organization for materials or services that are to be furnished to the party that performed the evaluation.

[98]

NCA-3842.2 Evaluation of the Qualified Material Organization's Program by Accredited Material Organizations or Certificate Holders.

Evaluation of a Material Organization's Quality System Program by parties other than the Society, as provided by NCA-3820(b), shall be performed in accordance with the requirements of NCA-3842.2(a) through (h) below.

(a) The Quality System Program shall be surveyed, accepted, and audited by the party performing the evaluation on the basis of its compliance with the applicable material requirements of this Section and the requirements of NCA-3850.

(b) The Quality System Manual (NCA-3853.1) shall be the party's guide for surveying and auditing the qualified Material Organization's continued compliance with the accepted Quality System Program.

(c) The qualified Material Organization shall make available for on-site review by the party performing the evaluation any procedures, process sheets, or drawings as are necessary to understand the Program. The qualified Material Organization shall keep a controlled copy of the Manual on file and in a place and manner readily available to the party performing the audit.

(d) The qualified Material Organization shall notify purchasers of material, source material, or subcontracted services accepting its Program of proposed revisions to its Quality System Manual. The party accepting the Program shall evaluate and accept such revisions prior to the implementation of the revisions on purchased materials or services.

(e) When the qualified Material Organization's scope of activities includes utilization of unqualified source material (NCA-3855.5), this activity shall be included in the Quality System Manual, and shall be reviewed by the party accepting the Program.

(f) When the qualified Material Organization's scope of activities includes approval and control of suppliers (NCA-3855.3), this activity shall be included in the Quality System Manual, and shall be reviewed by the party accepting the Program. During surveys or audits of qualified Material Organizations, the party performing the evaluation shall review objective evidence that the qualified Material Organization's control of suppliers is adequate to assure compliance with the applicable material requirements of this Section.

(g) Audits by parties performing evaluations of qualified Material Organizations shall meet the following requirements:

(1) The party performing the evaluation shall include audit frequency in their Manual.

(2) Audit frequencies shall be commensurate with the schedule of production or procurement, but shall be conducted at least once triennially during the interval in which materials are controlled or services are performed by the Material Organization being evaluated.

(3) Audits shall meet the requirements of NCA-3859.1(a) through (c).

(h) The party performing the evaluation shall supplement triennial audits with annual audits or performance assessments documenting the effectiveness of the qualified Material Organization's Quality System Program. Performance assessments shall meet the following requirements:

(1) Assessment frequencies shall be commensurate with the schedule of production or procurement, but shall be conducted at least once annually during the interval in which materials or source materials are controlled, or services are supplied by the Material Organization being evaluated.

(2) Assessments shall include a documented review of the qualified Material Organization's history of conditions adverse to quality, nonconformances, and corrective actions.

(3) Assessments shall include a documented review of periodic testing performed since the last assessment to demonstrate conformance of sample materials to selected requirements of the material specification. Such testing shall be conducted during the period since the last assessment by the party performing the evaluation.

[98]

NCA-3850 QUALITY SYSTEM PROGRAM REQUIREMENTS

NCA-3851 Responsibility and Organization

NCA-3851.1 General

(a) The Material Organization shall establish a Quality System Program for the control of quality during manufacture or during other work it proposes to perform, and for the traceability of material or source material under its control. The Program shall be planned, documented, implemented, and maintained in accordance with the requirements of NCA-3850.

(b) The establishment of the Program shall include consideration of the technical aspects and provide for planning and accomplishment of activities affecting quality. The Program shall provide for any special

Page 33

controls, processes, test equipment, tools, and skills to attain the required quality and for verification of quality.

NCA-3851.2 Scope and Applicability

(a) The Quality System Manual shall define the specific activities included in the scope of the work the Material Organization proposes to perform, including any combination of:

(1) Operations performed during the melting and heat analysis, affecting the mechanical properties, conversion from one product form into another product form including applicable dimensional requirements, and certification to the applicable material specification.

(2) Testing, examination, repair, or treatments required by the material specification or the specific applicable material requirements of this Section and certification of the results of such tests, examinations, repairs, or treatments.

(3) Receipt, identification, verification, handling, storage, and shipment of material or source material.

(4) Qualification of Material Organizations permitted by NCA-3820(b).

(5) Approval and control of suppliers of source material or subcontracted services (NCA-3855.3).

(6) Utilization of unqualified source material (NCA-3855.5).

(b) The Program shall include measures to comply with all requirements of this Subarticle, to the extent necessary to assure compliance with the requirements of this Section.

NCA-3851.3 Organization

(a) The organizational structure for executing the Program may take various forms, provided the persons and organizations assigned the quality assurance functions have the required authority and organizational freedom.

(b) Persons or organizations responsible for defining and measuring the overall effectiveness of the Program shall:

(1) be designated;

(2)

- (3) have direct access to responsible management at a level where appropriate action can be initiated;
- (4) report regularly on the effectiveness of the Program.

(c) The organizational structure, functional responsibilities, levels of authority, and lines of communication for activities affecting quality shall be documented. Persons or organizations responsible for assuring that an appropriate Quality System Program has been established and verifying that activities affecting quality have been correctly performed shall have sufficient authority, access to work areas, and organizational freedom to:

- (1) identify quality problems;
- (2) initiate, recommend, or provide solutions to quality problems through designated channels;
- (3) verify implementation of solutions;
- (4) assure that further processing, delivery, or use is controlled until proper disposition of a nonconformance, deficiency, or unsatisfactory condition has occurred.

(d) Individuals or groups assigned the responsibility of checking, auditing, or otherwise verifying that production and quality control activities have been correctly performed, shall be independent of the individual or group directly responsible for performing the specific activity. Such persons shall not report directly to the supervisor with immediate responsibility for the work being verified.

(e) Management shall regularly review the status and adequacy of the Program.

NCA-3852 Personnel

NCA-3852.1 Indoctrination, Training, and Qualification of Personnel

(a) Measures shall be established to assure that all personnel performing or managing activities affecting quality are indoctrinated and trained. The assignment of personnel shall be at the discretion of the organization's management. Indoctrination and training measures shall reflect the following requirements:

- (1) Personnel to be indoctrinated or trained shall be identified.
- (2) The extent of indoctrination and training shall be commensurate with the scope, complexity, and nature of the activity as well as the education, experience, and proficiency of the person.
- (3) Personnel shall be indoctrinated in the general criteria, applicable codes, standards, company procedures, Quality System Program requirements, job responsibilities and authority as they relate to a particular function.
- (4) Training shall be provided, as needed, to achieve initial proficiency, maintain proficiency, and adapt to changes in technology, methods, and job responsibilities.

(b) All nondestructive examination personnel shall be qualified in accordance with para. NB-/NC-/ND-/NE-/NF-/NG-5521 of the applicable Subsection.

(c) Personnel who lead audits shall be qualified on the basis of education, experience, training, audit participation, and examination in accordance with the organization's Quality System Program.

Page 34

NCA-3852.2 Personnel Records

(a) Records shall be maintained of the implementation of indoctrination and training of personnel. Records of indoctrination and training may take the form of attendance sheets, training logs, or personnel training records.

(b) Qualification records of all nondestructive examination personnel shall be documented and maintained.

(c) Qualification records of personnel who lead audits shall be documented and maintained and shall include education, experience, audit training and examination, and audit participation used as the basis of qualification.

NCA-3853 Program Documentation

NCA-3853.1 Quality System Manual

(a) The Quality System Program shall be described and summarized in a Quality System Manual which shall be a major basis for demonstration of compliance with the rules of this Section.

(b) The Program documented in the Manual shall be implemented by written procedures which are maintained either separately or in the Quality System Manual.

(c) Detailed technical procedures and processes, such as those for nondestructive examination, are not considered part of the Manual; however, the controls of such procedures and processes shall be covered by the Manual.

NCA-3853.2 Procedures, Instructions, and Drawings

(a) Activities affecting quality shall be prescribed by and performed in accordance with documented instructions, procedures, or drawings of a type appropriate to the circumstances.

(b) These documents shall include or reference appropriate acceptance criteria for determining that the prescribed activities have been satisfactorily completed.

NCA-3853.3 Document Control.

The preparation, issue, and change of documents that specify quality requirements or prescribe activities affecting quality, such as Quality System Program Manuals, purchase specifications, instructions, procedures, and drawings shall be controlled to assure that the correct documents are being used at the location where the activity is performed. Such documents, including changes thereto, shall be reviewed for adequacy and approved for release by authorized personnel.

NCA-3853.4 Quality Assurance Records.

Records that furnish documentary evidence of quality shall be specified, prepared, controlled, and maintained. Records shall be legible, identifiable, and retrievable. Records shall be protected against damage, deterioration, or loss. Requirements and responsibilities for record transmittal, distribution, retention, maintenance, and disposition shall be established and documented.

NCA-3853.5 Records of Examinations and Tests.

All characteristics required to be reported by the material specification and this Section shall be verified and the results recorded. Records shall be traceable to the document and revision to which an inspection, examination, or test was performed.

NCA-3855 Control of Purchased Materials, Source Materials, and Services

NCA-3855.1 General

(a) Measures shall be established to assure that all purchased material, source material, and subcontracted services conform to the requirements of this Section.

(b) Welding material used in the repair of material or source material shall be controlled in accordance with this Section.

(c) These measures shall be designed to prevent the use of incorrect or defective material or source material, or materials which have not received the required examinations or tests.

NCA-3855.2 Sources of Material, Source Material, and Services

(a) Material shall be furnished by a Material Organization [NCA-3820(a) or NCA-3820(b)], or by a Certificate Holder [NCA-3820(c)].

(b) Except as provided in NCA-3855.5, source material shall be furnished by a Material Organization, by an approved supplier (NCA-3855.3), or by a Certificate Holder.

(c) Services including performance and certification of operations, processes, the results of tests, examinations, repairs, or treatments required by the material specification or by this Section shall be furnished by a Material Organization, by an approved supplier, or by a Certificate Holder.

NCA-3855.3 Approval and Control of Suppliers of Source Material and Services

(a) The Material Organization or Certificate Holder shall be responsible for the approval of and control of activities performed by suppliers of source materials and subcontracted services. Such control shall provide for source evaluation and selection, evaluation of objective evidence of quality, audit, and examination of items and services upon delivery, in accordance with requirements documented in the Material Organization's or Certificate Holder's Program.

Page 35

(b) The Material Organization or Certificate Holder shall be responsible for establishing and verifying that the supplier's controls applicable to the activities performed are adequate by:

(1) surveying and auditing the supplier's established quality system which is consistent with the requirements of this Subarticle, or

(2) having the supplier perform the activities in accordance with controls established by the Material Organization's or Certificate Holder's Program.

(c) The Material Organization or Certificate Holder shall be responsible for assuring that all material and activities conform to all applicable requirements of this Section.

NCA-3855.4 Procurement Document Control

(a) Procurement documents shall include requirements necessary to assure compliance with the requirements of this Section.

(b) Except as provided in NCA-3855.5, procurement documents shall require material, source material, or subcontracted services to be furnished in accordance with the applicable requirements of this Subarticle.

(c) Procurement documents shall require approved suppliers to reference the accepted quality system or controls established by the Material Organization or Certificate Holder on documentation that accompanies the source material or services furnished.

(d) Procurement documents that specify quality requirements or prescribe activities affecting quality shall be reviewed for adequacy and approved for release by authorized personnel.

NCA-3855.5 Utilization of Unqualified Source Material

(a) As an alternative to NCA-3855.2(b), when included in its scope of activities as permitted by the provisions of this Subarticle, a Material Organization may accept certification of the requirements of the material specification which must be performed during the melting, heat analysis, and heat treatment of the material, and may use or furnish unqualified source material, provided the requirements of NCA-3855.5(a)(1) through (4) below are met:

(1) No welding with filler metal has been performed on the unqualified source material.

(2) The Material Organization performs or subcontracts a product analysis to verify the chemical composition of each piece of unqualified source material.

(3) The Material Organization performs or subcontracts all other requirements of the material specification on each piece of unqualified source material. Where Certificates of Compliance [NCA-3862.1(g)] are acceptable, testing of each piece is not required. Alternatively, the Material Organization may perform or subcontract all other requirements of the material specification on each heat and lot of unqualified source material provided:

(a) A Certified Material Test Report is provided with the unqualified source material.

(b) The unqualified source material is traceable to the Certified Material Test Report.

(c) Procurement documents require that suppliers of unqualified source material establish written procedures for identifying source materials in a manner that provides traceability to the Certified Material Test Report.

(d) The Material Organization reviews and accepts the supplier's identification and traceability procedures and verifies compliance with the procedures at a frequency commensurate with the schedule of production or procurement, but at least once triennially.

(e) Upon receipt, the Material Organization shall verify by review of objective evidence, that the requirements of the procurement document have been met.

(4) The provisions of (a)(1) through (a)(3) above are performed in accordance with the Material Organization's Quality System Program.

(b) The provisions of (a)(1) through (a)(3) above may be performed by the Certificate Holder in accordance with his Quality Assurance Program.

NCA-3856 Identification, Marking, and Material Control

NCA-3856.1 General

(a) Control shall be established to assure that only correct and accepted material or source material is used. Identification shall be maintained on these materials or on documents traceable to these materials, or in a manner which assures that the identification is established and maintained.

(b) Measures shall be established for controlling and identifying material or source material, including that which is partially processed, throughout the manufacturing process, during the performance of tests, examinations, repairs, and treatments, and during receipt, storage, handling, and shipment.

(c) Identification marking shall be transferred to all pieces when material or source material is divided.

NCA-3856.2 Marking Method.

Materials and source materials shall be marked by any method acceptable to the purchaser which will not result in harmful contamination or sharp discontinuities and will identify these materials in accordance with the material specification.

Page 36

[98]

NCA-3856.3 Identification of Completed Material

(a) The identification of completed material shall consist of marking the material with the applicable specification and grade of the material, the heat number or heat code of the material, and any additional marking required by this Section to facilitate traceability of the material to reports of the results of all tests and examinations performed on the material.

(b) For those materials where Certificates of Compliance [NCA-3862.1(g)] are allowed, heat-number identification need not be indicated on the material or the Certificate.

(c) A marking symbol or code may be used which identifies the material, provided such code or symbol is explained in the Certified Material Test Report (NCA-3862.1) or Certificate of Compliance [NCA-3862.1], as applicable.

(d) All requirements of the material specification shall be met except where specifically exempted or superseded by a provision of this Section. When special requirements or provisions of this Section conflict with the requirements of the material specification, the material specification and grade number shall be followed with an asterisk (*) to indicate that the material specification has been revised as shown on the material certification.

(e) For nonferrous materials manufactured in accordance with material specifications which do not provide for heat identification, the material shall be marked with a symbol or code that identifies the lot, as defined in the material

specification, with the Certified Material Test Report.

(f) Except as required by the material specification, bolts and nuts 1 in. (25 mm) nominal diameter and smaller and other products where the largest space available for marking is less than 1 in. (25 mm) in any one direction need not be individually marked, provided they are packed in packages or containers which shall be clearly identified by legible marking to ensure positive identification of the material. The markings on the containers shall identify the material with the Certificate of Compliance [NCA-3862.1(g)] or Certified Material Test Report (NCA-3862.1), as applicable.

[98]

NCA-3856.4 Welding and Brazing Materials Identification.

Welding and brazing materials shall be clearly identified by legible marking on the package or container to ensure positive identification of the material. The marking shall include the heat or lot number as applicable, a control marking code which identifies the material with the Certified Material Test Report (NCA-3862.1), and other information such as specification, grade and classification number, Material Organization's name, and trade designation.

NCA-3857 Process Control

NCA-3857.1 General.

Processes affecting quality of materials, source materials, or services shall be controlled. Special processes that control or verify quality, such as those used in welding, heat treating, or nondestructive examination, shall be performed by qualified personnel using qualified procedures in accordance with specific requirements.

NCA-3857.2 Manufacturing Process Control.

Operations shall be performed under a controlled system such as process sheets, shop procedures, checklists, travelers, or equivalent procedures. Measures shall be established to ensure that processes, including heat treatment, are controlled in accordance with the material specification and the rules of this Section.

NCA-3857.3 Welding.

When welding is required in the repair of material or source material, it shall be performed in accordance with procedures and by welders or welding operators qualified in accordance with this Section and Section IX. The qualification of procedures and welders or welding operators shall be documented.

NCA-3857.4 Handling, Storage, Shipping, and Preservation.

Instructions shall be established for handling, storage, shipping, and preservation of material or source material to prevent damage or deterioration.

NCA-3858 Control of Examinations, Tests, and Nonconforming Material

NCA-3858.1 Inspection, Examination, and Test Control

(a) Inspections, examinations, and tests shall be established to assure conformance with the requirements of the material specification and this Section.

(b) Inspections or examinations required to verify conformance of material, source material, or an activity to specified requirements shall be planned. Characteristics to be inspected or examined, and inspection or examination methods to be employed, shall be specified. Inspection or examination results shall be documented.

(c) Tests required to verify conformance to specified requirements shall be planned. Characteristics to be tested and test methods to be employed shall be specified. Test results shall be documented and their conformance with acceptance criteria shall be evaluated.

NCA-3858.2 Control of Measuring and Test Equipment

(a) Procedures shall be in effect to assure that tools, gages, instruments, and other measuring and testing devices used to verify compliance with the material specification and this Section are calibrated and properly adjusted at specific periods or use intervals to maintain accuracy within necessary limits. Periodic checks on equipment may be performed to determine that calibration is maintained.

(b) Calibration shall be against certified equipment having known valid relationships and documented traceability to nationally recognized standards, where such standards exist. If no known nationally recognized standards exist, the basis for calibration shall be documented.

(c) Control measures shall include provisions for measuring and test equipment identification and for determining calibration status by equipment marking or on records traceable to the equipment.

NCA-3858.3 Discrepancies in Measuring or Testing Equipment

(a) When discrepancies in excess of tolerances for measuring or testing equipment are found at calibration, appropriate corrective action shall be taken, and material measured or tested since the previous calibration shall be reviewed to determine that all applicable requirements have been met.

(b) When periodic checks on equipment are performed to determine that calibration is maintained, potential material or source material discrepancies need only be resolved to the previous check, provided:

- (1) the methods used and frequency of periodic checking are described in calibration procedures; and
- (2) the calibration discrepancy was found by periodic check.

NCA-3858.4 Inspection and Test Status.

Measures shall be established so that the status and results of any required inspections, examinations, or tests can be determined at any time. Status shall be maintained through indicators such as physical location and tags, marking, shop travelers, stamps, inspection records, or other suitable means. The authority for application and removal of such indicators shall be specified.

NCA-3858.5 Control of Nonconforming Material

(a) Adequate control measures shall be established to prevent the use of material that does not conform to the requirements of the material specification and this Section.

(b) Material or source material with nonconformances shall be identified, segregated when practical, and reviewed for acceptance, rejection, or repair in accordance with documented procedures. The responsibility and authority for the disposition of nonconformances in these materials shall be defined.

(c) Repaired material or source material shall be reexamined in accordance with applicable procedures.

(d) Measures which control further processing of nonconforming or defective material or source material, pending a decision on its disposition, shall be established and maintained. These control measures shall extend to notification of other affected organizations, as appropriate.

NCA-3859 Audits and Corrective Action

NCA-3859.1 Audits

(a) Audits shall be performed in accordance with written procedures or checklists by personnel not having direct responsibility in the areas being audited.

(b) Audit results shall be documented by auditing personnel for review by management having responsibility in the area being audited.

(c) Procedures shall include provisions for documentation of corrective action taken in response to deficiencies.

Follow-up action, including re-audit of deficient areas where indicated, shall be taken to verify implementation of such corrective actions.

(d) In addition to audits of Material Organizations and suppliers, a comprehensive system of planned and periodic internal audits shall be carried out to assure compliance with all aspects of the Quality System Program and to determine the effectiveness of the Program.

(e) Internal audits shall be performed in accordance with the requirements of (a) through (c) above.

NCA-3859.2 Corrective Action

(a) Measures shall be established to assure that conditions adverse to quality such as failures, malfunctions, deviations, defective material and equipment, nonconformances, and quality system deficiencies, are promptly identified and reported to appropriate levels of management. The measures shall also assure that the cause of conditions adverse to established quality levels be determined and corrected.

(b) The identification of significant or recurring conditions adverse to quality, the cause of condition, and the corrective action taken shall be documented and reported to appropriate levels of management.

(c) These requirements shall also extend to the performance of the approved supplier's corrective action measures.

Page 38

NCA-3860 CERTIFICATION REQUIREMENTS

NCA-3861 Certification Requirements for Material Organizations

(a) The Material Organization whose scope of activities includes NCA-3830 shall provide a Certified Material Test Report or Certificate of Compliance, as applicable (NCA-3862), for the material.

(1) The certification affirms that contents of the report are correct and accurate and that all test results and operations performed by the Material Organization or its subcontractors are in compliance with the material specification and the specific applicable material requirements of this Section.

(2) Chemical analyses, tests, examinations, and heat treatments required by the material specification that were not performed shall be listed on the Certified Material Test Report or Certificate of Compliance, as applicable, or may be listed on an identified attachment.

(3) When the Material Organization's scope of activities includes product form conversion, the Material Organization shall also certify that the material conforms to the applicable dimensional requirements.

(b) The Material Organization shall transmit all certifications received from other Material Organizations or approved suppliers in accordance with (a) above, to the purchaser at time of shipment.

(c) The Certificate Holder shall complete all operations not completed by the Material Organization and shall provide a Certified Material Test Report for all operations performed by him or his approved suppliers. The Certificate Holder shall certify that the contents of the report are correct and accurate and that all test results and operations performed by the Certificate Holder or his approved suppliers are in compliance with the requirements of the material specification and this Section. Alternatively, the Certificate Holder shall provide a Certified Material Test Report for the operations it performed and at least one Certified Material Test Report from each of its approved suppliers for the operations they performed.

NCA-3862 Certification of Material

NCA-3862.1 Material Certification

(a) The Certified Material Test Report shall include the actual results of all required chemical analyses, tests, and examinations.

(b) When required chemical analyses (including melting mill heat analysis), heat treatment, tests, examinations, or repairs are subcontracted, the approved supplier's certification for the operations performed shall be furnished as an identified attachment to the Certified Material Test Report.

(c) The Certified Material Test Report shall also include a report of all weld repairs performed on the material as required by this Section. Radiographic film required for the examination of material repair welds shall be included as a part of the Certified Material Test Report, except for those radiographs required for the testing of welding or brazing materials.

(d) When specific times or temperatures (or temperature ranges) of heat treatments are required by material specifications, they shall be reported. When specific times and temperatures (or temperature ranges) are not required by the material specification, a statement of the type of heat treated condition shall be reported. In any case, a statement of the minimum solution annealing temperature is adequate for austenitic stainless steels and high nickel alloys. Additionally, the times and temperatures of postweld heat treatments of weld repaired materials as required by the fabrication requirements of this Section shall be reported.

(e) Reporting of actual dimensions and visual examination results is neither required nor prohibited by this paragraph.

(f) Notarization of the Certified Material Test Report is not required.

(g) A Certificate of Compliance with the material specification, grade, class, and heat treated condition, as applicable, may be provided in lieu of a Certified Material Test Report for material $\frac{3}{4}$ in. nominal pipe size (DN 20) and less (pipe, fittings, flanges, materials for valves and tubes except heat exchanger tubes), bolting 1 in. (25 mm) and less, as applicable.

(h) Material identification shall be described in the Certified Material Test Report or Certificate of Compliance, as applicable. Heat or lot traceability to the Certificate of Compliance is not required.

NCA-3862.2 Quality System Program Statement

(a) When the Material Organization holds a Quality System Certificate, the Material Organization's Quality System Certificate number and expiration date shall be shown on the Certified Material Test Report or Certificate of Compliance, as applicable, or on a certification included with the documentation that accompanies the material.

(b) When the Material Organization has been qualified by a party other than the Society, the revision and date of the applicable written Quality System Program shall be shown on the Certified Material Test Report or Certificate of Compliance, as applicable, or on a certification included with the documentation that accompanies the material.

Page 39

(c) The inclusion of the Quality System Certificate number and expiration date or reference to revision and date of the applicable written Quality System Program shall be considered the Material Organization's certification that all activities have been performed in accordance with the applicable requirements of this Subarticle.

NCA-3900 NONMETALLIC MATERIAL MANUFACTURER'S AND CONSTITUENT SUPPLIER'S QUALITY SYSTEM PROGRAM

NCA-3920 QUALITY SYSTEM CERTIFICATE (NONMETALLIC MATERIALS)

(a) A Nonmetallic Material Manufacturer may obtain a Quality System Certificate (Materials) issued by the Society verifying the adequacy of the Nonmetallic Material Manufacturer's Quality System Program. Alternatively, the Nonmetallic Material Manufacturer shall have his Quality System Program surveyed and qualified by the Constructor or Fabricator of the concrete component.

(b) A Nonmetallic Material Constituent Supplier may obtain a Quality System Certificate (Materials) issued by the Society verifying the adequacy of the Nonmetallic Material Constituent Supplier Identification and Verification Program. Alternatively, the Nonmetallic Material Manufacturer shall be responsible for assuring that the constituents supplied meet the requirements of NCA-3950(b) and NCA-3950(c).

NCA-3923 Evaluation for Quality System Certificates

(a) The Society, when requested by the Nonmetallic Material Manufacturer on forms issued by the Society, will arrange for an evaluation of the applicant's Quality System Program. The Program will be evaluated on the basis of its compliance

for an evaluation of the applicant's Quality System Program. The Program will be evaluated on the basis of its compliance with the applicable material requirements of this Section. The certificate which is issued for a 3 year period will describe and specify the scope and limits of work for which the applicant is qualified and will be subjected to a planned audit program by the Society. Not later than 6 months prior to the expiration of the Certificate, the Nonmetallic Material Manufacturer shall apply for a renewal evaluation and for the issuance of a new Certificate.

(b) The Society, when requested by the Nonmetallic Material Constituent Supplier on forms issued by the Society, will arrange for an evaluation of the applicant's Identification and Verification Program. The Program will be evaluated on the basis of its compliance with the applicable requirements of this Section. The certificate which is issued for a 3 year period will describe and specify the material constituent which the applicant is qualified to supply and will be subject to a planned audit program by the Society. Not later than 6 months prior to the expiration of the Certificate, the Nonmetallic Material Constituent Supplier shall apply for a renewal evaluation and for the issuance of a new Certificate.

NCA-3950 QUALITY PROGRAM REQUIREMENTS

(a) A Nonmetallic Material Manufacturer need not be a Certificate Holder, but his Quality Assurance Program shall conform to the requirements of NCA-4000, except for NCA-4134.2 and NCA-4134.3.

(b) A Nonmetallic Material Constituent Supplier shall meet all requirements of CB-2100 and CB-2200 or CC-2100 and CC-2200.

(c) The requirements for ice and water are limited to those tests required by CB-5225 or CC-5225.

NCA-3960 RESPONSIBILITY

NCA-3961 Constructor or Fabricator

(a) The Constructor or Fabricator responsible for the placement of nonmetallic materials (plastic concrete) shall assure that the plastic concrete meets the requirements of the Construction Specification, and that tests performed by the Manufacturer and Supplier of the nonmetallic materials and constituents meet the requirements of Section III, Division 2.

(b) The Constructor or Fabricator shall survey and qualify the Quality Assurance Program of the Nonmetallic Material Manufacturer if he does not obtain a Quality System Certificate (NCA-3923).

(c) The Constructor or Fabricator shall perform any of the functions required by the NCA-4000 which are not performed by the Manufacturer of plastic concrete. He may elect to perform any other Quality Program functions which would normally be the responsibility of the Manufacturer of plastic concrete.

(d) The Constructor or Fabricator shall make all necessary provisions so that the Authorized Inspector and his Authorized Inspection Agency can make the inspections necessary to comply with this Code.

(e) The functions performed by the Constructor or Fabricator shall be clearly defined and included in his Quality Assurance Program.

Page 40

NCA-3962 Nonmetallic Material Manufacturer

(a) The Nonmetallic Material Manufacturer shall have his Quality Assurance Program surveyed and qualified by the Constructor or Fabricator if he does not obtain a Quality System Certificate.

(b) The Nonmetallic Material Manufacturer, using the constituents, shall assure that the Nonmetallic Material Constituent Suppliers have met all the requirements of NCA-3950(b) and NCA-3950(c).

(c) The functions performed by the Nonmetallic Material Manufacturer shall be clearly defined and included in his Quality Assurance Program.

NCA-3963 Nonmetallic Material Constituent Supplier

If the Supplier does obtain a Quality System Certificate, he is responsible for implementing the Program on which that certificate was issued and meeting the requirements of NCA-3950(b) and NCA-3950(c).

July 1, 1998

American Society Of Mechanical Engineers

SEC III NCA-4000

ARTICLE NCA-4000 QUALITY ASSURANCE

Page 41

NCA-4100 REQUIREMENTS

NCA-4110 SCOPE AND APPLICABILITY

(a) This Article sets forth the requirements for planning, managing, and conducting Quality Assurance Programs for controlling the quality of activities performed under this Section and the rules governing the evaluation of such Programs prior to the issuance of Certificates for the construction, fabrication, manufacture, and installation of Class 1, 2, 3, CS, MC, CB, and CC items. The Quality Assurance requirements for Material Organizations for all Classes of construction are provided in NCA-3800. The Quality Assurance requirements for Nonmetallic Material Organizations and Constituent Suppliers for all Classes of construction are provided in NCA-3900. Certificate Holders are advised to consult other regulations for Quality Assurance requirements governing activities beyond the scope of this Section.

(b) N-Type Certificate Holders shall comply with the Basic Requirements and Supplements of ASME NQA-1-1989 Edition with 1a-1989, 1b-1991, and 1c-1992 Addenda, Quality Assurance Program Requirements for Nuclear Facilities, as modified and supplemented in NCA-4120(b) and NCA-4134.

NCA-4120 DEFINITIONS

(a) The definitions in NCA-9000 shall apply.

(b) The terms and definitions of NQA-1, Supplement S-1 shall apply except for those listed in (1) through (7) below. For the following terms, the definitions in NCA-9000 shall apply:

(1) *item*

(2) *Owner*

(3) *quality assurance*

(4) *repair*

(5) *rework*

(6) *service*

(7) *use-as-is*

NCA-4130 ESTABLISHMENT AND IMPLEMENTATION

NCA-4131 Material Organizations, Division 1

The requirements of NCA-3800 apply.

NCA-4132 Material Organizations for Division 2

NCA-4132.1 Material Organizations.

The requirements of NCA-3800 apply.

NCA-4132.2 Nonmetallic Material Organizations for Division 2.

The requirements of NCA-3900 apply.

NCA-4132.3 Constituent Suppliers, Division 2.

The requirements of NCA-3900 apply.

NCA-4133 Material Organizations, Division 1

The requirements of NCA-3800 apply.

NCA-4134 N, NV, NPT, and NA Certificate Holders for Class 1, 2, 3, MC, CS, CB, and CC Construction

NCA-4134.1 Organization.

The provisions of NQA-1, Basic Requirement 1 and Supplement 1S-1, shall apply.

NCA-4134.2 Quality Assurance Program

(a) The provisions of NQA-1, Basic Requirement 2 and Supplements 2S-1 and 2S-3, shall apply and the system used to meet these requirements shall be described in the Quality Assurance Manual. The Quality Assurance Manual shall also include a statement of policy and authority indicating management support. The specific responsibilities of the quality assurance organization of the Certificate Holder shall also include the review of written procedures and monitoring of the activities concerned with the Quality Assurance Program as covered in this Article.

Page 44

(b) In lieu of Supplement 2S-2, the qualification of nondestructive examination personnel shall be as required by NX-5520.

(c) The controls used in the Quality Assurance Program shall be documented in the Quality Assurance Manual. The Program need not be in the same format or sequential arrangement as the requirements in this Article, as long as all applicable requirements of this Article have been covered. A copy, including all changes that are made, shall be made available to the Inspector. The Certificate Holder shall make available to the Inspector such drawings and process sheets as are necessary to make the Quality Assurance Program intelligible.

(d) The Certificate Holder shall be responsible for advising its Authorized Inspection Agency of any significant changes which are proposed to be made to the Quality Assurance Manual, and shall have acceptance of the Authorized Inspection Agency's Authorized Nuclear Inspector Supervisor before putting such changes into effect. The Certificate Holder shall be responsible for promptly notifying the Inspector of such accepted changes, including evidence of acceptance by the Authorized Inspection Agency, and for simultaneously reconciling copies of the Quality Assurance Manual.

NCA-4134.3 Design Control

(a) The provisions of NQA-1, Basic Requirement 3 and Supplement 3S-1, shall apply.

(b) Measures shall be established to ensure that applicable requirements of the Design Specifications and of this Section for items are correctly translated into specifications, drawings, procedures, and instructions.

(c) Design documents shall be verified for adequacy and compliance with the Design Specification and this Section.

NCA-4134.4 Procurement Document Control.

The provisions of NQA-1, Basic Requirement 4 and Supplement 4S-1, shall apply, except that procurement documents shall require Suppliers to provide a Quality Assurance Program consistent with the applicable requirements of this Section.

NCA-4134.5 Instructions, Procedures, and Drawings.

The provisions of NQA-1, Basic Requirement 5, shall apply.

NCA-4134.6 Document Control.

The provisions of NQA-1, Basic Requirement 6 and Supplement 6S-1, shall apply.

NCA-4134.7 Control of Purchased Items and Services.

The provisions of NQA-1, Basic Requirement 7 and Supplement 7S-1, shall apply, except that:

(a) Supplement 7S-1, 8.3 is not applicable to the procurement of Authorized Inspection Agency services as required in NCA-8130;

(b) the decision to perform bid evaluation for materials to confirm conformance to procurement documents, required in 7S-1, 4.0, shall remain the responsibility of the Certificate Holder;

(c) changes, waivers, or deviations permitted by 7S-1, 8.2.1(b) shall not be acceptable if they do not meet the requirements of this Section;

(d) resolution of nonconformances identified in 7S-1, 8.2.1(c) shall be in conformance with the requirements of this Section; and

(e) documentary evidence that items conform to the requirements of this Section shall be available at the construction or installation site before use or installation. Requirements for documentary evidence are satisfied for material when the applicable rules of NCA-3800 and NCA-3900 for material certification are met. For stamped items, the requirements are satisfied by a Data Report.

NCA-4134.8 Identification and Control of Items

(a) The provisions of NQA-1, Basic Requirement 8 and Supplement 8S-1, shall apply.

(b) Welding and brazing materials for all Classes of construction shall be controlled.

(c) All characteristics required to be reported by the material specifications and by this Section shall appear on checklists, and each such characteristic shall be examined by accepted procedures as required and the results recorded. Characteristics included on Certified Material Test Reports or Certificates of Compliance need not be duplicated in the checklists. Checklists shall provide for a record that the Certified Material Test Reports and Certificates of Compliance have been received, reviewed, and found acceptable. When the results of the examination or test procedure conducted by the Certificate Holder are necessary to show compliance with material specification or other requirements, the checklists shall show the required range of values. The checklists shall include spaces for: inclusion of document number and revision to which examination or tests were made; a signature, initials, or stamp; the date of the examination performed by the Certificate Holder's representative; an Authorized Nuclear Inspector's signature, initials, or stamp; and the date on which those activities were witnessed.

NCA-4134.9 Control of Processes

(a) The provisions of NQA-1, Basic Requirement 9 and Supplement 9S-1, shall apply.

(b) The Certificate Holder shall prepare instructions, procedures, drawings, checklists, travelers, or other

Page 45

appropriate documents, including the document numbers and revisions to which the process conforms, with space provided for reporting results of completion of specific operations at checkpoints of fabrication, manufacture, or installation. The documents shall include space for: a signature, initials, or stamp; the date that the activity was performed by the Certificate Holder's representative; the Authorized Nuclear Inspector's signature, initials, or stamp; and the date on which those activities were witnessed.

NCA-4134.10 Inspection

(a) The provisions of NQA-1, Basic Requirement 10 and Supplement 10S-1, shall apply, except for para. 3.1 and the requirements of Inservice Inspection.

(b) The Certificate Holder shall prepare process sheets, travelers, or checklists, including the document numbers and revision to which the examination or test is to be performed, with space provided for recording results of examinations and tests. The documents shall include space for: a signature, initials, or stamp; the date that the activity was performed by the Certificate Holder's representative; the Authorized Nuclear Inspector's signature, initials, or stamp; and the date on which those activities were witnessed. The examination checklist for construction of items shall be filled in and completed by the Certificate Holder who applies the appropriate Code Symbol Stamp to the item.

(c) Mandatory hold points at which witnessing is required by the Certificate Holder's representative or the Authorized Nuclear Inspector shall be indicated in the controlling documents (NCA-4134.9). Work shall not proceed beyond mandatory hold points without the consent of the Certificate Holder's representative or the Authorized Nuclear Inspector, as appropriate.

NCA-4134.11 Test Control.

The provisions of NQA-1, Basic Requirement 11 and Supplement 11S-1, shall apply.

NCA-4134.12 Control of Measuring and Test Equipment

(a) The provisions of NQA-1, Basic Requirement 12 and Supplement 12S-1, shall apply.

(b) The Certificate Holder may perform periodic checks on equipment to determine that calibration is maintained. When periodic checking is used, discrepancies need only be resolved to the prior check, provided the discrepancy is discovered by the periodic check. The methods and frequency of periodic checking, when used, shall be included in the Certificate Holder's Quality Assurance Program.

NCA-4134.13 Handling, Storage, and Shipping.

The provisions of NQA-1, Basic Requirement 13 and Supplement 13S-1, shall apply.

NCA-4134.14 Inspection and Test Status.

The provisions of NQA-1, Basic Requirement 14, shall apply for inspections and tests, but not for operating status.

NCA-4134.15 Control of Nonconforming Items.

The provisions of NQA-1, Basic Requirement 15 and Supplement 15S-1, shall apply, except that the definition of *repair* given in this Section shall apply in lieu of *repair* and *rework* given in NQA-1.

NCA-4134.16 Corrective Action

(a) The provisions of NQA-1, Basic Requirement 16, shall apply.

(b) The requirements shall also extend to the performance of the subcontractor's corrective action measures.

NCA-4134.17 Quality Assurance Records

(a) *General.* The provisions of NQA-1, Basic Requirement 17 and Supplement 17S-1, shall apply, except that the requirements for classification in 17S-1, 2.7, retention of records in 17S-1, 2.8, and facility in 17S-1, 4.4 are not applicable. Such records shall be classified and maintained as required by this Section.

(b) *Records Index.* The records shall be indexed. The records and the indices thereto shall be accessible to the Owner, Owner's designee, and Authorized Nuclear Inspector.

(c) *Reproduction of Radiographs.* Radiographs may be reproduced provided the following requirements are met:

(1) the reproduction process shall be subject to the Owner's approval;

(2) when radiographs are reproduced for either an Owner or Certificate Holder, the Quality Assurance Program of the Certificate Holder responsible for the reproduction process shall include a system for controlling and monitoring the accuracy of the process so that the image, when reproduced to its original size, will provide the same information retrieval capability as the original radiograph;

(3) procedures shall contain applicable requirements pertaining to exposure, scanning, focusing, contrast, resolution, and distinguishing film artifacts that might appear as material discontinuities in the reproduced image.

(d) *Lifetime Records.* For Classes 1, 2, CS, MC, CC, and CB, the records listed in Table NCA-4134.17-1 shall be classified as lifetime records. For Class 3, only records 1, 2, 3, 4, 8, 9, 15, and 16 in Table NCA-4134.17-1 shall apply. The Certificate Holder shall be responsible for the retention and maintenance of these

Page 46

records while they are under his control. The Owner shall be responsible for retention and maintenance of those records which are transferred to him.

TABLE NCA-4134.17-1¹
LIFETIME QUALITY ASSURANCE RECORDS

Record	Record
1. Index to lifetime records (NCA-4134.17)	10. Records of post-tensioning sequence, procedure, and loads
2. Code Data Reports (NCA-8400)	11. Heat treatment records [Note (2)]
3. Design Specification (NCA-3250) [Note (3)]	12. Qualification test reports such as for concrete design mixes (CB-2460 and CC-2460) and safety valves (NB-7700)
4. Design Output Documents, Division 1 (NCA-3350 and NCA-3550) [Note (3)]	13. Structural integrity test reports (CB-6260 and CC-6260)
5. Design Report, Division 2	14. Final hydrostatic and pneumatic test results (NCA-5280)
6. Overpressure Protection Report (NB-7200, NC-7200, or ND-7200)	15. Final nondestructive examination reports; final radiographs as specified by the Owner for Section XI applications
7. Construction Specification (NCA-3340)	16. Repair records when required by Code (NX-4130)
8. As-built drawings (NCA-3454)	17. Weld procedures
9. Certified Material Test Reports (CMTR) and documentation providing traceability to location used, if required (NX-4122)	18. Construction Report (NCA-3454)

NOTES:

- (1) Nonconformance reports that affect those records listed shall be incorporated into the record or be retained with the records.
- (2) Either heat treatment charts or certified summaries of time and temperature data may be provided. These data may be included as part of the CMTR.
- (3) For supports designed by Load rating the Load Capacity Data Sheet is the Design Output Document to be maintained as a lifetime quality assurance record. For standard supports designed by analysis and supplied with a Certified Design Report Summary the Certified Design Report Summary is the Design Output Document to be maintained as a Lifetime quality assurance record.

TABLE NCA-4134.17-1¹ LIFETIME QUALITY ASSURANCE RECORDS

TABLE NCA-4134.17-2¹
NONPERMANENT QUALITY ASSURANCE RECORDS

Record	Retention Period
1. QA Program Manual	3 years after superseded or invalidated
2. Design procurement and QA procedures (NCA-4134.5)	3 years after superseded or invalidated
3. Installation and NDE procedures (NX-5112)	10 years after superseded or invalidated
4. Personnel qualification records (NX-5520 and NX-4322)	3 years after superseded or invalidated
5. Purchase orders	10 years after superseded or invalidated
6. Audit and survey reports (NCA-4121 and NCA-4134.18)	3 years after completion of report
7. Final radiographs not covered in Table NCA-4134.17-1, Record 15	10 years after completion
8. Calibration records (NCA-4134.12)	Until recalibrated
9. Process sheets, travelers, or checklists (NCA-4134.10)	10 years after completion
10. Rebar splice test reports (CB-4330 and CC-4330)	10 years after completion of report
11. Joint-welder identification records when such records are used in lieu of physical marking of welds (NX-4322)	10 years after completion of report

NOTE:

(1) Nonconformance reports, which affect those records listed and are not incorporated into the record, shall be retained for the retention period applicable to the record the nonconformance report affects.

TABLE NCA-4134.17-2¹ NONPERMANENT QUALITY ASSURANCE RECORDS

(e) *Nonpermanent Records.* For Classes 1, 2, CS, MC, CC, and CB, the records listed in Table NCA-4134.17-2 shall be classified as nonpermanent records. For Class 3, only records 3, 7, and 8 in Table NCA-4134.17-2 shall apply. The Certificate Holder shall be responsible for their retention for the period specified in Table NCA-4134.17-2. In no case need nonpermanent records be retained for longer than 10 years after completion of applicable Code Data Report.

NCA-4134.18 Audits

(a) The provisions of NQA-1, Basic Requirement 18 and Supplement 18S-1, shall apply.

(b) Results of audits shall be made available to the Authorized Nuclear Inspector.

(c) The audit frequency shall be specified in the Certificate Holder's Quality Assurance Manual. The Certificate Holder's audit frequency shall be commensurate with his schedule of activities and shall be such that each ongoing Code activity is audited at least once annually.

July 1, 1998

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

SEC III NCA-5000

ARTICLE NCA-5000 AUTHORIZED INSPECTION

Page 49

Page 51

NCA-5100 INTRODUCTION

NCA-5110 APPLICABILITY

(a) This Article provides the requirements for the inspection of items constructed in accordance with this Section by the Authorized Inspection Agency.

(b) When preservice examinations are required by this Section inspection of the preservice examinations by the Authorized Inspection Agency shall be in accordance with IWA-2100 of Section XI.

NCA-5120 PERFORMANCE OF INSPECTION

NCA-5121 Authorized Inspection Agency

(a) An Authorized Inspection Agency is one designated by, or is one acceptable to, the appropriate Enforcement Authority of a state of the United States or a province of Canada. The Authorized Inspection Agency shall be accredited by the Society in accordance with the provisions set forth in ASME QAI-1-1995, Qualification for Authorized Inspection.

(b) The Authorized Inspection Agency shall notify the Society when it enters into an agreement with an Owner or a Certificate Holder, or whenever an existing agreement is terminated. The Authorized Inspection Agency shall also notify the Enforcement Authority whenever an agreement with an Owner is written or an Owner's agreement is terminated.

NCA-5122 Authorized Nuclear Inspector Supervisor

The Authorized Inspection Agency shall employ Authorized Nuclear Inspection Supervisors qualified in accordance with ASME QAI-1-1995, Qualification for Authorized Inspection to supervise the Inspectors.

NCA-5123 Authorized Nuclear Inspector

The Authorized Inspection Agency shall also employ Authorized Nuclear Inspectors qualified in accordance with ASME QAI-1-1995, Qualification for Authorized Inspection to perform inspections required by this Section. The inspections required by this Section shall be performed by an Authorized Nuclear Inspector. Any reference to Inspector throughout this Section shall mean Authorized Nuclear Inspector. The Authorized Nuclear Inspector shall not be in the employ of an N Certificate Holder.

NCA-5125 Duties of Authorized Nuclear Inspector Supervisors

(a) Supervisors, in conjunction with Inspectors employed by the same Authorized Inspection Agency (NCA-5121), shall participate in the Society's review of the applicant's Quality Assurance Program (NCA-8160). In those cases where the Supervisor performs the functions of the Inspector, he may represent both during the review of the Program. A Supervisor designated by the Authorized Inspection Agency shall review and accept any proposed modifications to Quality Assurance Manuals before they are put into effect. The Authorized Nuclear Inspector Supervisor shall audit the Inspector's performance at least twice per year at locations where the Certificate Holder is actively engaged in Section III work. The Supervisor shall be available as needed for consultation and support of the local inspection staff. The Supervisor shall maintain supervisory control over one or more Authorized Nuclear Inspectors and shall perform all of the functions and maintain the records required of him in ASME QAI-1-1995, Qualification for Authorized Inspection.

(b) The portion of a Certificate Holder's Quality Assurance Program that involves supply or manufacture

and supply of materials [NCA-3820(e)] shall be audited by the Supervisor at least once each year.

NCA-5130 ACCESS FOR INSPECTION AGENCY PERSONNEL¹

NCA-5131 Access to the Certificate Holder's Facilities

(a) The Certificate Holder shall arrange for the Inspection Agency Personnel to have free access at all times to those locations where Code activities, including those concerned with supply or manufacture of materials, are being performed on an item, when so requested. The Certificate Holder shall keep the Inspector informed of the progress of the work and shall notify him reasonably in advance when the item will be ready for any required tests or inspections.

(b) The Certificate Holder shall provide personnel to accompany the Authorized Nuclear Inspector Supervisor during his required audits.

NCA-5132 Access to the Owner's Facilities

The Owner shall arrange for the Authorized Inspection Agency Personnel to have free access to the Owner's facilities as required to perform duties under the Owner's Agreement with the Authorized Inspection Agency (NCA-5121).

NCA-5200 DUTIES OF INSPECTOR

NCA-5210 GENERAL INSPECTION DUTIES

(a) The Inspector who performs the detailed inspections in compliance with this Section shall witness or otherwise verify all examinations and make all inspections required by this Section. He shall also make any other inspections and witness or verify (including making measurements) any other examinations and additional investigations which, in his judgment, are necessary to ascertain whether the item being inspected has been constructed (NCA-1110, footnotes 1 and 2) in compliance with the rules of this Section. Parts and piping subassemblies shall be in accordance with the accepted documents (NCA-3251). For Division 2, this shall include verification that the items being inspected have been constructed and installed in accordance with the approved Design Drawings and Construction Specifications.

1 Includes Inspectors and Authorized Nuclear Inspector Supervisors.

(b) The duties of the Inspector shall not be interpreted by virtue of these rules to extend to any construction requirements beyond those of this Section which may be set forth in the Design Specification (NCA-3251) or on Design Drawings and Construction Specifications (NCA-3340). However, such requirements shall not result in construction which fails to conform with the requirements of this Section (NCA-3252).

[98]

NCA-5220 CATEGORIES OF INSPECTOR'S DUTIES

The duties of the Inspector shall include but not necessarily be limited to those given in (a) through (m) below:

- (a) verifying the scope of work to be performed [NCA-5230(a)];
- (b) monitoring of the Certificate Holder's Quality Assurance Program including subcontracted activities (NCA-5240);
- (c) reviewing of Certificate Holder's qualification records (NCA-5250);
- (d) verifying materials (NCA-5260);
- (e) witnessing or verifying in-process fabrication, nondestructive examination, and tests (NCA-5270);
- (f) witnessing final pressure tests (NCA-5280);
- (g) reviewing and signing Data Reports and Construction Reports (NCA-5290);
- (h) reviewing drawings and inspecting in accordance with them;
- (i) assuring that Design Reports which are not required by NCA-3551.1 to be certified by a registered Professional Engineer are available;
- (j) assuring that capacity test data has been reviewed and accepted by an ASME designee before signing the pressure and vacuum relief valve Data Report Form NV-1;

- (k) monitoring the Code activities of the Owner [NCA-5242(c)];
 - (l) performing all other duties specifically required in ASME QAI-1-1995, Qualification for Authorized Inspection, as applicable; and
 - (m) verify all preservice examinations have been completed to Section XI edition specified [NCA-3252(c)].
- [98]

NCA-5230 SCOPE OF WORK, DESIGN SPECIFICATIONS, AND DESIGN REPORTS

- (a) The Inspector shall verify that the scope stated in the Certificate includes the work to be performed.

Page 53

(b) The Inspector shall verify that the Design Specification, Design Drawings, Construction Specifications, Construction Reports, Design Reports, Load Capacity Data Sheets, and Certified Design Report Summaries, when required (NCA-3256 and NCA-3550), are on file and that they have been properly certified in accordance with NCA-3255, NCA-3260, NCA-3360, NCA-3380, and NCA-3555.

(c) The Inspector shall not be held responsible for the scope or adequacy of the Design Specifications, for the completeness or accuracy of the Design Report or calculations, for the information reported in the Construction Report, or for the qualification of registered Professional Engineers certifying documents in compliance with the requirements of this Section.

(d) The Inspector shall verify that Design Calculations have been prepared for those components and supports not requiring Design Reports. The Inspector shall not be responsible for the accuracy of the calculations.

NCA-5240 QUALITY ASSURANCE PROGRAMS

NCA-5241 Stipulation of Inspections Prior to Issuance of Process Sheets or Controls

Prior to the issuance of process sheets or controls required by NCA-4134.9, the Certificate Holder shall review them and the applicable drawings with the Inspector, who shall then stipulate the inspections he intends to make in order to fulfill the requirements of NCA-5210.

NCA-5242 Monitoring of Quality Assurance Programs

(a) The Inspector shall monitor the performance of the Certificate Holder for conformity to the requirements of their Quality Assurance Program accepted by the Society. The Inspector shall verify that all changes to the Quality Assurance Manual have been accepted by the Authorized Inspection Agency before they are put into effect.

(b) The Inspector shall assure that the procedures employed in the batching, mixing, conveyance, placing, and curing of structural concrete have been approved under the provisions of the Construction Specification and as specified in Division 2. Certificate Holders shall submit evidence to the Inspector that these requirements have been met.

(c) The Inspector shall monitor the Owner's progress in compiling supporting data needed to complete the ASME Data Report Form N-3.

NCA-5243 Process Control Checklist

The Inspector shall indicate on the Certificate Holder's process sheets or checklist his concurrence that compliance has been attained at each point stipulated by him (NCA-5241).

NCA-5250 QUALIFICATION RECORDS

NCA-5251 Review of Qualification Records

The Inspector shall review the qualification records of the Certificate Holder.

NCA-5252 Structural Concrete Placement

The Inspector shall assure that the procedures employed in the batching, mixing, conveyance, placing, and curing of structural concrete have been approved under the provisions of the Construction Specification and as specified in this Section. The Certificate Holder shall submit evidence to the Inspector that these requirements have been met.

NCA-5253 Welding Procedures

The Inspector shall assure himself that the welding procedures employed in construction have been qualified under the provisions of this Section. The Certificate Holder shall submit evidence to the Inspector that these requirements have been met. When there is a specific reason to question the welding procedure, the Inspector may require requalification as a requirement for the procedure to be used on work subject to his inspection.

NCA-5254 Welders and Welding Operators

The Inspector shall assure himself that all welding is performed by welders or welding operators qualified under the provisions of this Section. The Certificate Holder shall make available to the Inspector a certified copy of the record of performance qualification tests of each welder and welding operator as evidence that these requirements have been met. When there is a specific reason to question the ability of the welder or the welding operator to make welds that meet the requirements of the specification, the Inspector may require requalification before the welder or welding operator is permitted to continue welding on work

Page 54

subject to his inspection. The Inspector shall also assure himself that each welder and welding operator has been assigned an identifying symbol and that such symbols are regularly and consistently applied when required by this Section.

NCA-5255 Examination Procedures

The Inspector shall assure himself that the examination and testing procedures required by this Section have been qualified. When there is a specific reason to question whether the examination or testing procedure requirements are being met, the Inspector may require requalification of the procedure.

NCA-5256 Nondestructive Examination Personnel

The Inspector has the duty to verify the qualification and certification of nondestructive examination personnel employed by the Certificate Holder and has the duty to monitor the nondestructive examination activities and require requalification of any personnel when there is reason to question the performance of that person. In addition, the Inspector shall monitor the Certificate Holder's Quality Assurance Program as it relates to the nondestructive examination activities of Material Manufacturers, Material Suppliers, and NDE subcontractors that the Certificate Holder qualified.

NCA-5260 MATERIALS, PARTS, AND HEAT TREATMENT

NCA-5261 Inspection of Materials for Compliance

The Inspector shall assure himself that all materials used comply with all applicable requirements of this Section. The Certificate Holder shall make available to the Inspector certified reports of the results of all tests performed in accordance with (a) and (b) below:

(a) the material specifications;

(b) the requirements in the applicable materials Articles of this Section, including certified reports of the results of all required tests and examinations performed.

NCA-5262 Dimensional Check

The Inspector shall satisfy himself:

(a) that the item is being constructed within the tolerance required by the Design Specification, Design Drawings, and

Construction Specifications, and this Section;

(b) that head and shell sections conform to the prescribed shape and meet the thickness requirements;

(c) that nozzles and attachments to be welded to the vessel fit properly to the curvature of the vessel surface. If required by the Inspector, the Certificate Holder responsible for the vessel shall make available accurately formed templates for his use.

NCA-5263 Check of Heat Treatment Practice

The Inspector shall satisfy himself that all heat treatment operations required by this Section are correctly performed and that the temperature readings and gradients conform to the requirements.

NCA-5270 EXAMINATIONS AND TESTS

The Inspector shall witness in-process fabrication nondestructive examinations and destructive tests, when feasible; alternatively, he shall check the examination and test records to determine the acceptability of the items involved.

NCA-5280 FINAL TESTS

The Inspector shall witness final hydrostatic, pneumatic, or structural integrity tests required by this Section and examinations performed during such tests by the Certificate Holder. Hydrostatic, pneumatic, or structural integrity tests are not required for core support structures or supports.

[98]

NCA-5290 DATA REPORTS AND CONSTRUCTION REPORTS

(a) The appropriate Data Reports prepared by the Certificate Holder shall be reviewed and signed by the Inspector only after they have been certified by a responsible representative of the Certificate Holder and after he has satisfied himself that all requirements of this Section have been met and that each Data Report certified is a correct record. For Division 2 items, certification by the Designer is also required prior to verification by the Inspector.

(b) The Inspector shall review and separately verify that the information contained in the Construction Report for Division 2 construction is valid and corresponds to the requirements of Division 2 and that the Designer's review and certification of the Construction Report have taken account of all requirements of this Section.

Page 55

(c) The N-3 Data Report (Form NCA-3220) shall be reviewed and signed by the Inspector only after:

(1) it has been certified by the Owner;

(2) the Inspector has reviewed the N-3 Form and verified that the Data Reports referenced on the N-3 Form are on file and that such Data Reports verify Code compliance of all components, parts, appurtenances, supports, and core support structures incorporated into the nuclear power system or that portion of the system covered by the N-3 Form;

(3) the Inspector has verified that required documents for overpressure protection exist and are properly filed for that portion of the system covered by the N-3 Form .

[98]

NCA-5300 RESPONSIBILITIES OF THE AUTHORIZED INSPECTION AGENCY

The responsibilities of the Authorized Inspection Agency shall include but not necessarily be limited to those given in (a) through (k) below.

(a) Maintain a staff of Authorized Nuclear Inspectors and Authorized Nuclear Inspector Supervisors (NCA-5123).

(b) Make agreements with Certificate Holders and Owners for inspection service (NCA-5121 and NCA-8130). Notify the Society whenever such agreements are terminated (NCA-5121).

- (c) Provide for participation in the Society's review of the applicant's Quality Assurance Program (NCA-5125).
- (d) Provide for the review and acceptance of any proposed modifications to Quality Assurance Manuals before they are put into effect (NCA-5125).
- (e) Review and accept the Certificate Holder's method of securing the nameplate to components to which, because of size or other considerations, the nameplate cannot be directly attached [NCA-8220(b)].
- (f) Review and accept the Certificate Holder's alternative method of identification, including the unique method of marking of components to which, because of size or other considerations, nameplates cannot be directly attached [NCA-8220(b)].
- (g) Review and accept the Certificate Holder's alternative method of marking of parts, appurtenances, supports, and piping subassemblies (NCA-8230).
- (h) Review and accept the Certificate Holder's provisions of positive identification and traceability of items from which nameplates are removed [NCA-8240(b)].
- (i) Determine by agreement with the Certificate Holder the sequence for stamping and the completion of the Code Data Report [NCA-8310(c)].
- (j) Review and accept the Certificate Holder's procedure for providing traceability of parts or piping subassemblies which are furnished without stamping (NCA-8332).
- (k) And all other duties specifically required in ASME QAI-1-1995, Qualification for Authorized Inspection as applicable.

July 1, 1998

American Society Of Mechanical Engineers

SEC III NCA-8000

ARTICLE NCA-8000 CERTIFICATES, NAMEPLATES, CODE SYMBOL STAMPING, AND DATA REPORTS

Page 57

NCA-8100 AUTHORIZATION TO PERFORM CODE ACTIVITIES

NCA-8110 GENERAL

Authorization to use the official Code Symbol Stamps or to certify work by other means provided in this Section (see Table NCA-8100-1) will be granted by the Society for a 3 year period pursuant to the provisions set forth in this Subarticle. Authorization to certify Owner's Data Report Forms, N-3, will be granted pursuant to the provisions set forth in this Subarticle.

[98]

NCA-8120 SCOPE OF CERTIFICATES

(a) The Certificate (NCA-8120) will identify the shop or field facility covered and state the scope of activities for which authorization is granted. The Society may, at its discretion, limit or extend the scope of an authorization to any types or classes of items or to a specific location.

(b) A Certificate of Authorization will be issued by the Society to an organization for the use of a Code Symbol Stamp, certifying a data report form, or performing welding or certifying joining.

(c) The installation of items by mechanical means need not be performed by a Certificate Holder. The responsibility for the hydrostatic or pneumatic test of completed components must be assumed by a holder of a Certificate of Authorization and witnessed by the Authorized Nuclear Inspector regardless of the method of assembly. This does not preclude an organization that installs items by mechanical means only from obtaining a Certificate of Authorization.

(d) A Certificate of Accreditation (Corporate) will be issued by the Society to an organization for performing Code activities other than those specified in (b) or (c) above.

(e) A Certificate of Accreditation with an appropriate scope may be issued by the Society to an Organization who has documented a Quality Assurance Program and whose ability to staff, equip, or otherwise implement the described Quality Assurance Program has been evaluated and accepted by the Society. It is not necessary that the Program is or ever was implemented.

(f) The Society may, at any time, make regulations concerning the issuance and use of Certificates and Code Symbol Stamps as it deems appropriate, and all regulations shall become binding upon the holders of a valid Certificate.
[98]

NCA-8130 INSPECTION AGREEMENT REQUIRED

Certificate Holders and Owners shall possess an agreement with an Authorized Inspection Agency¹ to provide inspection and audit services. The agreement with the Authorized Inspection Agency shall be made prior to application for a survey or, in the case of the Owner, an interview. Certificate Holders and Owners shall notify the Society whenever their agreements with an Authorized Inspection Agency are cancelled or changed to another Authorized Inspection Agency.

NCA-8140 QUALITY ASSURANCE PROGRAM REQUIREMENTS

It is a requirement that a Certificate Holder have a Quality Assurance Program (NCA-4000) which has been evaluated and accepted by the Society.

¹ A list of acceptable Authorized Inspection Agencies may be obtained from the Society.

TABLE NCA-8100-1
CERTIFICATES AND CODE SYMBOL STAMPS ISSUED BY THE SOCIETY FOR CONSTRUCTION OF NUCLEAR POWER PLANTS

Type of Organization	Scope	Division 1						Division 2	Data Report Form	Notes
		Class 1	Class 2	Class 3	Class CS	Class MC	Class CB & CC			
N Certificate Holder	Vessel	N1	N2	N3	None	NMC	None	None	N-1/N-1A	(9)
	Concrete reactor vessel	None	None	None	None	None	NCB	C-1	C-1	...
	Concrete containment	None	None	None	None	None	NCC	C-1	C-1	...
	Pump	N1	N2	N3	None	None	None	None	NPV-1	(1)
	Pressure relief valves	NV1	NV2	NV3	None	None	None	None	NV-1	(1)
	Line valve	N1	N2	N3	None	None	None	None	NPV-1	(1), (6)
	Storage tank	None	N2	N3	None	None	None	None	N-6	...
	Piping systems	N1	N2	N3	None	None	None	None	N-5	(1)
	Core support structures	None	None	None	NCS	None	None	None	NCS-1	(2)

TABLE NCA-8100-1 CERTIFICATES AND CODE SYMBOL STAMPS ISSUED BY THE SOCIETY FOR CONSTRUCTION OF NUCLEAR POWER PLANTS

Page 61

TABLE NCA-8100-1 (CONT'D)
CERTIFICATES AND CODE SYMBOL STAMPS ISSUED BY THE SOCIETY FOR CONSTRUCTION OF NUCLEAR POWER PLANTS

Type of Organization	Scope	Division 1						Division 2		Data Report Form	Notes
		Class 1	Class 2	Class 3	Class CS	Class MC	Class CB & CC				
NPT Certificate Holder	Tubular products welded with filler metal				None			NM-1	(1), (7)		
	Part							N-2	(1), (4), (8), (9)		
	Appurtenance							N-2	(1), (4), (8), (9)		
	Piping subassembly				None	None	None	NPP-1	(1), (3), (9)		
	Supports				None		None	NF-1	(1), (4), (5)		
NA Certificate Holder	All items						None	N-5	(1), (9)		
Quality System Certificate Holder	Material	None	None	None	None	None	None	None	(7), (9)		
Owners	Owner	None	None	None	None	None	None	N-3	...		

Notes to Table NCA-8100-1 follow on next page

TABLE NCA-8100-1 (CONT'D) CERTIFICATES AND CODE SYMBOL STAMPS ISSUED BY THE SOCIETY FOR CONSTRUCTION OF NUCLEAR POWER PLANTS

Table NCA-8100-1 (CONT'D)

NOTES:

- (1) Items within the containment system, excluding the Class CC and MC vessel and its supports, shall be stamped Class 1 or 2 in accordance with the classification stated in the Design Specification or Construction Specification.
- (2) A Data Report shall be filled out on Form NCS-1 by the Certificate Holder assuming overall responsibility. If this Certificate Holder also performs the fabrication, the Form NCS-1 shall be completed by this Certificate Holder and shall be certified by the Inspector for the core support structure to be stamped with the Code N Symbol and no N-2 Form is required. When a Certificate Holder is responsible for fabrication only, the Form N-2 shall be completed by that Certificate Holder and certified by the Inspector for core support structures, appurtenances, or parts which are to be stamped with the Code NPT Symbol.
- (3) Data Report Form NPP-1 shall be forwarded in duplicate to the N Certificate Holder taking overall responsibility for the piping system and the NA Certificate Holder installing the piping system.
- (4) Data Report Form N-2 for parts shall be forwarded in duplicate to the Certificate Holder of the finished component or support.
- (5) Data Report Form NF-1 for assembled supports shall be forwarded in duplicate to the Certificate Holder who performs installation. A single Data Report may be used for ten completed, assembled supports when each is of the same design and each is identified on the Data Report by serial number.
- (6) A single Data Report may be used for each group of 25 line valves and pumps of the same size and design with inlet piping connection of 4 in. nominal pipe size and smaller when each is identified on the Data Report by an individual serial number.
- (7) Material (NCA-1220) shall be documented by a Certified Material Test Report or a Certificate of Compliance in accordance with NB-NG-2000.
- (8) A multiple number of parts or appurtenances for a single nuclear power plant may be included on the N-2 Data Report, provided the parts or appurtenances are of the same class, size, and design and that the parts or appurtenances are manufactured for the same N Certificate Holder and authorized by the Inspector for stamping on the same day. Each part or appurtenance must be identified on the Data Report by an individual serial number.
- (9) Miscellaneous items as described in NCA-1270 shall be Code symbol stamped and listed on the appropriate Data Report Form when constructed as an "N" or "NPT" item or installed under an "NA" Certificate. When furnished as material, an appropriate Certified Material Test Report or Certificate of Compliance is required in lieu of Data Reports and stamping.

TABLE NCA-8100-1 (CONT'D)

NCA-8150 APPLICATION FOR ACCREDITATION

An Organization desiring a Certificate shall apply to the Society upon forms issued by the Society describing the scope of Code activities to be performed.

NCA-8151 Field Operations

The N, NA, or NPT certificates may be extended to include field operations such as installation, completion, or repair of components, parts, or appurtenances constructed under that authorization. The Society requires that an audit acceptable to the Society be performed at each field site to assure that the Quality Assurance Program described in the Manual is implemented and enforced.

NCA-8152 Shop Assembly

Shop assembly of components to components, or components to appurtenances and piping subassemblies or other items, may be by either NA or N Certificate Holders if such activities are included within the scope of their Certificate.

NCA-8153 Code Activities Prior to Obtaining a Certificate

Code activities performed prior to issuance of a Certificate shall be subject to the acceptance of the Inspector.

NCA-8160 EVALUATION

NCA-8161 Evaluation for a Certificate

(a) Applicants for a new or renewed Certificate for Class 1, 2, 3, CS, CB, CC, or MC construction require a survey of their shop or field facilities. The purpose of the survey is to evaluate the applicant's Quality Assurance Manual and the

implementation of the Quality Assurance Program.

(b) The extent of the survey will be determined by the Society based on a review of the applicant's intended scope of Code activities described in the application. The acceptance by the Society of the Quality Assurance Program shall not be interpreted to mean endorsement of technical capability to perform design work such as system design or stress analysis. Such capability is implied for the specific component involved by the certification of Design Reports (NCA-3360, NCA-3555) by a Registered Professional Engineer.

(c) Authorization to apply a Code Symbol Stamp to an item will be granted only after a survey by the Society has satisfactorily demonstrated the adequacy and implementation of the Quality Assurance Program.

[98]

NCA-8162 Evaluation for an Interim Letter

[98]

NCA-8162 Evaluation for an Owner's Certificate

(a) The Owner, after receipt of notification from the regulatory authority that an application for a construction permit for a specific plant has been docketed, shall obtain an Owner's Certificate (NCA-3230) from the Society for unit(s) docketed concurrently for each nuclear power plant site prior to field installation. In lieu of a survey, the Owner will be interviewed for the Society to verify the Owner's understanding of Code responsibilities (NCA-3220) and to obtain the Owner's agreement to meet the requirements.

(b) The Owner's Certificate (NCA-3230) shall be applicable to nuclear power plant unit(s) docketed concurrently for each site.

[98]

NCA-8170 ISSUANCE

Each Certificate Holder shall have agreed that each Certificate and Code Symbol Stamp (if one is issued) is at all times the property of the Society, that it will be used according to the rules and regulations of this Section, and that the Certificate and Code Symbol Stamp will be promptly returned to the Society upon demand, or when the Certificate Holder discontinues the scope of Code activities covered by his Certificate. The holder of a Code Symbol Stamp shall not permit any other party to use its Certificate or Code Symbol Stamp. The Society reserves the absolute right to cancel or refuse to renew such authorization, returning fees paid for the prorated unexpired term.

NCA-8180 RENEWAL

(a) Not later than 6 months prior to the date of expiration of any Certificate, the Certificate Holder shall apply for a renewal of such authorization and the issuance of a new Certificate.

(b) A Certificate issued for a specific field site, or a Certificate which has been extended to a specific field site activity, is valid for the duration of the contract at the specified site or 3 years, whichever occurs first.

(c) The Owner's Certificate expires when all N-3 Data Reports for the units listed on the Certificate have been completed. Triennially, the Society shall review the status of construction and determine whether the Owner's Certificate shall be renewed.

Page 64

NCA-8200 NAMEPLATES AND STAMPING

NCA-8210 GENERAL REQUIREMENTS

NCA-8211 Nameplates

Each item and installation to which a Code Symbol Stamp is applied shall have a nameplate, except as otherwise permitted by this Subarticle. Marking shall be as required by (a) through (f) below:

- (a) the applicable official Code Symbol Stamp, as shown in Table NCA-8100-1;
- (b) Class of construction;
- (c) the statement "Certified by"
- (d) Certificate Holder's name;
- (e) Certificate Holder's serial number and, if applicable, national board number and/or Canadian registration number;
- (f) marking for line valves shall include the ANSI pressure class rating.

NCA-8212 Stamping

The Code Symbol Stamp shall be stamped on a nameplate attached to an item, except as otherwise permitted by this Subarticle. The arrangement of markings shall be as shown in Fig. NCA-8212-1. The data shall be in characters not less than $\frac{3}{32}$ in. (2.4 mm) high. The selected method shall not result in any harmful contamination or sharp discontinuities. Stamping directly on items, when used, shall be done with blunt-nosed continuous or blunt-nose interrupted dot die stamps.

NCA-8213 Attachment of Nameplates

- (a) The nameplate shall be attached by a method (acceptable to the Designer for Division 2 items) that will not affect the structural integrity of the item.
- (b) If the nameplate is marked before it is attached, the Certificate Holder shall assure that the nameplate with the correct marking has been attached and the Inspector shall verify that this has been done.
- (c) When nameplates are attached with pressure sensitive acrylic adhesive systems, in addition to the requirements of this Article, those of Appendix XXI shall be met.

NCA-8220 NAMEPLATES FOR COMPONENTS

- (a) The markings required by NCA-8210 shall be applied to a separate nameplate attached to the component. In the case of core support structures, the marking shall be applied directly to the support.

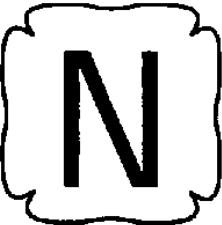
	Certified by (Name of Certificate Holder)
Class	(Serial number)

FIG. NCA-8212-1 FORM OF STAMPING

FIG. NCA-8212-1 FORM OF STAMPING

(b) If because of size or other considerations the nameplates cannot be directly attached to the component, the Certificate Holder may secure the nameplate to the component in a manner acceptable to the Authorized Inspection Agency and apply a unique identification mark to the component which will serve to identify the component with the appropriate Data Report. The marking shall be of a visible, permanent type and not detrimental to the component. The type, method, and manner of marking shall be described in the Certificate Holder's Quality Assurance Program or Procedure. The use of this alternative method of identification, including the method of marking, shall be reviewed by and found acceptable to the Authorized Inspection Agency (NCA-5121) prior to implementation by the Certificate Holder.

NCA-8230 NAMEPLATES FOR NPT STAMPED ITEMS

(a) Parts, appurtenances, piping subassemblies, and supports assembled by welding shall have a separate nameplate equivalent to that required for completed components when the size and use of the item will accommodate such a nameplate. When the size or use of the item will not permit the installation of a nameplate, the marking shall consist of suitable identification of the item until it has been incorporated into the finished component or other NPT stamped item. This alternative method of marking shall be reviewed with and found acceptable to the Authorized Inspection Agency before being used by the Certificate Holder.

(b) When the NPT and NA Certificate Holder is not the same organization, the Code Symbol Stamp shown in Table NCA-8100-1 for supports shall be applied to

Page 65

supports assembled by welding which are not furnished integrally with the component. When the NPT and NA Certificate Holder is the same, supports assembled by welding may be furnished without applying the NPT Code Symbol Stamp, provided the Code Symbol Stamp shown in Table NCA-8100-1 for installation of supports is applied to the installation.

(c) In the case of tubular products welded with filler metal, nameplates are not required. The marking shall be applied directly to the material by etching or stamping.

NCA-8240 REMOVED NAMEPLATES

If nameplates secured as noted in NCA-8220 are removed from items which have been installed in a nuclear power plant system, the Certificate Holder responsible for completion of the N-5 Data Report shall verify and document that the required nameplate had been attached to the item. Provisions of positive identification and traceability of the items to a specific location and applicable Data Report shall be included in the Quality Assurance Program or procedure of the Certificate Holder responsible for installation. This alternative shall be reviewed with and found acceptable to the Authorized Inspection Agency (NCA-5121) before being used by the Certificate Holder.

[98]

NCA-8300 CODE SYMBOL STAMPS

[98]

NCA-8310 GENERAL REQUIREMENTS

(a) The Code Symbol Stamp shall be applied by the Certificate Holder only with authorization of the Inspector. In any case, the Code Symbol Stamp shall not be applied until completion of the required examination and testing.

(b) Table NCA-8100-1 provides Code Symbol Stamp requirements as related to type of certificates, scope of work, and class of construction. The class of construction shall be indicated by the applicable number 1, 2, or 3, or letters CS, CB, CC, or MC stamped below and outside the official Code Symbol Stamp.

(c) The completed Code Data Report Form indicates that the Inspector has inspected the item and authorized the application of the Code Symbol Stamp. The sequence for stamping and the completion of the Code Data Report shall be determined by agreement between the Authorized Nuclear Inspector and the Certificate Holder.

[98]

NCA-8320 APPLICATION OF THE N SYMBOL STAMP

NCA-8321 Authorization and Time of Stamping

The N Symbol Stamp shall be applied only with the authorization of the Inspector after the pressure test² requirements have been satisfied and all other examinations, tests, and inspections have been satisfactorily completed.

NCA-8322 Application of the N Symbol Stamp at Field Sites or Other Locations

The N Certificate Holder may apply the N Symbol Stamp to the component in the field, without having the N Certificate of Authorization extended to a field site or other location, under the following provisions:

(a) where the N Certificate Holder elects to substitute the system pressure test [NB/NC/ND-6221(a)] for the component pressure test, the test is conducted under the responsibility of an N or NA Certificate of Authorization issued for that field site and is witnessed and accepted by the N Certificate Holder responsible for the component; or

(b) where the N Certificate Holder elects to subcontract the performance of the component pressure test, the N Certificate Holder shall be responsible for supervising, witnessing, and accepting the pressure test and assuring that the test is controlled in accordance with the suppliers' approved program; or

(c) where the N Certificate Holder elects to perform the component pressure test at a field site or other location, the pressure test shall be controlled in accordance with the N Certificate Holder's Quality Assurance Program.

The completed shop fabrication portion of the Data Report Form, together with the Inspector's own inspections of the component, shall be authority for that field Inspector to witness the test and authorize stamping of the completed component.

² Pressure tests include hydrostatic, pneumatic, and structural integrity tests. Hydrostatic or pneumatic tests are not required for Core Support Structures.

³ In this usage, organization may be the same company at a single site, a multiplant corporation with extended corporate Certificates.

NCA-8330 PARTS AND PIPING SUBASSEMBLIES FURNISHED WITHOUT STAMPING

(a) An organization³ with separate or extended Certificates may manufacture and ship items such as parts

and piping subassemblies without the NPT Symbol Stamp for use at another of its facilities, provided its Quality Assurance Manual includes the provisions of (1) through (3) below.

(1) Requirements for legible and specific identification of each item. Identification shall be permanent and not detrimental to the item. Identification shall be on the item.

(2) Requirements for completing a transmittal form with each shipment of items. The form shall list all items and their corresponding identification number, and shall indicate that the items do not contain the NPT Symbol Stamp. The form shall be signed by the Certificate Holder and the Authorized Nuclear Inspector prior to shipment.

(3) Requirements for receipt of items shipped without the NPT Symbol Stamp. Requirements shall include inspection upon receipt and maintenance and retention of transmittal forms.

(b) Neither an NPT Symbol Stamp, nameplate, Code Data Report, nor transmittal form is required on items manufactured and installed at the same facility by the same Certificate Holder, provided that the Certificate Holder's Quality Assurance Program provides for control of these items through completion of installation.

NCA-8400 DATA REPORTS

NCA-8410 GENERAL REQUIREMENTS

The appropriate Data Report,⁴ as specified in Table NCA-8100-1, shall be filled out by the Certificate Holder or Owner and shall be signed by the Certificate Holder or Owner and the Inspector for each item (except as provided elsewhere in this Article) to be marked with a Code Symbol Stamp.

NCA-8411 Compiling Data Report Records

Data Reports, which are the basis for approval of the C-1, N-3, and N-5 Data Reports, may be compiled in any one of the following methods:

(a) by attaching each Data Report for items which make up that piping system, portion of a piping system, concrete reactor vessel, concrete containment, or nuclear power system to its respective Data Report Form C-1, N-3, or N-5; or

⁴ Samples of the forms referred to in this Subarticle may be found in Appendix V. Copies of these forms may be obtained from the Society.

(b) by assigning each Data Report for items which make up that piping system, portion of a piping system, concrete reactor vessel, concrete containment, or nuclear power system a unique identifying number and listing the numbers on the Data Report Form C-1, N-3, or N-5; or

(c) by attaching a drawing which uniquely identifies each item which makes up that piping system, portion of a piping system, concrete reactor vessel, concrete containment, or nuclear power system to its respective Data Report Form C-1, N-3, or N-5.

NCA-8412 Availability of Data Reports

All Data Reports and referenced supporting material shall be available to the Inspector and enforcement authority having jurisdiction at the location of the nuclear power plant site.

NCA-8420 OWNER'S DATA REPORT

The Owner who has obtained an Owner's Certificate shall be responsible for completing one or more of Form N-3. The Owner shall certify, by signing the form, that each Certificate Holder was the holder of the appropriate Certificate and that components and installation comply with the applicable requirements of this Section. Review of the completed Owner's Data Report Form N-3, including attached Data Reports for all components and installation as required to verify Code Compliance, plus provision of the Overpressure Protection Report or the Overpressure Protection Analysis, when required, shall be the Inspector's authority to sign the Owner's Data Report.

NCA-8430

FILLER METAL

(a) Each piece of tubular products or fittings with filler metal shall be listed on a Data Report Form NM-1. This Data Report shall be completed by the Certificate Holder and signed by the Inspector.

(b) Multiple items may be listed on a single NM-1 Data Report Form, provided they are from the same heat and lot of material.

(c) When tubular products welded with filler metal are used to manufacture fittings, all the fittings made from the NPT stamped tubular product may be identified on one CMTR or NM-1, as applicable, prepared by the fitting manufacturer, which lists all the operations performed by him. The fitting manufacturer shall provide a copy of his CMTR or NM-1, as applicable, and a

Page 67

copy each of the CMTR and the NM-1 Data Report which were supplied with the tubular product.

NCA-8440 DATA REPORTS FOR SUPPORTS

(a) Supports assembled by welding by an NPT Certificate Holder shall be listed on NF-1 Data Report Form, except when the NPT and NA Certificate Holder are the same. When the NPT and NA Certificate Holder are the same, supports may be listed on the N-5 Data Report Form.

(b) Material supplied for supports under provisions of NF-2130 and NF-2150 shall be listed on the N-5 Data Report Form by the NA Certificate Holder.

July 1, 1998

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

SEC III NCA-9000

ARTICLE NCA-9000 GLOSSARY

Page 69

NCA-9100 INTRODUCTION

This Article defines selected terms used in this Section. The definitions in this Glossary shall prevail should a conflict exist with definitions found elsewhere in this Section or other documents referenced in this Section.

[98]

NCA-9200 DEFINITIONS

Approved Supplier. A supplier that has been evaluated and approved by a Material Organization or Certificate Holder in accordance with the requirements of NCA-3800.

Appurtenance. An item intended to be attached to a completed and stamped component which has work performed on it requiring verification by an Inspector.

Audit. A documented evaluation performed to verify, by examination of objective evidence, that those selected elements of a previously approved quality program have been developed, documented, and implemented in accordance with specified requirements. An audit does not include surveillance or inspection for the purpose of process control, or acceptance of material or items.

Authorized Inspection Agency. An organization that is empowered by an enforcement authority to provide inspection personnel and services as required by this Section.

Authorized Nuclear Inspector. An Authorized Nuclear Inspector is an employee of an Authorized Inspection Agency who has qualifications for and has been properly qualified for Division 1 or Division 2.

Authorized Nuclear Inspector Supervisor. An Authorized Nuclear Inspector Supervisor is an employee of an Authorized Inspection Agency who has been assigned by that agency to oversee and direct the work of one or more Authorized Nuclear Inspectors and who has qualifications for and has been properly qualified for Division 1 or Division 2.

Building Structure. The structure whose purpose is to support, house, and protect nuclear power plant components. Rules for construction of building structures are outside the scope of this Section.

Certificate. A Certificate of Authorization, Certificate of Accreditation, Quality System Certificate (Materials), or Owner's Certificate issued by the Society.

Certificate of Accreditation. A document issued by the Society which authorizes the performance of Code activities for a specified time and for a specified scope of activity.

Certificate of Authorization. A document issued by the Society which authorizes the use of an ASME Code Symbol Stamp for a specified time and for a specified scope of activity.

Certificate of Compliance. A written statement attesting that the materials are in accordance with specified requirements.

Certificate Holder. An organization holding a Certificate of Authorization or Certificate of Accreditation issued by the Society.

Certification. The act of verifying and attesting in writing that documents, processes, procedures, items, or the qualifications of personnel are in accordance with specified requirements.

Certified Material Test Report. A document attesting that the material is in accordance with specified requirements, including the actual results of all required chemical analyses, tests, and examinations.

Code Addenda. Additions and revisions to individual sections of the Code published annually.

Code Cases. Documents issued by the Society to clarify the intent of existing Code requirements or to provide alternative rules for construction.

Code Class. The classification, specified by the Owner (or his designee) and included in the Design Specification, which establishes the rules for design and construction of items.

Page 70

Code Editions. Documents issued at 3 year intervals by the Society which include all revisions and additions previously included in Addenda and corrections included in Errata published since the previous Edition.

Code Symbol Stamp. A metallic stamp issued by the Society for use in impressing one of the symbols shown in Table NCA-8100-1.

Compliance. Conforming to the Code, a specification, or a procedure.

Component. A vessel, concrete reactor vessel, concrete containment, pump, pressure relief valve, line valve, storage tank, piping system, or core support structure that is designed, constructed, and stamped in accordance with the rules of this Section.

Component Support. A support for a vessel, pump, or storage tank. A support which is attached to a valve may be classified as a component support when identified in the Design Specification.

Concrete Constituents. Cement, aggregates, admixtures, and water.

Concrete Containment. A composite steel and concrete component that is designed as an integral part of the containment's pressure retaining barrier which retains or controls the release of radioactive or hazardous effluents released from the nuclear power plant equipment which the containment encloses.

Concrete Reactor Vessel. A composite steel and concrete component which functions as a component of the principal pressure containing barrier for the nuclear fuel's primary heat extraction fluid (primary coolant).

Construction (as used in Division I). An all-inclusive term comprising materials, design, fabrication, examination, testing,

inspection, and certification required in the manufacture and installation of an item.

Construction (as used in Division 2). All operations required to build an item in accordance with Design Drawings and the Construction Specification.

Construction Permit. A document issued by the Nuclear Regulatory Commission which authorizes the Owner to construct a nuclear power plant.

Construction Procedure. A written description of construction or fabrication methods the Constructor or Fabricator uses to ensure conformance with the requirements of the Construction Specification, Design Drawings, and this Section.

Construction Report. A report prepared by the Constructor that summarizes activities performed to construct the component in accordance with the Construction Specification, Design Drawings, and the requirements of this Section.

Construction Specification. A document prepared by the Designer that establishes requirements for the construction of a component.

Constructor. The N Certificate Holder in Division 2 responsible for construction [see definition of Construction (as used in Division 2)] and stamping of a component.

Containment System. An item which forms a structure that encloses a nuclear power system or that may be connected to other containment items and which is designed to provide a pressure containing barrier for the primary purpose of containing, within leakage limits, or of channeling, for containment or for controlled disposal, radioactive or hazardous effluents released from the system.

Core Support Structures. Those structures or parts of structures which are designed to provide direct support or restraint of the core (fuel and blanket assemblies) within the reactor pressure vessel.

Corrective Action. Measures taken to rectify conditions adverse to quality, and, where necessary, to preclude repetition.

Data Report. A document which certifies that an item was constructed in accordance with the requirements of this Section.

Data Report Form. The form approved by the Society which is used to record the required Code Data.

Defective Material. Material that does not meet specified requirements.

Design Drawings. Drawings which are prepared to illustrate the structural and mechanical details necessary to comply with the Design Specification and this Section.

Designee. Any organization that performs specified activities at the request of the Owner. The Owner retains the responsibility for the activity performed by the designee.

Design Input Documents. Documents which include those criteria, parameters, bases, or other design requirements upon which detailed final design is based. For this Section, these include the Design Specifications and any other documents referenced by it.

Design Limits. Stress and stress intensity limits applicable to Design Loadings given in the Design Specifications.

Design Loadings. The temperatures, pressures, mechanical loads, and other loading conditions specified in Design Specifications which are the basis for design.

Design Output Documents. Documents defining technical requirements for Section III items such as Certified Design Reports, drawings, calculations, Load Capacity Data Sheets, Certified Design Report Summaries, and Construction Specifications.

Design Pressure. The pressures stated in the Design Specifications for which Design Limits are applicable.

Design Report. The design document which shows that the allowable limits stated in this Section are not exceeded for the loadings specified in the Design Specification.

Design Specification (Division 1). A document prepared by the Owner or Owner's designee which provides a complete basis for construction in accordance with this Section.

Design Specification (Division 2). A document prepared by the Owner or Owner's designee which provides a complete basis for design in accordance with this Section.

Designer. The Division 2 organization responsible for preparation of Design Output Documents.

Discrepancy. A condition outside of an established tolerance or requirement.

Document Control. Those measures established to control the preparation, review, release, issuance, and disposition of documents, such as design calculations, purchase orders, specifications, instructions, procedures, and drawings, including changes thereto, which describe or document activities affecting quality.

Enforcement Authority. A regional or local governing body, such as a state or municipality of the United States or a Canadian province, empowered to enact and enforce boiler and pressure vessel legislation.

Environmental Conditions. Those conditions to which the item is subjected such as radiation, pressure, temperature, humidity, site elevation, wind, and wind direction.

Examination. Specific actions by qualified personnel using qualified procedures to verify that items, fabrication processes, and preservice requirements are in conformance with specified requirements. This term, when used in conjunction with qualification of personnel to perform quality-related activities, shall mean a written examination.

Fabrication. Those actions required to manufacture components, parts, and appurtenances. These actions may include forming, machining, assembling, welding, brazing, heat treating, examination, testing, inspection, and certification. Fabrication does not include design.

Full Penetration Weld. A nonstandard welding term for complete joint penetration.

Hold Point. A designated stopping place during or following a specific activity at which inspection or examination is required before further work can be performed.

Hydrostatic Test. The pressurization of an item to a test pressure using water or other liquid as a testing medium with the required examination prescribed by the Code.

Identification and Verification Program. A documented system for the positive identification of material during storage and handling and verification of the identity of material on the accompanying Certified Material Test Report at the time of shipment.

Inspector. The Authorized Nuclear Inspector as defined in NCA-5122. The term Inspector, as used in this Subsection, is the same as the term Authorized Inspector as used in Division 2.

Installation. Those actions required to place and attach components to their supports and join items of a nuclear power system by welding or mechanical means.

Instructions. Detailed written directions provided to persons or organizations to ensure proper completion of a task.

Intervening Element. An element in the support load path which is constructed to rules other than those of this Section. Intervening elements include, but are not limited to, diesel engines, electric motors, coolers, valve actuators, instrument racks, and access structures.

Item. A product constructed under a Certificate of Authorization (NCA-3120) or material (NCA-1220).

Joining. The act of connecting two or more items to one another, by welding, brazing, bolting, or other mechanical means.

Jurisdictional Boundaries. The physical limits of a Code item which are identified to determine the applicability of Code rules for that item.

Linear Support (Linear-Type Support). A structural element acting under essentially a single component of direct stress. Such elements may also be subjected to shear stresses. Examples of such structural elements are tension and compression struts, beams and columns subjected to bending, trusses, frames, rings, arches, and cables.

Load Capacity Data Sheet. The design document used in lieu of a Design Report when a component support is designed by Load Rating to verify that the requirements of NF-3000 have been met.

Material. For Section III, Division 1, metallic materials manufactured to an SA, SB, SFA, or any other material specification permitted in Section III and which are manufactured, identified, and certified in accordance with the requirements of Section III. For Section III, Division 2, metallic materials, as well as to nonmetallic

Page 72

materials, conforming to the specifications permitted in Section III.

Material Organization (Metallic). An organization accredited by holding Quality System Certificate issued by the Society, or qualified by an accredited Material Organization or Certificate Holder, in accordance with the requirements of Section III, NCA-3800.

Material Specification. A document which establishes the requirements for a material.

Monitor. Observe or check compliance with this Section and the Owner's or Certificate Holder's Quality Assurance Program. This activity is not necessarily documented or required to be continuous.

NA Certificate Holder. The organization which performs those activities required to place and attach components to their support structures and joins items requiring an NA Symbol Stamp.

N Certificate Holder (Division 1). The organization assuming responsibility for Code compliance with respect to material, design, fabrication, installation, examination, testing, inspection, certification, and stamping of items requiring an N Symbol Stamp.

N Certificate Holder (Division 2). The organization assuming responsibility for constructing and stamping of the component, including but not limited to installation of parts in accordance with the Design Drawings and Construction Specification.

Nonconformance. A deficiency in a characteristic, documentation, or procedure that renders an item or activity unacceptable or indeterminate.

Nonmetallic Material. Plastic concrete and grout.

Nonmetallic Material Constituent Supplier. An organization which manufactures, produces, and supplies the concrete constituents for plastic concrete or grout in accordance with the Construction Specification.

Nonmetallic Material Manufacturer. An organization which receives, stores, conveys, and combines the concrete constituents to produce plastic concrete or grout in accordance with the Construction Specification.

NPT Certificate Holder. The organization which fabricates parts, piping subassemblies, supports, or appurtenances requiring an NPT Symbol Stamp.

Nuclear Power Plant. One or more nuclear power systems and containment systems as well as other systems not covered by the rules of this Section.

Nuclear Power System. A system which serves the purpose of producing and controlling an output of thermal energy from nuclear fuel and those associated systems essential to the functions and overall safety of the nuclear power system.

Nuclear Power System Item. An item that is designed to provide a pressure containing barrier or is a pressure retaining member in the system, or an item that is designed as a core support structure or a support.

Owner. The organization legally responsible for the construction and/or operation of a nuclear facility including but not limited to one who has applied for, or has been granted, a construction permit or operating license by the regulatory authority having lawful jurisdiction.

Part. An item which is attached to or becomes a portion of a component or support before completion and stamping of the component or support. Parts have work performed on them requiring verification by an Inspector.

Penetration Assembly. An electrical or mechanical part or appurtenance that permits piping, mechanical devices, or electrical connections to pass through the pressure retaining boundary of a containment vessel.

Performance Assessment. For Section III, a documented evaluation of material supplied by a previously audited and accepted Quality System Program to verify continued compliance with Code requirements.

Piping Subassembly

Piping Subassembly. A section of piping system consisting of fittings and pipes or tubes which are fabricated as subassemblies in a shop or in the field before being installed in a nuclear power system.

Piping Support. A support for piping. A support which is attached to an in-line valve may be classified as a piping support when identified in the Design Specification.

Piping System. A piping system is an assembly of piping, piping supports, components, and, if applicable, component supports of one or more Code Classes, with a defined function as described in the Design Specification for the piping system.

Pneumatic Test. The pressurization of an item to a test pressure using a gas as the testing medium with the required examination prescribed by the Code.

Qualified Procedure. A procedure that has been demonstrated to meet the specified requirements for its intended purpose.

Quality Assurance. As used in this Section, quality assurance comprises all those planned and systematic actions necessary to provide adequate confidence that all items designed and constructed are in accordance with the rules of this Section.

Quality Assurance Manual. A written document which describes a Quality Assurance Program.

Quality Assurance Program. A controlled system of planned and systematic actions required to provide

Page 73

adequate confidence that items designed and constructed are in accordance with the rules of the Code.

Quality System Certificate. A Certificate issued by the Society which permits an organization to perform specified Material Manufacturer or Material Supplier activities in accordance with Code requirements.

Quality System Program. A documented system of actions required to provide adequate confidence that materials conform to the requirements of the material specification and the rules of Section III.

Regulatory Authority. A Federal Government Agency, such as the United States Nuclear Regulatory Commission, empowered to issue and enforce regulations concerning the design, construction, and operation of nuclear power plants.

Repair. The process of physically restoring a nonconformance to a condition such that an item complies with Code requirements.

Rework. Refer to *Repair*.

Service. An activity performed by a subcontractor such as designing, rigging, temporary bolting, and nondestructive examination.

Service Limits. Stress and stress intensity limits applicable to Service Loadings given in the Design Specification.

Shop and Field Drawings. Drawings provided by the Constructor or Fabricator (Division 2) which describe construction, fabrication, and installation details, physical dimensions, arrangements, and any significant engineering features needed to establish conformance to the Design Drawings, Construction Specification, and this Section.

Society. The American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017.

Source Material. For Section III, metallic products used for conversion to or qualification as material by a Certificate Holder or Material Organization.

Special Process. A process, the results of which are highly dependent on the control of the process or skill of the operator, or both.

Standard Support. A support consisting of one or more units usually referred to as catalog items and generally mass produced.

Supplier. Any individual or organization that furnishes materials or services in accordance with a procurement document.

Support. A metal element, excluding an intervening element, which transmits loads between nuclear power plant components and the building structure. A support may be either a component support or a piping support.

Survey. A documented evaluation of an organization's ability to perform Code activities as verified by a determination of the adequacy of the organization's quality program and by a review of the implementation of that program at the location of the

work.

Testing. An element of verification for the determination of the capability of an item to meet specified requirements by subjecting the item to a set of physical, chemical, environmental, or operating conditions.

Traceability. The ability to verify the history, location, or application of an item by means of recorded identification.

Unqualified Source Material. Source material not produced by a Certificate Holder, Material Organization, or approved supplier in accordance with the requirements of Section III, NCA-3800.

Use-as-is. A disposition assigned an item previously identified as nonconforming after reconciling Design Output Documents with the item's as-built condition and verifying that applicable requirements of this Section have been met.

Verification. A review to ensure that activities have been performed and documented in accordance with applicable requirements.

[98]

July 1, 1998

American Society Of Mechanical Engineers

SEC III NCA SI UNITS

SI UNITS

Page 75

The 1998 Edition of the Boiler and Pressure Vessel Code is based on U.S. Customary (ft-lb) units of measurement which are to be regarded as the standard. This supplement is provided as a convenience to the Code user and contains SI conversion factors for units contained in the Code.

Page 76

Page 77

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

Quantity	Unit	Symbol	Other Units or Limitations
Space and Time			
plane angle	radian	rad	degree (decimalized)
length	meter	m	
area	square meter	m ²	
volume	cubic meter	m ³	liter (L) for liquid only (use without prefix other than in milliliter, mL)
time	second	s	minute (min), hour (h), day (d), week, and year
Periodic and Related Phenomena			
frequency	hertz	Hz	revolutions per second (r/s)
rotational frequency	revolutions per second	s ⁻¹	revolutions per minute (r/m)
Mechanics			
mass	kilogram	kg	
density	kilogram per cubic meter	kg/m ³	
moment of inertia	kilogram · meter ²	kg · m ²	
force	newton	N	
moment of force (torque)	newton-meter	N · m	
pressure and stress	pascal	Pa	(pascal = newton per square meter)
energy, work	joule	J	kilowatt-hour (kW · h)
power	watt	W	
impact strength	joule	J	
section modulus	meter ³	m ³	
moment of section	meter ⁴	m ⁴	
(second moment of area)			
fracture toughness	Pa · $\sqrt{m}$		
Heat			
temperature — thermodynamic [Note (2)]	kelvin	K	degree Celsius (°C)
temperature — other than thermodynamic	degree Celsius	°C	kelvin (K)
linear expansion coefficient	meter per meter-kelvin	K ⁻¹	°C ⁻¹
quantity of heat	joule	J	
heat flow rate	watt	W	
thermal conductivity	watt per meter-kelvin	W/(m · K)	W/(m · °C)
thermal diffusivity	square meter per second	m ² /s	
specific heat capacity	joule per kilogram-kelvin	J/(kg · K)	J/(kg · °C)
Electricity and Magnetism			
electric current	ampere	A	
electric potential	volt	V	
current density	ampere per meter ²	A/m ²	
magnetic field strength	ampere per meter	A/m	

NOTES:

- (1) Conversion factors between SI units and U.S. customary are given in SI-1, "ASME Orientation and Guide for Use of SI (Metric) Units," and ASTM E 380.
- (2) Preferred use for temperature and temperature interval is degrees Celsius (°C), except for thermodynamic and cryogenic work where kelvins may be more suitable. For temperature interval, 1 K = 1°C exactly.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

COMMONLY USED CONVERSION FACTORS
(For Others See ASTM E 380) [See Note (1)]

Quantity	To Convert From	To	Multiply by [Note (2)]	
plane angle	degree	rad	1.745 329	E-02
length	in	m	2.54*	E-02
	ft	m	3.048*	E-01
	yd	m	9.144*	E-01
area	in ²	m ²	6.451 6*	E-04
	ft ²	m ²	9.290 304*	E-02
	yd ²	m ²	8.361 274	E-01
volume	in ³	m ³	1.638 706	E-05
	ft ³	m ³	2.831 685	E-02
	US gallon	m ³	3.785 412	E-03
	Imperial gallon	m ³	4.546 09	E-03
	liter	m ³	1.0*	E-03
mass	lbm	kg	4.535 924	E-01
	ton (metric) (mass)	kg	1.000 00*	E+03
	ton (short 2000 lbm)	kg	9.071 847	E+02
force	kgf	N	9.806 65*	E+00
	lbf	N	4.448 222	E+00
bending, torque	kgf · m	N · m	9.806 65*	E+00
	lbf · in	N · m	1.129 848	E-01
	lbf · ft	N · m	1.355 818	E+00
pressure, stress	kgf/m ²	Pa	9.806 65*	E+00
	lbf/ft ²	Pa	4.788 026	E+01
	lbf/in ² (psi)	Pa	6.894 757	E+03
	kips/in ²	Pa	6.894 757	E+06
	bar	Pa	1.0*	E+05
energy, work	Btu (IT) [Note (3)]	J	1.055 056	E+03
	ft · lbf	J	1.355 818	E+00
power	hp (550 ft · lbf/s)	W	7.456 999	E+02
fracture toughness	ksi $\sqrt{\text{in}}$	Pa · $\sqrt{\text{m}}$	1.098 843	E+06
temperature	°C	K	$t_K = t_C + 273.15$	
	°F	K	$t_K = (t_F + 459.67)/1.8$	
	°F	°C	$t_C = (t_F - 32)/1.8$	
temperature interval	°C	K	1.0*	E+00
	°F	K or °C	5.555 555	E-01

NOTES:

- (1) Care should be taken when converting formulas or equations that contain constant terms or factors. The value of these terms must be understood and may also require conversion.
- (2)(a) Relationships that are exact in terms of the base units are followed by a single asterisk.
 (b) The factors are written as a number greater than 1 and less than 10 with 6 or less decimal places. The number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example: 3.523 907 E-02 is $3.523\ 907 \times 10^{-2}$ or 0.035 239 07.
- (3) International Table

COMMONLY USED CONVERSION FACTORS

July 1, 1998
American Society Of Mechanical Engineers
SEC III D1 NB A98
1998 ADDENDA SUMMARY OF CHANGES

Page xxv

Changes given below are identified on the pages by a margin note, **98**, placed next to the affected area.

Page	Location	Change
20	NB-2224	Title corrected by Errata
65	NB-3133.2	In definition for S , last cross-reference corrected by Errata
79, 80	Figure NB-3222-1	(1) Note (3) through (6) references redesignated as (4) through (7), respectively (2) In second row of tabular entries, new Note (3) references added (3) Notes (3) through (6) redesignated as (4) through (7), respectively (4) New Note (3) added
84	NB-3223	Subparagraph (a)(1) revised
87	NB-3227.3	Last cross-reference corrected by Errata
88	NB-3228.1	Last cross-reference corrected by Errata
90	NB-3229	Second cross-reference corrected by Errata
105	NB-3411.2	Subparagraph (a) revised
	NB-3412.1	First paragraph corrected by Errata
112	NB-3512.2	In subparagraph (d)(2), last cross-reference corrected by Errata
135	Figure NB-3594.3-1	Callout corrected by Errata
140	NB-3630	Subparagraph (d)(2)(c) corrected by Errata
141	NB-3641.1	Definitions for P_a and t corrected by Errata
148	NB-3647.3	Last cross-reference corrected by Errata
155	NB-3658.1	In definition for S_y , cross-reference corrected by Errata
	NB-3658.2	Subparagraph (a) corrected by Errata
	NB-3658.3	Subparagraph (a) corrected by Errata
159	Table NB-3681(a)-1	(1) Note (1) through (13) references (throughout Table) redesignated as (2) through (14), respectively (2) In Table title, new Note (1) reference added (3) Notes (1) through (13) redesignated as (2) through (14), respectively (4) New Note (1) added

162-167	NB-3683.2	In subparagraph (b), cross-reference corrected by Errata (1) Second sentence corrected by Errata (2) In definition for S_y , cross-reference corrected by Errata
---------	-----------	--

Page xxvi

Page	Location	Change
162-167	NB-3683.4	(1) Title corrected by Errata (2) First paragraph deleted by Errata (3) Subparagraphs (a), (b), (c), (c)(1), and (c)(2) corrected by Errata
	NB-3683.5	Subparagraphs (a) and (b) corrected by Errata
	NB-3683.6	(1) First paragraph corrected by Errata (2) In subparagraph (c)(2), second equation revised
	NB-3683.7	First paragraph corrected by Errata
	NB-3683.8	First paragraph corrected by Errata
	NB-3683.9	First paragraph corrected by Errata
	NB-3685.1	Corrected by Errata
	NB-3685.2	In definition for E , cross-reference corrected by Errata
171	NB-3686.5	In subparagraphs (c) and (d), equations revised
254	NB-7220	Subparagraph (n) deleted by Errata

NOTE:

Volume 42 of the Interpretations to Section III, Divisions 1 and 2, of the ASME Boiler and Pressure Vessel Code follows the last page of the Edition to Subsection NCA.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NB INTRO

Introduction

1998 ASME
BOILER &
PRESSURE VESSEL CODE
AN INTERNATIONAL CODE

III

Division 1 -

Subsection NB

Class 1

Components

RULES FOR CONSTRUCTION OF NUCLEAR POWER PLANT COMPONENTS

[ASME logo] The American Society of
Mechanical Engineers

IMPORTANT INFORMATION ON THE 1998 BOILER AND PRESSURE VESSEL CODE ADDENDA DISTRIBUTION SCHEDULE

There is a change in the way the Addenda to the 1998 Edition of the ASME Boiler and Pressure Vessel Code are distributed. The 1998 Edition, published July 1, 1998, incorporates the 1998 Addenda revisions, additions, or deletions. There will be no separate 1998 Addenda issued in a replacement page format. Two additional Addenda to the 1998 Edition, in the form of replacement pages, will be issued on July 1, 1999 and July 1, 2000.

The Summary of Changes published with the 1998 Edition lists and describes the revisions that are part of the 1998 Addenda. These changes are identified with a margin note, **98**, denoting the affected area.

The Addenda for 1999 and 2000 will also have a Summary of Changes and identifiers printed on the replacement pages. The revisions, additions, or deletions will be incorporated directly into the affected pages. It is advisable to retain the title sheets and all replaced pages for reference.

The effective dates for Code Editions and Addenda are described in the Foreword.

ASME BOILER AND PRESSURE VESSEL CODE
AN INTERNATIONAL CODE

RULES FOR CONSTRUCTION OF NUCLEAR POWER PLANT COMPONENTS

III

Division 1 -

Subsection NB

Class 1

Components

1998 Edition

July 1, 1998

ASME BOILER AND PRESSURE VESSEL COMMITTEE SUBCOMMITTEE ON NUCLEAR POWER

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
NEW YORK, NEW YORK

Date of Issue - July 1, 1998

(Includes all Addenda dated December 1997 and earlier)

This code or standard was developed under procedures accredited as meeting the criteria for American National Standards. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment which provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not "approve," "rate," or "endorse" any item, construction, proprietary device, or activity.

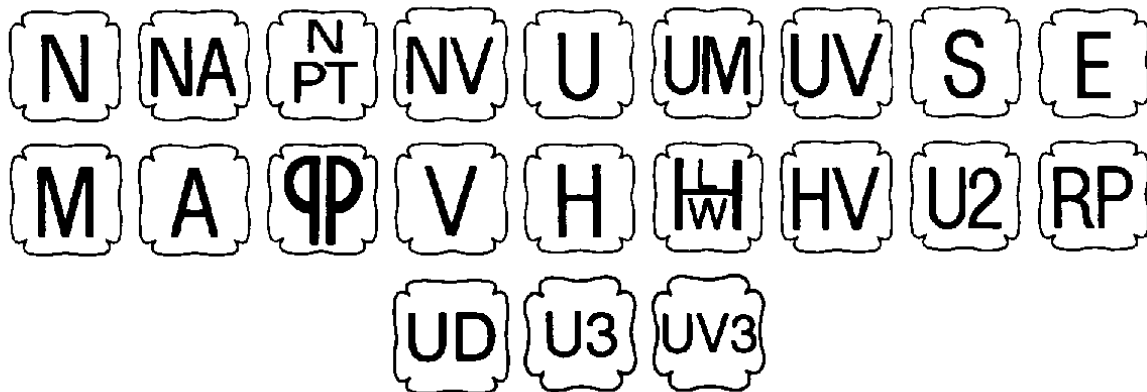
ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of any applicable Letters Patent, nor assume any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations issued in accordance with governing ASME procedures and policies which preclude the issuance of interpretations by individual volunteers.

The footnotes in this document are part of this American National Standard.

[ASME logo] ASME collective membership mark



LOGO

The above ASME symbols are registered in the U.S. Patent Office.

"ASME" is the trademark of the American Society of Mechanical Engineers.

No part of this document may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Library of Congress Catalog Card Number: 56-3934

Printed in the United States of America

Adopted by the Council of the American Society of Mechanical Engineers, 1914.

Revised 1940, 1941, 1943, 1946, 1949, 1952, 1953, 1956, 1959, 1962, 1965, 1968, 1971, 1974, 1977, 1980, 1983, 1986, 1989, 1992, 1995, 1998

The American Society of Mechanical Engineers
Three Park Avenue, New York, NY 10016-5990

Copyright © 1998 by
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
All Rights Reserved

1998 ASME
BOILER AND PRESSURE VESSEL CODE

SECTIONS

I Rules for Construction of Power Boilers

II Materials

Part A - Ferrous Material Specifications

Part B - Nonferrous Material Specifications

Part C - Specifications for Welding Rods, Electrodes, and Filler Metals

Part D - Properties

III Subsection NCA - General Requirements for Division 1 and Division 2

III Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

III Division 2 - Code for Concrete Reactor Vessels and Containments

III Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

IV Rules for Construction of Heating Boilers

V Nondestructive Examination

VI Recommended Rules for the Care and Operation of Heating Boilers

VII Recommended Guidelines for the Care of Power Boilers

VIII Rules for Construction of Pressure Vessels

Division 1

Division 2 - Alternative Rules

Division 3 - Alternative Rules for Construction of High Pressure Vessels

IX Welding and Brazing Qualifications

X Fiber-Reinforced Plastic Pressure Vessels

XI Rules for Inservice Inspection of Nuclear Power Plant Components

ADDENDA

Colored-sheet Addenda, which include additions and revisions to individual Sections of the Code, are published annually and will be sent automatically to purchasers of the applicable Sections up to the publication of the 2001 Code. The 1998 Code is available only in the loose-leaf format; accordingly, the Addenda will be issued in the loose-leaf, replacement-page format.

INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code. The Interpretations for each individual Section will be published separately and will be included as part of the update service to that Section. They will be issued semiannually (July and December) up to the publication of the 2001 Code. Interpretations of Section III, Divisions 1 and 2, will be included with the update service to Subsection NCA.

CODE CASES

The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 1998 Code Cases book: (1) Boilers and Pressure Vessels and (2) Nuclear Components. Supplements will be sent automatically to the purchasers of the Code Cases books up to the publication of the 2001 Code.

Page v

FOREWORD

The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety governing the design, fabrication, and inspection during construction of boilers and pressure vessels, and to interpret these rules when questions arise regarding their intent. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property and to provide a margin for deterioration in service so as to give a reasonably long, safe period of usefulness. Advancements in design and material and the evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction,¹ and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

¹ Construction, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are responsible for the application of these programs to their design.

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practice as determined by the engineer.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Boiler and Pressure Vessel Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Mandatory Appendix covering preparation of technical inquiries). Proposed revisions to the Code resulting from inquiries will be presented to the Main Committee for appropriate action. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by ASME.

Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute and published in *Mechanical Engineering* to invite comments from all interested persons. After the allotted time for public review and final

Page viii

approval by ASME, revisions are published annually in Addenda to the Code.

Code Cases may be used in the construction of components to be stamped with the ASME Code symbol beginning with the date of their approval by ASME.

Code Editions may be used on or after the date of issue shown in the Edition. After Code revisions are approved by ASME, they may be used beginning with the date of issue shown on the Addenda. Revisions to material specifications are originated by the American Society for Testing and Materials (ASTM) and other recognized national or international organizations, and are usually adopted by ASME. However, those revisions may or may not have any effect on the suitability of material, produced to earlier editions of specifications, for use in ASME construction. ASME material specifications approved for use in each construction Code are listed in the Appendices of Section II, Parts A and B. These Appendices list, for each specification, the latest edition adopted by ASME, and earlier and later editions considered by ASME to be identical for ASME construction.

Owners of nuclear power plants are cautioned that Code Editions, Addenda, and Cases to be used in construction shall be acceptable to the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

Each state and municipality in the United States and each province in Canada that adopts or accepts one or more Sections of the Boiler and Pressure Vessel Code is invited to appoint a representative to act on the Conference Committee to the Boiler and Pressure Vessel Committee. Since the members of the Conference Committee are in active contact with the administration and enforcement of the rules, the requirements for inspection in this Code correspond with those in effect in their respective jurisdictions. The required qualifications for an Authorized Inspector under these rules may be obtained from the administrative authority of any state, municipality, or province which has adopted these rules.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, method of fabrication, inspection, and safety devices. Permission may be granted to regulatory bodies and organizations publishing safety standards to use a complete Section of the Code by reference. If usage of a Section, such as Section IX, involves exceptions, omissions, or changes in provisions, the intent of the Code might not be attained.

Where a state or other regulatory body, in the printing of any Section of the Boiler and Pressure Vessel Code, makes additions or omissions, it is recommended that such changes be clearly indicated.

The National Board of Boiler and Pressure Vessel Inspectors is composed of chief inspectors of states and municipalities in

the United States and of provinces in Canada that have adopted the Boiler and Pressure Vessel Code. This Board, since its organization in 1919, has functioned to uniformly administer and enforce the rules of the Boiler and Pressure Vessel Code. The cooperation of that organization with the Boiler and Pressure Vessel Committee has been extremely helpful.

The Code Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The Scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Code for vessels or components not considered to be within its Scope or may establish additions or deletions in that Scope. Accordingly, inquiries regarding such laws or regulations are to be directed to the issuing enforcement or regulatory body.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the ASME Boiler and Pressure Vessel Committee. ASME is to be notified should questions arise concerning improper use of an ASME Code symbol.

The specifications for materials given in Section II are identical with or similar to those of specifications published by ASTM, AWS, and other recognized national or international organizations. When reference is made in an ASME material specification to a non-ASME specification for which a companion ASME specification exists, the reference shall be interpreted as applying to the ASME material specification. Not all materials included in the material specifications in Section II have been adopted for use in this Section. Usage is limited to those materials and grades listed in at least one of the tables of Section II, Part D, Subpart 1, identified as applicable to this Section. All materials allowed by this Section and used for construction within the scope of these rules shall be furnished in accordance with material specifications contained in Section II or referenced in Appendices A of Section II, Parts A and B except where otherwise

Page ix

provided in Code Cases or in this Section of the Code. Materials covered by these specifications are acceptable for use in items covered by the Code Sections only to the degree indicated in the applicable Section. Materials for Code use should preferably be ordered, produced, and documented on this basis. Material produced to an acceptable specification with requirements different from the requirements of the corresponding specification listed in Appendix A of Part A or Part B may also be used in accordance with the above, provided the material manufacturer or vessel manufacturer certifies with evidence acceptable to the Authorized Inspector that the corresponding ASME specification requirements of specifications listed in Appendix A of Part A or Part B have been met. Material produced to an acceptable material specification is not limited as to country of origin.

When required by context in this Section, the singular shall be interpreted as the plural, and vice-versa; and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

Publication of the SI (Metric) Edition of the ASME Boiler and Pressure Vessel Code was discontinued with the 1986 Edition. Effective October 1, 1986, the SI Edition was withdrawn as an ASME Boiler and Pressure Vessel Code document.

Page xi

STATEMENT OF POLICY ON THE USE OF CODE SYMBOLS AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use Code Symbols for marking items or constructions which have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the symbols, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not

"approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications which might so indicate. An organization holding a Code Symbol and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code."

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified items will carry the symbol. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

The ASME logo, which is the cloverleaf with the letters ASME within, shall not be used by any organization other than ASME.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Code Symbol Stamp described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the various Code Symbols shall not be used on any item which is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME which tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

Page xiii

PERSONNEL ASME Boiler and Pressure Vessel Committee Subcommittees, Subgroups, and Working Groups

As of December 31, 1997

MAIN COMMITTEE

D. A. Canonico, *Chair*

G. G. Karcher, *Vice Chair*

J. S. Brzuszkiewicz, *Secretary*

R. W. Barnes

F. P. Barton

D. L. Berger

M. D. Bernstein

M. N. Bressler

W. J. Carter

T. M. Cullen

J. R. Farr

R. E. Feigel

J. G. Feldstein

M. Gold

O. F. Hedden

A. J. Justin

D. F. Landers
W. M. Lundy
J. R. MacKay
T. J. Mawson
T. G. McCarty
G. C. Millman
R. A. Moen
C. C. Neely
C. J. Pieper
R. F. Reedy
B. W. Roberts
F. J. Schaaf, Jr.
A. Selz
K. K. Tam
D. E. Tanner

EXECUTIVE COMMITTEE (MAIN COMMITTEE)

G. G. Karcher, *Chair*
D. A. Canonico, *Vice Chair*
J. S. Brzuszkiewicz, *Secretary*
F. P. Barton
J. R. Farr
J. G. Feldstein
M. Gold
O. F. Hedden
A. J. Justin
J. R. MacKay
T. G. McCarty
T. P. Pastor
T. E. Quaka
R. F. Reedy
A. J. Spencer

HONORARY MEMBERS (MAIN COMMITTEE)

R. D. Bonner
R. J. Bosnak
H. M. Canavan
L. J. Chockie
J. S. Clarke
W. E. Cooper
W. D. Doty
R. C. Griffin
E. J. Hemzy
E. C. Kistner, Jr.
J. E. Lattan

J. E. Lattan
J. LeCoff
F. N. Moschini
C. E. Rawlins
W. E. Somers
L. P. Zick, Jr.

HONORS AND AWARDS COMMITTEE

J. R. MacKay, *Chair*
A. J. Spencer, *Vice Chair*
F. R. Lyons, *Secretary*
F. P. Barton
W. J. Carter
J. G. Feldstein
M. Gold
F. E. Gregor
E. C. Kistner, Jr.
T. P. Pastor
R. F. Reedy

MARINE CONFERENCE GROUP

J. Tiratto, *Chair*
C. F. Banks
L. W. Douthwaite
J. L. Jones
G. F. Wright

CONFERENCE COMMITTEE

D. E. Tanner - Tennessee (*Chair*)
R. D. Reetz - North Dakota (*Vice Chair*)
A. J. Justin - National Board of Boiler and Pressure Vessel Inspectors (*Secretary*)
R. J. Aben, Jr. - Michigan
J. S. Aclaro - Los Angeles, California
E. A. Anderson - Chicago, Illinois
J. Anderson - South Dakota
R. Barkdoll - Washington
F. P. Barton - Virginia
C. Castle - Nova Scotia, Canada
R. R. Cate - Louisiana
L. Chase - Northwest Territories, Canada
R. A. Coomes - Kentucky
J. Corcoran - Connecticut
M. H. Diehl, Jr. - Maryland
D. A. Douin - Illinois
D. Eastman - Newfoundland and Labrador, Canada

G. L. Ebeyer - New Orleans, Louisiana
F. Ellis - New Hampshire
E. Everett - Georgia
P. C. Hackford - Utah
D. Hanrath - North Carolina
J. B. Harlan - Delaware
K. Hynes - Prince Edward Island, Canada
D. T. Jagger - Ohio
D. J. Jenkins - Kansas
M. Kotb - Quebec, Canada
J. P. Larson - Minnesota
K. T. Lau - Alberta, Canada
J. Lemire - California
G. A. Lundberg - Florida
W. C. Lundine - Oregon
M. A. Malek - Maine
I. W. Mault - Manitoba, Canada
H. T. McEwen - Mississippi
A. W. Meiring - Indiana
R. Mile - Ontario, Canada
T. J. Monroe - Oklahoma
Y. Nagpaul - Hawaii
J. D. Payton - Pennsylvania
D. K. Peetz - Missouri
D. C. Price - Yukon Territory, Canada
R. S. Pucek - Wisconsin
T. E. Rennie - Arizona
L. Roussinos - British Columbia, Canada
M. Shuff - West Virginia
R. Snyder - New Jersey
N. Surtees - Saskatchewan, Canada
M. J. Verhagen - Wisconsin
R. B. West - Iowa
M. J. Wheel - Vermont
K. A. White - Nevada
R. K. White - New York
T. F. Wickham - Rhode Island
C. S. Withers - Colorado

SUBCOMMITTEE ON POWER BOILERS (SC I)

J. R. MacKay, *Chair*
M. D. Bernstein, *Vice Chair*
P. D. Stumpf, *Secretary*
D. L. Berger
E. Everett

D. N. French
F. R. Gerety
J. Hainsworth
T. E. Hansen
J. S. Hunter
W. L. Lowry
T. C. McGough
P. A. Molvie
D. K. Parrish
J. T. Pillow
R. G. Presnak
B. W. Roberts
R. D. Schueler, Jr.
R. V. Wielgoszinski
R. L. Williams

Page xiv

Subgroup on Design (SC I)

M. D. Bernstein, *Chair*
R. D. Schueler, Jr., *Vice Chair*
P. A. Molvie, *Secretary*
M. A. Farrugia
J. D. Fishburn
C. F. Jeerings
K. C. Morrison
A. Nassif
N. Surtees
R. V. Wielgoszinski

Subgroup on Fabrication and Examination (SC I)

D. L. Berger, *Chair*
R. E. McLaughlin, *Secretary*
R. W. Boyce
D. N. French
J. Hainsworth
T. E. Hansen
M. H. Iken
J. M. Lyons
J. T. Pillow
M. E. Reese
R. D. Schueler, Jr.
R. F. Slack, Sr.
R. V. Wielgoszinski

Subgroup on General Requirements (SC I)

T. C. McGough, *Chair*
M. D. Bernstein, *Vice Chair*
W. L. Lowry, *Secretary*
D. L. Berger
E. Everett
F. R. Gerety
J. Hainsworth
C. F. Jeerings
J. M. Lyons
R. E. McLaughlin
D. K. Parrish
J. T. Pillow
W. E. Somers
R. L. Williams

Subgroup on Materials (SC I)

B. W. Roberts, *Chair*
C. E. Spaeder, Jr., *Chair*
J. S. Hunter, *Secretary*
T. M. Cullen
D. N. French
J. F. Henry
J. P. Libbrecht
F. Masuyama
J. M. Tanzosh

Subgroup on Piping (SC I)

T. E. Hansen, *Chair*
D. L. Berger
M. D. Bernstein
P. D. Edwards
W. L. Lowry
T. C. McGough
R. G. Presnak
E. Whittle
P. L. Ziegler

SUBCOMMITTEE ON MATERIALS (SC II)

M. Gold, *Chair*
T. M. Cullen, *Vice Chair*
F. R. Lyons, *Secretary*
A. P. Ahrendt
M. N. Bressler
A. Cohen

A. Cohen
R. Dirscherl
W. D. Doty
W. D. Edsall
D. Gandy
M. H. Gilkey
J. J. Heger
J. F. Henry
G. C. Hsu
F. Masuyama
E. Michalopoulos
R. A. Moen
R. K. Nanstad
E. G. Nisbett
J. T. Parsons
D. W. Rahoi
B. W. Roberts
E. Shapiro
C. E. Spaeder, Jr.
R. W. Swindeman
J. M. Tanzosh
B. E. Thurgood
A. W. Zeuthen

Subgroup on External Pressure (SC II)

R. W. Mikitka, *Chair*
D. J. Green
D. S. Griffin
E. Michalopoulos
B. R. Morelock
D. Nadel
C. E. Spaeder, Jr.
C. H. Sturgeon

Subgroup on Ferrous Specifications (SC II)

E. G. Nisbett, *Chair*
B. M. Dingman
W. D. Edsall
T. Graham
W. N. Holliday
E. A. Jonas
D. C. Krouse
J. F. Longenecker
W. C. Mack
A. S. Melilli

J. T. Parsons
E. J. Rozic, Jr.
E. Upitis
A. W. Zeuthen
R. H. Zong

Subgroup on International Material Specifications (SC II)

J. T. Parsons, *Chair*
D. C. Agarwal
J. Cameron
R. Dirscherl
W. D. Doty
D. M. Fryer
M. Gold
M. H. Iken
W. M. Lundy
H. Masahisa
T. F. Miskell
F. Osweiller
A. P. Povilonis
R. D. Schueler, Jr.
R. R. Seeley
E. A. Steen
E. Upitis
E. O. Woolridge

Subgroup on Nonferrous Alloys (SC II)

D. W. Rahoi, *Chair*
D. C. Agarwal, *Secretary*
W. R. Apblett
L. G. Coffee
A. Cohen
R. Dirscherl
M. H. Gilkey
G. C. Hsu
M. Katcher
E. Shapiro
L. E. Shoemaker
R. C. Sutherlin

Subgroup on Strength, Ferrous Alloys (SC II)

B. W. Roberts, *Chair*
J. M. Tanzosh, *Secretary*
A. P. Ahrendt
W. R. Apblett

W. R. Apblett
T. M. Cullen
M. Gold
J. J. Heger
C. L. Hoffmann
A. Iseda
F. Masuyama
R. A. Moen
J. W. Raho
C. E. Spaeder, Jr.
R. W. Swindeman
B. E. Thurgood

Subgroup on Strength of Weldments (SC II & SC IX)

C. E. Spaeder, Jr., *Chair*
W. D. Doty
D. W. Raho
B. W. Roberts
C. Robino
W. J. Sperko
J. M. Tanzosh
B. E. Thurgood

Subgroup on Toughness (SC II)

J. M. Barsom
D. A. Hansen
A. Selz
R. S. Vecchio
S. Yukawa
R. Zawierucha

Page xv

SUBCOMMITTEE ON NUCLEAR POWER (SC III)

C. J. Pieper, *Chair*
R. M. Jessee, *Vice Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
Y. Asada
R. W. Barnes
J. N. Baysden
W. H. Borter
E. B. Branch
M. N. Bressler
F. C. Cherny
G. D. Cooper

R. P. Deubler
W. D. Doty
F. R. Drahos
K. Ennis
B. A. Erler
D. Hanrath
C. L. Hoffmann
K.-H. Hsu
D. F. Landers
W. C. LaRochelle
T. J. Mawson
W. N. McLean
R. A. Moen
D. B. Nickerson
R. F. Perrin
R. F. Reedy
M. W. Smith
J. D. Stevenson
R. E. Tome
K. R. Wichman

Subgroup on Containment Systems for Spent Fuel and High-Level Waste Transport Packagings (SC III)

J. D. Stevenson, *Chair*
H. H. Chung
R. R. Doggart
E. L. Farrow
K. Goldmann
R. H. Jones
W. H. Lake
R. W. Lambert
H. W. Lee
P. McConnell
R. E. Nickell
D. J. Nolan
D. T. Raske
T. Saegusa
R. H. Smith
K. B. Sorenson
P. Turula
N. Urabe
C. R. Witt
S. Yukawa

Subgroup on Design (SC III)

R. W. Barnes, *Chair*

R. W. Barnes, *Chair*
E. B. Branch, *Vice Chair*
R. S. Hill III, *Secretary*
Y. Asada
M. N. Bressler
C. W. Bruny
J. R. Cole
G. D. Cooper
R. P. Deubler
N. W. Edwards
R. E. Gimple
D. Hanrath
R. W. Haupt
T. Iida
B. Jarman
D. F. Landers
W. N. McLean
D. B. Nickerson
E. C. Rodabaugh
J. R. Santangelo
G. C. Slagis
J. D. Stevenson
J. H. Wawrzeniak
K. R. Wichman
R. Wray

Working Group on Administration (SG-D) (SC III)

E. B. Branch, *Chair*
R. W. Barnes, *Vice Chair*
R. S. Hill III, *Secretary*
C. W. Bruny
G. D. Cooper
R. P. Deubler
J. T. Land
D. F. Landers
W. N. McLean
D. B. Nickerson
J. R. Santangelo
R. Wray

Working Group on Core Support Structures (SG-D) (SC III)

J. T. Land, *Chair*
R. H. Hansen
K. B. Larsen
J. F. Mullooly

B. L. Silverblatt

Working Group on Dynamic and Extreme Load Conditions (SG-D) (SC III)

R. Wray, *Chair*

A. E. Meligi, *Secretary*

P. L. Anderson

M. K. Au-Yang

R. D. Blevins

G. J. Bohm

D. L. Caldwell

P.-Y. Chen

A. Hadjian

M. Hartzman

W. S. LaPay

H. Lockert

P. R. Olson

R. F. Perry

J. Wallach

Working Group on Piping (SG-D) (SC III)

D. F. Landers, *Chair*

R. S. Hill III, *Vice Chair*

P. Hirschberg, *Secretary*

T. M. Adams

G. A. Antaki

J. R. Cole

A. B. Glickstein

R. W. Haupt

J. C. Hennart

R. D. Hookway

R. B. Jenkins

K. A. Manoly

J. C. Minichiello

S. E. Moore

A. N. Nguyen

D. B. Nickerson

O. O. Oyamada

R. D. Patel

E. C. Rodabaugh

J. R. Santangelo

M. S. Sills

G. C. Slagis

E. A. Wais

Working Group on Pumps (SG-D) (SC III)

D. B. Nickerson, *Chair*
H. L. Brammer
P. Burchett
R. E. Cornman, Jr.
A. A. Fraser
M. Higuchi
G. R. Jones
J. W. Leavitt
J. E. Livingston
R. A. Schussler
H. Tafarirodi
G. K. Vaghasia

Working Group on Supports (SG-D) (SC III)

R. P. Deubler, *Chair*
R. M. Dulin, Jr., *Secretary*
U. S. Bandyopadhyay
F. J. Birch
M. N. Bressler
J. R. Cole
J. C. Finneran, Jr.
R. W. Haupt
J. C. Hennart
A. S. Laurensen
A. Lee
R. J. Masterson
A. E. Meligi
A. N. Nguyen
J. R. Stinson

Working Group on Valves (SG-D) (SC III)

W. N. McLean, *Chair*
E. A. Bake
R. R. Brodin
W. G. Knecht
R. Koester
J. J. McGavin
S. N. Shields
H. R. Sonderegger
J. C. Tsacoyeanes
R. G. Visalli
J. R. Zahorsky

Working Group on Vessels (SG-D) (SC III)

C. W. Bruny, *Chair*
T. K. Burr, Sr.
G. D. Cooper
G. A. Deaver
N. W. Edwards
D. Hanrath
W. J. Heilker
B. Jarman
T. M. Khan
O. Maekawa
K. A. Manoly
A. Merend
G. K. Miller
W. Z. Novak
E. Pelling
H. S. Thornton

Page xvi

Special Working Group on Environmental Effects (SG-D) (SC III)

R. S. Hill III, *Chair*
Y. Asada
W. J. Heilker
C. L. Hoffmann
R. A. Moen
W. Z. Novak
S. Yukawa

Special Working Group on Seismic Piping Rules (SG-D) (SC III)

E. B. Branch, *Chair*
T. M. Adams
G. A. Antaki
R. D. Hookway
J. C. Minichiello
M. S. Sills
E. A. Wais

Subgroup on General Requirements (SC III & SC 3C)

W. C. LaRochelle, *Chair*
K. Ennis, *Secretary*
A. Appleton
J. R. Barbee
J. N. Baysden
L. M. Beason
B. H. Berg

R. E. Kelley
G. S. Korin
A. S. Laurenson
C. Lizotte
M. J. Meyer
M. R. Minick
L. C. Oakes
R. F. Perrin
U. Potapovs
B. B. Scott
D. E. Tanner
D. V. Walshe

Subgroup on Materials, Fabrication, and Examination (SC III)

C. L. Hoffmann, *Chair*
G. P. Milley, *Secretary*
C. W. Allison
D. Doyle
F. R. Drahos
G. M. Foster
G. B. Georgiev
J. E. Harris
R. W. Jackson
R. M. Jessee
C. C. Kim
R. A. Moen
C. J. Pieper
R. R. Seeley
N. M. Simpson
R. C. Soin
W. J. Sperko
K. B. Stuckey
S. Yukawa

Subgroup on Pressure Relief (SC III)

F. C. Cherny, *Chair*
S. F. Harrison, Jr.
E. M. Petrosky
M. W. Smith
A. L. Szeglin
B. S. York
J. R. Zahorsky

Special Working Group on Editing and Review (SC III)

R. F. Reedy, *Chair*
W. H. Borter
M. N. Bressler
R. P. Deubler
B. A. Erler
W. C. LaRochelle
M. W. Smith
J. D. Stevenson
E. O. Woolridge

JOINT ACI-ASME COMMITTEE ON CONCRETE COMPONENTS FOR NUCLEAR SERVICE (SC 3C)

B. A. Erler, *Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
R. M. Attar
A. C. Eberhardt
J. Gutierrez
D. J. Haavik
M. F. Hessheimer
T. E. Johnson
G. R. Murphy
S. F. Putman
B. B. Scott
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Design (SC 3C)

D. G. Adams
A. C. Eberhardt
T. E. Johnson
S. F. Putman
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Materials, Construction, and Examination (SC 3C)

D. J. Haavik, *Chair*
J. F. Artuso
R. M. Attar
B. A. Erler
J. Gutierrez

SUBCOMMITTEE ON HEATING BOILERS (SC IV)

F. P. Barton, *Chair*
P. A. Molvie, *Vice Chair*
B. P. Feder, *Secretary*
R. B. Duggan
W. L. Haag, Jr.
W. M. Hiddleston
J. D. Hoh
K. M. McTague
R. I. Mullican
E. A. Nordstrom
J. L. Seigle
D. E. Tanner
S. V. Voorhees
R. H. Weigel
R. V. Wielgoszinski
J. I. Woodworth
T. L. Bedeaux, Alternate

Subgroup on Care and Operation of Heating Boilers (SC IV)

J. I. Woodworth, *Chair*
B. P. Feder, *Secretary*
K. J. Hoey
J. D. Hoh
F. M. Lucas
K. M. McTague
P. A. Molvie
R. I. Mullican
R. H. Weigel
T. F. Wickham
T. L. Bedeaux, Alternate

Subgroup on Cast Iron Boilers (SC IV)

K. M. McTague, *Chair*
R. B. Duggan
R. H. Weigel
T. F. Wickham
J. I. Woodworth
T. L. Bedeaux, Alternate

Subgroup on Water Heaters (SC IV)

W. L. Haag, Jr., *Chair*
T. D. Gantt
W. M. Hiddleston
F. M. Lucas

F. M. Lucas
K. M. McTague
R. I. Mullican
D. Smith
D. E. Tanner
M. A. Taylor

Subgroup on Welded Boilers (SC IV)

P. A. Molvie, *Chair*
T. L. Bedeaux
D. H. Mapes
E. A. Nordstrom
J. L. Seigle
R. F. Slack, Sr.
R. P. Sullivan
D. E. Tanner
R. V. Wielgoszinski

SUBCOMMITTEE ON NONDESTRUCTIVE EXAMINATION (SC V)

T. G. McCarty, *Chair*
J. E. Batey, *Vice Chair*
F. S. Fitzgerald, *Secretary*
A. S. Birks
B. H. Clark, Jr.
W. T. Clayton
R. A. Coomes
N. Y. Faransso
H. C. Graber
O. F. Hedden
G. W. Hembree
F. B. Kovacs
J. F. Manning
W. C. McGaughey
R. D. McGuire

Page xvii

Subgroup on General Requirements/Personnel Qualifications and Inquiries (SC V)

R D. McGuire, *Chair*
J. E. Batey
W. T. Clayton
N. Y. Faransso
H. C. Graber
G. W. Hembree
J. R. MacKay
J. P. Swezy

Subgroup on Surface Examination Methods (SC V)

H. C. Graber, *Chair*

S. J. Akrin

T. Alexander

A. S. Birks

B. H. Clark

R. A. Coomes

G. W. Hembree

Subgroup on Volumetric Methods (SC V)

J. E. Batey, *Chair*

S. J. Akrin

W. T. Clayton

N. Y. Faransso

H. C. Graber

G. W. Hembree

B. Kellerhall

E. K. Kietzman

F. B. Kovacs

R. W. Kruzic

J. F. Manning

W. C. McGaughey

J. R. Mitchell

Working Group on Acoustic Emissions (SG-VM) (SC V)

B. H. Clark, Jr.

P. M. Horrigan

J. F. Manning

J. R. Mitchell

Working Group on Radiography (SG-VM) (SC V)

G. W. Hembree, *Chair*

S. J. Akrin

T. Alexander

J. E. Batey

N. Y. Faransso

H. C. Graber

F. B. Kovacs

Working Group on Ultrasonics (SG-VM) (SC V)

W. T. Clayton, *Chair*

O. F. Hedden
B. Kellerhall
E. K. Kietzman
J. F. Manning
W. C. McGaughey
R. Paillaman
F. J. Sattler
M. L. Shakinovsky

SUBCOMMITTEE ON PRESSURE VESSELS (SC VIII)

T. P. Pastor, *Chair*
K. Mokhtarian, *Vice Chair*
A. J. Roby, *Secretary*
A. P. Ahrendt
V. Bogosian
S. M. Caldwell
W. J. Carter
S. C. Cyr
R. Dirscherl
R. M. Elliott
J. R. Farr
R. E. Feigel
J. G. Feldstein
G. L. Hollinger
M. J. Houle
W. S. Jacobs
G. G. Karcher
G. B. Komora
K. T. Lau
R. W. Mikitka
U. R. Miller
C. C. Neely
K. J. Schneider
A. Selz
J. R. Sims, Jr.
A. J. Spencer
E. A. Steen
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Design (SC VIII)

U. R. Miller, *Chair*
R. E. Knoblock, *Secretary*
M. R. Bauman
M. R. Breach

S. M. Caldwell
N. W. Edwards
J. R. Farr
J. A. Hayward
G. L. Hollinger
W. S. Jacobs
G. G. Karcher
G. B. Komora
R. W. Mikitka
K. Mokhtarian
T. P. Pastor
M. D. Rana
A. Selz
S. C. Shah
J. W. Stokes
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Fabrication and Inspection (SC VIII)

E. A. Steen, *Chair*
K. Mokhtarian, *Vice Chair*
W. J. Bees
R. W. Boyce
S. C. Cyr
R. E. Feigel
H. E. Gordon
M. J. Houle
W. S. Jacobs
R. A. Johnson
A. S. Lester III
F. C. Ouyang
M. J. Rice
W. P. Webb

Subgroup on General Requirements (SC VIII)

R. M. Elliott, *Chair*
A. P. Ahrendt
V. Bogosian
W. J. Carter
W. P. Crow
J. P. Glaspie
C. R. Good
D. B. Kadakia
J. C. Keenan
W. E. Laveck, Jr.

A. S. Mann
C. C. Neely
A. S. Olivares
K. J. Schneider
A. J. Spencer

Subgroup on Materials (SC VIII)

R. Dirscherl, *Chair*
D. C. Agarwal
A. P. Ahrendt
J. Cameron
W. D. Doty
W. D. Edsall
M. Katcher
W. M. Lundy
E. E. Morgenegg
E. G. Nisbett
J. T. Parsons
D. W. Raho
K. K. Tam
B. K. Thakur

Special Working Group on Heat Transfer Equipment (SC VIII)

G. B. Komora, *Chair*
R. P. Zoldak, *Secretary*
C. F. Andreone
D. E. Bolt
S. M. Caldwell
T. K. Haldas
M. J. Holtz
W. G. Jandrasits
R. Mahadeen
U. R. Miller
F. Osweiller
J. E. Soehrens
A. I. Soler
W. A. Treff
S. Yokell

Page xviii

Special Working Group on High-Pressure Vessels (SC VIII)

J. R. Sims, Jr., *Chair*
P. A. Reddington, *Secretary*
L. P. Antalffy

J. E. Baxter
R. C. Biel
T. B. Boyd
D. J. Burns
P. N. Chaku
E. L. Danfelt
R. E. Feigel
D. M. Fryer
J. L. Heck, Jr.
A. H. Honza
V. T. Hwang
M. M. James
P. Jansson
J. A. Kapp
D. P. Kendall
A. K. Khare
S. C. Mordre
G. J. Mraz
E. H. Perez
L. M. Picqueur
E. D. Roll
W. L. Stewart
J. F. Sullivan
F. W. Tatar

Special Working Group on Toughness (SC VIII)

W. S. Jacobs, *Chair*
J. Cameron
W. D. Doty
D. A. Hansen
G. G. Karcher
G. B. Komora
K. Mokhtarian
J. L. Mooney
C. C. Neely
M. D. Rana
J. W. Stokes

SUBCOMMITTEE ON WELDING (SC IX)

J. G. Feldstein, *Chair*
W. J. Sperko, *Vice Chair*
J. Labrador, *Secretary*
R. Barkdoll
D. A. Bowers
M. L. Carpenter

W. D. Doty
P. D. Flenner
M. J. Houle
R. A. Johnson
W. M. Lundy
R. D. McGuire
J. J. Meyer
A. H. Miller
B. R. Newmark
P. P. Norris
S. D. Reynolds, Jr.
W. K. Scattergood
G. W. Spohn III
M. J. Stanko
J. M. Tanzosh
R. R. Young

Subgroup on Brazing (SC IX)

M. J. Houle, *Chair*
A. S. Artayet
M. L. Carpenter
C. F. Jeerings
A. H. Miller
C. Robino

Subgroup on General Requirements (SC IX)

B. R. Newmark, *Chair*
R. Barkdoll
P. R. Evans
P. C. Filean
R. M. Jessee
D. W. Mann
A. S. Olivares
C. E. Wainwright
R. A. Weiss
K. R. Willens

Subgroup on Materials (SC IX)

M. L. Carpenter, *Chair*
L. P. Connor
P. D. Flenner
R. M. Jessee
A. H. Miller
H. A. Sadler

C. E. Sainz
C. E. Spaeder, Jr.
W. J. Sperko
M. J. Stanko
R. R. Young

Subgroup on Performance Qualification (SC IX)

J. J. Meyer, *Chair*
V. A. Bell
D. A. Bowers
L. P. Connor
R. A. Coomes
P. D. Flenner
G. Herrmann
M. J. Houle
W. M. Lundy
R. D. McGuire
S. R. Nordman
P. P. Norris
W. K. Scattergood
G. W. Spohn III

Subgroup on Procedure Qualification (SC IX)

J. J. Meyer, *Chair*
R. K. Brown, Jr.
R. A. Johnson
A. H. Miller
P. P. Norris
A. S. Olivares
F. C. Ouyang
S. D. Reynolds, Jr.
M. J. Rice
W. K. Scattergood
W. J. Sperko
T. C. Wiesner

SUBCOMMITTEE ON FIBER-REINFORCED PLASTIC PRESSURE VESSELS (SC X)

P. J. Conlisk, *Chair*
D. Eisberg, *Vice Chair*
A. J. Roby, *Secretary*
K. M. Agrawal
F. L. Brown
J. L. Bustillos
T. W. Cowley

T. J. Fowler
S. V. Hoa
L. E. Hunt
J. C. Murphy
A. L. Newberry
D. J. Painter
J. A. Rolston
B. F. Shelley
P. R. Wilt

SUBCOMMITTEE ON NUCLEAR INSERVICE INSPECTION (SC XI)

O. F. Hedden, *Chair*
T. J. Mawson, *Vice Chair*
G. L. Fechter, *Secretary*
C. W. Allison
W. H. Bamford, Jr.
R. L. Beverly
J. M. Bloom
R. W. Boyce
C. D. Cowfer
D. D. Davis
R. L. Dyle
T. N. Epps III
R. E. Gimple
F. E. Gregor
L. B. Gross
K. Iida
C. A. Ireland
R. D. Kerr
D. F. Landers
T. F. Lentz
J. T. Lindberg
G. C. Millman
C. R. Osman
P. C. Riccardella
L. Sage
F. J. Schaaf, Jr.
J. E. Staffiera
R. P. Sullivan
R. W. Swayne
R. J. Tamminga
J. C. Tobin
R. A. Yonekawa

Honorary Members (SC XI)

S. H. Bush
L. J. Chockie
J. P. Houstrup
L. R. Katz
R. R. MacCary

Page xix

Subgroup on Evaluation Standards (SC XI)

W. H. Bamford, Jr., *Chair*
M. Kupinski, *Secretary*
J. M. Bloom
R. C. Cipolla
R. M. Gamble
T. J. Griesbach
P. J. Hijeck
K. Iida
Y. Imamura
J. G. Merkle
S. Ranganath
P. C. Riccardella
D. A. Scarth
W. L. Server
C. A. Tomes
W. A. Van Der Sluys
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa

Working Group on Flaw Evaluation (SG-ES) (SC XI)

R. C. Cipolla, *Chair*
W. H. Bamford, Jr.
M. Basol
J. M. Bloom
E. Friedman
T. J. Griesbach
F. D. Hayes
D. N. Hopkins
K. Iida
Y. Imamura
M. Kupinski
H. S. Mehta
J. G. Merkle
J. S. Panesar
R. K. Qashu

S. Ranganath
D. A. Scarth
T. S. Schurman
W. L. Server
F. A. Simonen
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Working Group on Operating Plant Criteria (SG-ES) (SC XI)

T. J. Griesbach, *Chair*
W. H. Bamford, Jr.
H. Behnke
B. A. Bishop
W. F. Brady
E. Friedman
S. R. Gosselin
E. M. Hackett
P. J. Hijek
S. D. Leshnoff
P. Manbeck
J. S. Panesar
W. E. Pennell
J. H. Phillips
S. Ranganath
S. T. Rosinski
W. L. Server
E. A. Siegel
F. A. Simonen
T. D. Spry
K. K. Yoon
S. Yukawa

Working Group on Pipe Flaw Evaluation (SG-ES) (SC XI)

D. A. Scarth, *Chair*
G. M. Wilkowski, *Secretary*
W. H. Bamford, Jr.
J. M. Bloom
R. C. Cipolla
N. G. Cofie
S. K. Daftuar
G. H. De Boo

E. Friedman
D. N. Hopkins
K. Iida
H. S. Mehta
J. G. Merkle
J. S. Panesar
D. Quinones
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Subgroup on Liquid-Metal-Cooled Systems (SC XI)

C. G. McCargar, *Chair*
W. L. Chase
S. Hattori
R. Hundal
W. Kwant
J. C. Tobin

Working Group on Liquid-Metal Reactor Covers (SG-LMCS) (SC XI)

W. L. Chase, *Chair*
S. Hattori
R. Hundal
W. Kwant

Subgroup on Nondestructive Examination (SC XI)

R. L. Beverly, *Chair*
N. R. Bentley, *Secretary*
D. C. Adamonis
F. L. Becker
F. T. Carr
C. B. Cheezem
W. T. Clayton
C. D. Cowfer
F. J. Dodd
T. N. Epps III
D. O. Henry
M. R. Hum
S. N. Liu
R. D. McGuire
M. C. Modes
C. R. Osman
F. J. Schaaf, Jr.

J. C. Spanner, Jr.

C. J. Wirtz

Working Group on Personnel Qualification and Surface Visual and Eddy Current Examination (SG-NDE) (SC XI)

C. J. Wirtz, *Secretary*

B. L. Curtis

N. Economos

H. B. Garland

D. O. Henry

H. E. Houserman

J. J. McArdle III

R. D. McGuire

S. A. Redner

M. F. Sherwin

A. L. Smith

D. Spake

J. C. Spanner, Sr.

J. C. Spanner, Jr.

T. V. Tran

Working Group on Pressure Testing (SG-NDE) (SC XI)

G. P. Alexander

T. M. Anselmi

T. B. Basso

J. Boughman

T. R. Bugelholl

R. J. Cimoch

C. E. Jensen

W. N. Keisler

D. Lamond

F. J. Schaaf, Jr.

D. Terao

Working Group on Procedure Qualification and Volumetric Examination (SG-NDE) (SC XI)

C. D. Cowfer, *Chair*

C. E. Larsen, *Secretary*

D. C. Adamonis

F. L. Becker

N. R. Bentley

B. Bevins

F. T. Carr

C. B. Cheezem

W. T. Clayton

S. R. Doctor

F. J. Dodd
T. N. Epps III
B. Kellerhall
G. A. Lofthus
J. K. McClanahan
M. C. Modes
M. Saporito
T. T. Taylor
S. M. Walker

Subgroup on Repairs, Replacements, and Modifications (SC XI)

R. E. Gimple, *Chair*
W. C. Holston, *Secretary*
R. W. Boyce
M. N. Bressler
S. B. Brown
C. E. Hartz
R. A. Hermann
C. A. Ireland
R. D. Kerr
D. F. Landers
R. S. Lewis
T. J. Mawson
M. S. McDonald
R. R. Stevenson
R. P. Sullivan
R. W. Swayne
R. E. Tome
D. E. Waskey
R. A. Yonekawa

Page xx

Working Group on Design Reconciliation (SG-RR&M) (SC XI)

W. C. Holston, *Chair*
J. T. Conner, *Secretary*
R. W. Boyce
S. B. Brown
J. E. Charnley
T. E. Hiss
E. V. Imbro
D. N. Irvine, Jr.
D. F. Landers
R. W. Swayne
F. Tehranchi
H. J. Thailer

R. E. Tome

Working Group on Responsibilities and Program Requirements (SG-RR&M) (SC XI)

R. A. Yonekawa, *Chair*

R. R. Stevenson, *Secretary*

S. K. Fisher

G. M. Foster

C. E. Hartz

R. S. Lewis

M. S. McDonald

U. Potapovs

S. M. Swilley

A. J. Walcutt

J. Ghergurovich, *Alternate*

Working Group on Welding and Special Repair Processes (SG-RR&M) (SC XI)

D. E. Waskey, *Chair*

R. E. Cantrell, *Secretary*

D. A. Delsignore

A. L. Finney

P. D. Fisher

A. J. Giannuzzi

R. A. Hermann

R. P. Indap

R. D. Kerr

B. R. Newton

P. P. Norris

J. E. O'Sullivan

J. H. Sodergren

K. R. Willens

Subgroup on Water-Cooled Systems (SC XI)

T. F. Lentz, *Chair*

K. Christian, *Secretary*

C. W. Allison

W. J. Briggs

T. R. Bugelholll

D. D. Davis

A. F. Deardorff

R. L. Dyle

L. B. Gross

T. C. Hinkle

S. D. Kulat

M. P. Lintz

J. E. Staffiera
C. W. Tahnk
R. J. Tamminga
D. Terao
S. M. Walker
R. A. West

Working Group on Concrete Containment (SG-WCS) (SC XI)

W. J. Briggs, *Chair*
B. Talmadge, *Secretary*
H. G. Ashar
K. K. N. Chao
M. J. Ferlisi
H. T. Hill
R. D. Hough
C. N. Krishnaswamy
D. Naus
S. C. Petitgout
C. G. Ranganath

Working Group on Implementation of Risk-Based Examination (SG-WCS) (SC XI)

T. J. Mawson, *Chair*
A. McNeill III, *Secretary*
J. Agold
S. A. Ali
B. A. Bishop
J. W. Connor
A. F. Deardorff
H. Q. Do
R. Fougrousse
S. R. Gosselin
J. T. Lindberg
I. Mach
R. K. Mattu
P. J. O'Regan
J. H. Phillips
F. A. Simonen
T. V. Vo
R. A. West

Working Group on Inspection of Systems and Components (SG-WCS) (SC XI)

R. L. Dyle, *Chair*
G. C. Park, *Secretary*
G. L. Belew

T. W. Brombach
R. Fougereousse
T. C. Hinkle
M. R. Hum
S. D. Kulat
J. T. Lindberg
M. P. Lintz
T. K. McLellan
C. Pendleton
C. M. Ross
C. W. Tahnk
K. B. Thomas
E. Throckmorton
R. A. West
J. Whitiman

Working Group on Metal Containment (SG-WCS) (SC XI)

J. E. Staffiera, *Chair*
W. E. Norris, *Secretary*
W. J. Briggs
K. K. N. Chao
M. J. Ferlisi
R. W. Hammelmann
M. P. Lintz
S. C. Petitgout
C. G. Ranganath
G. W. Robin
R. T. Zak

Special Working Group on Low-Temperature Heavy Water Reactors (SG-WCS) (SC XI)

C. D. Cowfer, *Chair*
J. M. Morrison, *Secretary*
B. Awadalla
K. F. Schmidt
P. R. Vormelker
S. H. Zaidi

Working Group on General Requirements (SC XI)

A. T. Roberts III, *Chair*
R. G. Edl, *Secretary*
D. A. Graham
L. B. Gross
C. A. Ireland
D. A. Jackson
R. K. Mattu

R. K. Mattu
L. Sage
R. J. Scott
J. C. Shropshire
R. J. Tamminga

Special Working Group on Editing and Review (SC XI)

R. W. Swayne, *Chair*
R. L. Beverly
L. B. Gross
M. P. Lintz
J. E. Staffiera
C. J. Wirtz

Special Working Group on Plant Life Extension (SC XI)

F. E. Gregor, *Chair*
L. B. Gross, *Secretary*
D. D. Davis
D. A. Graham
D. L. Harrison
M. P. Lintz
P. Manbeck
H. W. Massie, Jr.
D. W. Peltola
D. A. Piccione
C. M. Regan
V. N. Shah
R. J. Tamminga

SUBCOMMITTEE ON TRANSPORT TANKS (SC XII)

A. Selz, *Chair*
P. D. Stumpf, *Secretary*
A. N. Antoniou
S. C. Cyr
K. Ennis
M. Hennemand
C. H. Hochman
G. G. Karcher
P. P. Laluc
G. McRae
M. R. Minick
T. P. Pastor
M. D. Rana
C. M. Serratella
G. R. Stoeckinger

N. Surtees
J. P. Swezy
A. P. Varghese
S. V. Voorhees
W. L. White

Page xxi

Subgroup on Design and Materials (SC XII)

M. D. Rana, *Chair*
D. A. Canonico
W. D. Doty
G. G. Karcher
P. P. Laluc
T. P. Pastor
T. A. Rogers
C. M. Serratella
A. P. Varghese
E. Whittle

Subgroup on Fabrication and Inspection (SC XII)

S. V. Voorhees, *Chair*
D. A. Canonico
M. L. Coats
M. Hennemand
D. J. Kreft
G. McRae
M. R. Minick
N. Surtees
J. P. Swezy

Subgroup on General Requirements (SC XII)

C. H. Hochman, *Chair*
T. Alexander
A. N. Antoniou
D. Carter
K. Ennis
M. A. Garrett
J. C. Keenan
F. A. Licari
G. R. Stoeckinger
W. L. White

SUBCOMMITTEE ON BOILER AND PRESSURE VESSEL ACCREDITATION (SC-BPVA)

A. J. Spencer, *Chair*
A. J. Justin, *Vice Chair*
K. I. Baron, *Secretary*
M. B. Doherty
D. A. Douin
P. D. Edwards
R. M. Elliott
C. E. Ford
J. J. Greene
R. C. Howard
B. B. MacDonald
M. L. Sisk
B. C. Turczynski
R. V. Wielgoszinski
R. L. Williams
V. A. Bell, Alternate
V. Bogosian, Alternate
M. A. De Vries, Alternate
J. R. Farr, Alternate
R. G. Friend, Alternate
W. C. LaRochelle, Alternate
A. S. Lester III, Alternate
K. M. McTague, Alternate
G. P. Milley, Alternate
R. E. Muise, Alternate
P. G. Scheckermann, Alternate
N. Surtees, Alternate

SUBCOMMITTEE ON NUCLEAR ACCREDITATION (SC-NA)

T. E. Quaka, *Chair*
R. R. Stevenson, *Vice Chair*
S. Griffin, *Secretary*
C. W. Allison
M. N. Bressler
G. Deily
F. R. Drahos
J. E. Harris
M. Kotb
W. C. LaRochelle
U. Potapovs
H. B. Prasse
A. J. Spencer
G. M. Tolson
L. M. Beason, Alternate
R. W. Boyce, Alternate
S. Dasgupta, Alternate

P. D. Edwards, Alternate
J. P. Ellenberger, Alternate
R. E. Feigel, Alternate
D. Hanrath, Alternate
K. A. Huber, Alternate
A. J. Justin, Alternate
N. C. Kist, Alternate
A. A. Lotfi, Alternate
R. P. McIntyre, Alternate
O. E. Trapp, Staff Representative

SUBCOMMITTEE ON DESIGN (SC-D)

W. J. Carter, *Chair*
F. S. Fitzgerald, *Secretary*
R. W. Barnes
C. Becht IV
O. F. Hedden
R. W. Mikitka
K. Mokhtarian
W. J. O'Donnell
R. D. Schueler, Jr.
M. P. Schwartz
A. Selz

Subgroup on Design Analysis (SC-D)

T. P. Pastor, *Secretary*
P. J. Conlisk
A. G. Eggers
J. L. Hechmer
G. L. Hollinger
D. P. Jones
A. Kalnins
W. J. Koves
T. H. Liu
O. Maekawa
A. Merend
T. V. Narayanan
E. L. Thomas, Jr.

Subgroup on Elevated Temperature Design (SC-D)

C. Becht IV, *Chair*
J. M. Corum, *Secretary*
C. R. Brinkman
R. D. Campbell

D. S. Griffin
R. I. Jetter
C. Lawton
W. J. O'Donnell
D. A. Osage
C. C. Schultz, Jr.
L. K. Severud
D. F. Shaw
A. L. Snow
B. E. Thurgood

Subgroup on Fatigue Strength (SC-D)

C. R. Brinkman
P. R. Donavin
J. A. Hayward
J. L. Hechmer
D. P. Jones
G. Kharshafdjian
C. Lawton
A. Merend
H. H. Ziada

Subgroup on Openings (SC-D)

M. P. Schwartz, *Chair*
R. W. Mikitka, *Secretary*
M. R. Breach
V. T. Hwang
S. C. Lou
R. B. Luney
J. P. Madden
K. C. Morrison
D. R. Palmer
M. D. Rana
E. C. Rodabaugh

Special Working Group on Bolted Flanged Joints (SC-D)

R. W. Mikitka, *Chair*
G. D. Bibel
G. Kharshafdjian
D. L. Kurle
E. Michalopoulos
S. N. Pagay
J. R. Payne
R. W. Schneider

R. D. Schueler, Jr.

A. Selz

SUBCOMMITTEE ON SAFETY VALVE REQUIREMENTS (SC-SVR)

E. C. Kistner, Jr., *Chair*

M. D. Bernstein, *Vice Chair*

U. D'Urso, *Secretary*

J. F. Ball

J. A. Cox

R. D. Danzy

R. J. Doelling

D. A. Douin

R. G. Friend

H. I. Gregg

S. F. Harrison, Jr.

C. F. Laitner

H. D. Michael

C. A. Neumann

J. W. Reynolds

M. Robinson

D. J. Scallan

C. M. Schroepfer

A. J. Spencer

J. C. Standfast

E. A. Steen

L. L. Thompson

J. A. West

T. J. Ferrigan, *Alternate*

Page xxii

Subgroup on Design (SC-SVR)

R. G. Friend, *Chair*

J. Cahoon, Jr.

R. D. Danzy

D. B. DeMichael

R. J. Doelling

H. I. Gregg

S. R. Irvin

C. F. Laitner

P. R. Sievert

A. J. Spencer

E. A. Steen

T. R. Tarbay

J. A. West

Subgroup on General Requirements (SC-SVR)

M. D. Bernstein, *Chair*

J. F. Ball

V. M. Deluca

D. A. Douin

H. D. Michael

C. A. Neumann

J. W. Reynolds

M. Robinson

J. C. Standfast

L. L. Thompson

Subgroup on Testing (SC-SVR)

S. F. Harrison, Jr., *Chair*

S. Cammeresi

J. A. Cox

W. F. Hart

D. M. Papa

D. J. Scallan

C. M. Schroepfer

D. E. Snyder

Page xxiii

ORGANIZATION OF SECTION III

1. GENERAL

Section III consists of Division 1, Division 2, and Division 3. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter "N" for Division 1, by the letter "C" for Division 2, and by the letter "W" for Division 3. The following eleven books make up the three Divisions.

Subsection NCA - General Requirements for Division 1 and Division 2

Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

Division 2 - Code for Concrete Reactor Vessels and Containments

Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

The Division 2 book includes Subsection CC - Concrete Containments and Division 2 Appendices.

The Division 3 book includes Subsections WA and WB for General Requirements and Class TP (Type B) Containment, respectively.

2. SUBSECTIONS

Subsections are divided into Articles, Subarticles, paragraphs, and, where necessary, subparagraphs and subsubparagraphs.

3. ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections followed by Arabic numbers, such as NB-1000. Where possible, Articles dealing with the same topics are given the same number in each Subsection in accordance with the following general scheme:

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination
6000	Testing
7000	Overpressure Protection
8000	Nameplates, Stamping, and Reports

The numbering of Articles and the material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the rules have been prepared with some gaps in the numbering.

4. SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

5. SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as NB-2130, and generally have no text. When a number such as NB-1110 is followed by text, it is considered a paragraph.

6. PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

7. SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as NB-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

8. SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

References used within Section III generally fall into one of the following four categories.

A. References to Other Portions of Section III

When a reference is made to another Article, Subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to NB-3000 includes all material in Article NB-3000; reference to NB-3200 includes all material in Subarticle NB-3200; reference to NB-3230 includes all paragraphs NB-3231 through NB-3236.

B. References to Other Sections

Other Sections referred to in Section III are:

Section II, Materials. When a requirement for a material, or for the examination or testing of a material, is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II. These references begin with the letter "S."

Section V, Nondestructive Examination. Section V references begin with the letter "T" and relate to the nondestructive examination of material or welds.

Section IX, Welding and Brazing Qualifications. Section IX references begin with the letter "Q" and relate to welding and brazing requirements.

Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components. When a reference is made to inservice inspection, the rules of Section XI shall apply.

C. Reference to Specifications and Standards Other Than Published in Code Sections

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials. At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E71-64 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

2 The American National Standards Institute (ANSI) was formerly known as the American Standards Association. Standards approved by the Association were designated by the prefix "ASA" followed by the number of the standard and the year of publication. More recently, the American National Standards Institute was known as the United States of America Standards Institute. Standards were designated by the prefix "USAS" followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the numbers of the standards have remained unchanged.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by the American Society of Mechanical Engineers and approved by the American National Standards Institute.² When a product is to conform to such a standard, for example ANSI B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NB-3132-1, for example ANSI B16.5-1977. Standards published by the American Society of Mechanical Engineers are available from ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-6, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, 127 Park Street, N.E., Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NB-3132-1, for example MSS SP-6-1963.

(4) Specifications for welding and brazing materials are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33135. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix "SF," for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-620 and API-2000. When documents so designated are referred to in Section III, they are standards published by the American Petroleum Institute.

D. References to Appendices

Two types of Appendices are used in Section III and are designated Mandatory and Nonmandatory.

(1) Mandatory Appendices contain requirements which must be followed in construction; such references are designated by a Roman numeral followed by Arabic numerals. References to II-1100 or XI-3212, for example, relate to the Mandatory Appendices.

(2) Nonmandatory Appendices provide information or guidance for the use of Section III; such references are designated by a capital letter followed by Arabic numerals. A reference to D-1100, for example, relates to a Nonmandatory Appendix.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NB-1000

ARTICLE NB-1000 INTRODUCTION

Page 1

NB-1100 SCOPE

NB-1110 ASPECTS OF CONSTRUCTION COVERED BY THESE RULES

(a) Subsection NB contains rules for the material, design, fabrication, examination, testing, overpressure relief, marking, stamping, and preparation of reports by the Certificate Holder of items which are intended to conform to the requirements for Class 1 construction.

(b) The rules of Subsection NB cover the requirements for strength and pressure integrity of items, the failure of which would violate the pressure-retaining boundary. The rules cover initial construction requirements, but do not cover deterioration which may occur in service as a result of corrosion, radiation effects, or instability of material. NCA-1130 gives further limitations to the rules of this Subsection.

NB-1120 TEMPERATURE LIMITS

The rules of Subsection NB shall not be used for items which are to be subjected to metal temperatures other than those for which design stress intensity values are given in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4. Above those temperatures, the creep and stress rupture characteristics of materials permitted to be used become significant factors which are not presently covered by the rules of this Subsection. Fatigue design curves and specified methods for fatigue analysis are not applicable above 700°F (371°C) for materials covered by Figs. I-9.1 and I-9.4, and above 800°F (427°C) for materials covered by Figs. I-9.2 and I-9.3.

NB-1130 BOUNDARIES OF JURISDICTION APPLICABLE TO THIS SUBSECTION

NB-1131 Boundary of Components

The Design Specification shall define the boundary of a component to which piping or another component is attached. The boundary shall not be closer to a vessel, tank, pump, or valve than:

- (a) the first circumferential joint in welded connections (the connecting weld shall be considered part of the piping);
- (b) the face of the first flange in bolted connections (the bolts shall be considered part of the piping);
- (c) the first threaded joint in screwed connections.

NB-1132 Boundary Between Components and Attachments

NB-1132.1 Attachments

(a) An *attachment* is an element in contact with or connected to the inside or outside of the pressure-retaining portion of a component.

(b) Attachments may have either a pressure-retaining or a nonpressure-retaining function.

(1) Attachments with a pressure-retaining function include items such as pressure boundary stiffeners, and branch pipe and vessel opening reinforcement.

(2) Attachments with a nonpressure-retaining function include items such as:

(a) valve guides, thermal sleeves, and turning vanes;

(b) core support structures, internal structures, or other permanent structures within the reactor pressure vessel; and

(c) vessel saddles, support and shear lugs, brackets, pipe clamps, trunnions, skirts, and other items in the support load path.

(c) Attachments may also have either a structural or nonstructural function.

Page 4

(1) Attachments with a structural function (structural attachments):

(a) perform a pressure-retaining function;

(b) are core support structures, internal structures, or other permanent structures within the reactor pressure vessel; or

(c) are in the support load path.

(2) Attachments with a nonstructural function (nonstructural attachments):

(a) do not perform a pressure-retaining function;

(b) are not in the support load path.

Nonstructural attachments include items such as name-plates, insulation supports, and locating and lifting lugs.

NB-1132.2 Jurisdictional Boundary.

The jurisdictional boundary between a pressure-retaining component and an attachment defined in the Design Specification shall not be any closer to the pressure-retaining portion of the component than as defined in (a) through (g) below. Figures NB-1132.2-1 through NB-1132.2-3 are provided as an aid in defining the boundary and construction requirements of this Subsection.

(a) Attachments cast or forged with the component and weld buildup on the component surface shall be considered part of the component.

(b) Attachments, welds, and fasteners having a pressure-retaining function shall be considered part of the component.

(c) Except as provided in (d) and (e) below, the boundary between a pressure-retaining component and an attachment not having a pressure-retaining function shall be at the surface of the component.

(d) The first connecting weld of a nonpressure-retaining structural attachment to a component shall be considered part of the component unless the weld is more than $2t$ from the pressure-retaining portion of the component, where t is the nominal thickness of the pressure-retaining material. Beyond $2t$ from the pressure-retaining portion of the component, the first weld shall be considered part of the attachment.

(e) The first connecting weld of a welded nonstructural attachment to a component shall be considered part of the attachment. At or within $2t$ from the pressure-retaining portion of the component, the first connecting weld shall conform to NB-4430.

(f) Mechanical fasteners used to connect a nonpressure-retaining attachment to the component shall be considered part of the attachment.

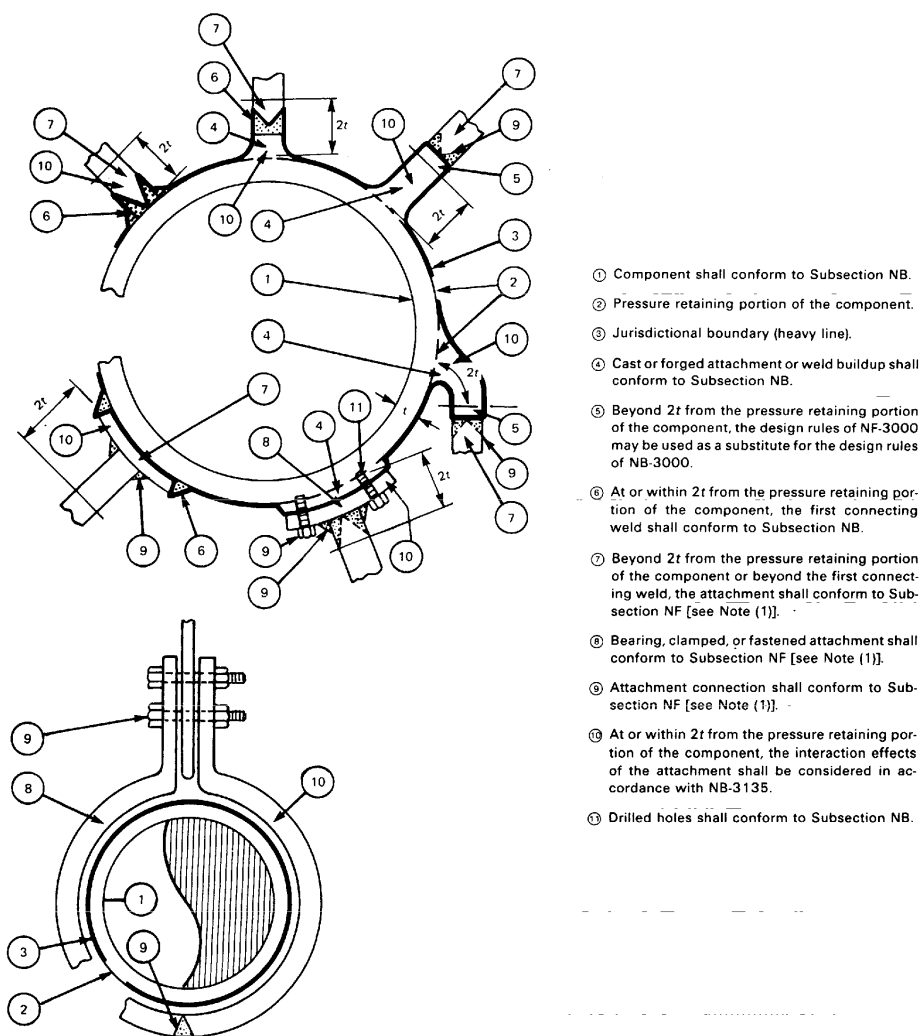
(g) The boundary may be located further from the pressure-retaining portion of the component than as defined in (a) through (f) above when specified in the Design Specification.

NB-1140 ELECTRICAL AND MECHANICAL PENETRATION ASSEMBLIES

Electrical and mechanical penetration assemblies shall be constructed in accordance with the rules for vessels, except that the design and the material performing the electrical conducting and insulating functions need not meet the requirements of this Subsection.

Page 5

Page 6



GENERAL NOTE:

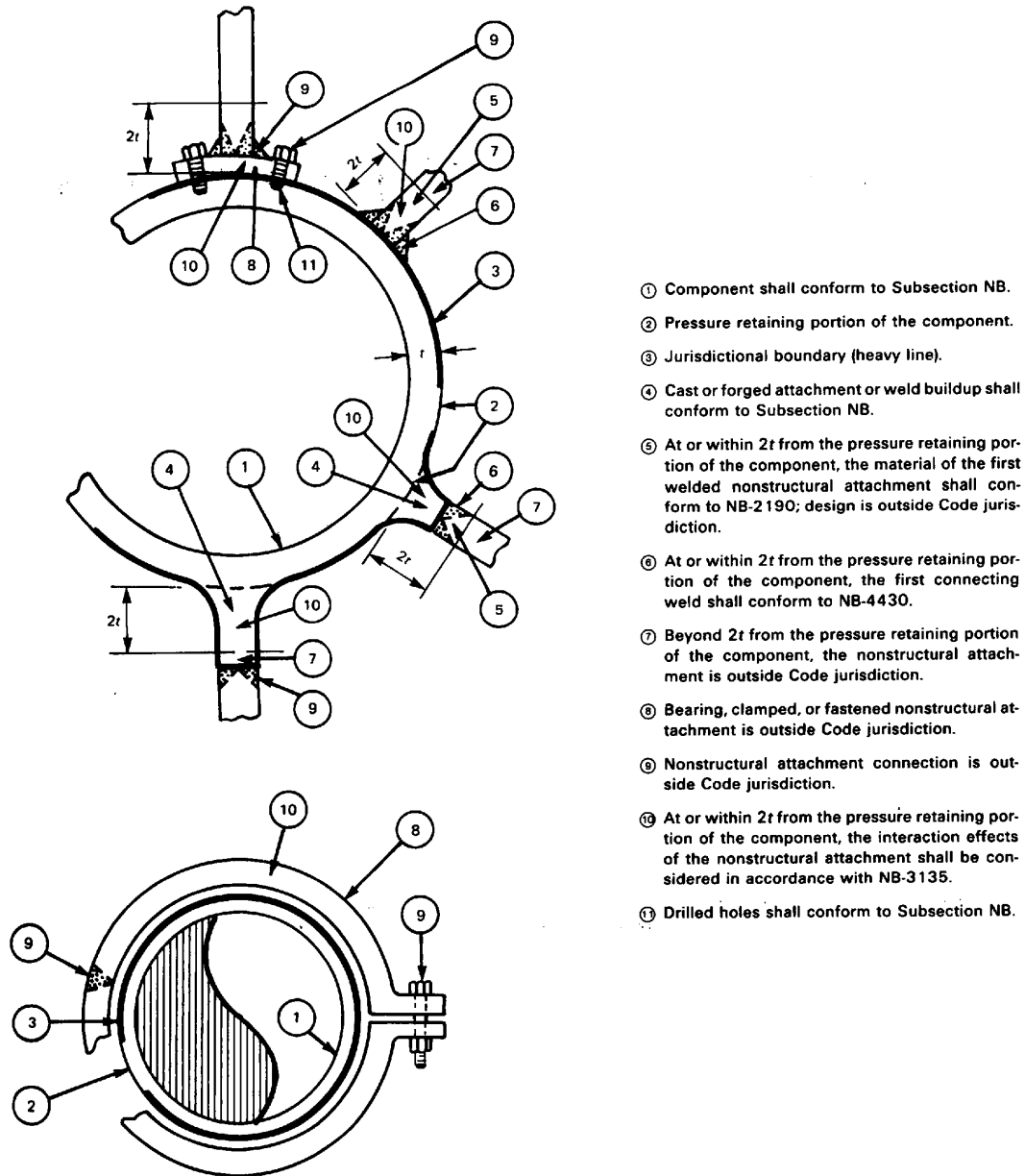
These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

NOTE:

(1) If the attachment is an intervening element [NF-1110(c)], material, design, and connections, as appropriate, are outside Code jurisdiction.

FIG. NB-1132.2-1 ATTACHMENTS IN THE COMPONENT SUPPORT LOAD PATH THAT DO NOT PERFORM A PRESSURE-RETAINING FUNCTION

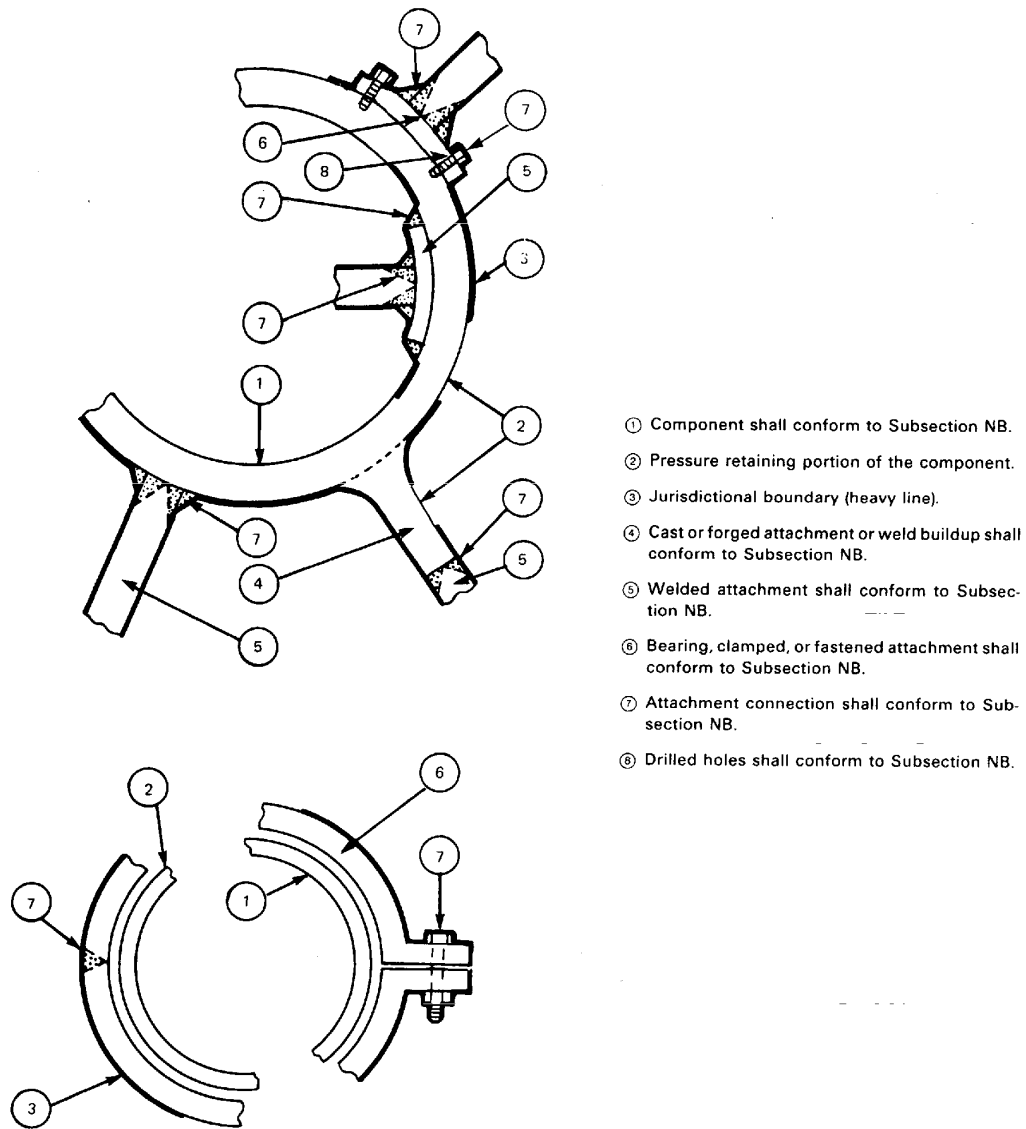
FIG. NB-1132.2-1 ATTACHMENTS IN THE COMPONENT SUPPORT LOAD PATH THAT DO NOT PERFORM A PRESSURE-RETAINING FUNCTION



GENERAL NOTE:

These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

FIG. NB-1132.2-2 ATTACHMENTS THAT DO NOT PERFORM A PRESSURE-RETAINING FUNCTION AND ARE NOT IN THE COMPONENT SUPPORT LOAD PATH (NONSTRUCTURAL ATTACHMENTS)



GENERAL NOTE:
These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

FIG. NB-1132.2-3 ATTACHMENTS THAT PERFORM A PRESSURE-RETAINING FUNCTION

FIG. NB-1132.2-3 ATTACHMENTS THAT PERFORM A PRESSURE-RETAINING FUNCTION

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NB-2000

ARTICLE NB-2000 MATERIAL

Page 9

NB-2100 GENERAL REQUIREMENTS FOR MATERIAL

NB-2110 SCOPE OF PRINCIPAL TERMS EMPLOYED

(a) The term *material* as used in this Subsection is defined in NCA-1220. The term *Material Organization* is defined in NCA-9000.

(b) The term *pressure-retaining material* as used in this Subsection applies to items such as vessel shells, heads, and nozzles; pipes, tubes, and fittings; valve bodies, bonnets, and disks; pump casings and covers; and bolting which joins pressure-retaining items.

(c) The requirements of this Article make reference to the term *thickness*. For the purpose intended, the following definitions of nominal thickness apply.

(1) *plate* - the thickness is the dimension of the short transverse direction

(2) *forgings* - the thickness is the dimension defined as follows:

(a) *hollow forgings* - the nominal thickness is measured between the inside and outside surfaces (radial thickness)

(b) *disk forgings* (axial length less than the outside diameter) - the nominal thickness is the axial length

(c) *flat ring forgings* (axial length less than the radial thickness) - for axial length ≤ 2 in. (51 mm), the axial length is the nominal thickness. For axial length > 2 in. (51 mm), the radial thickness is the nominal thickness.

(d) *rectangular solid forgings* - the least rectangular dimension is the nominal thickness

(3) *castings*

(a) Thickness t for fracture toughness testing is defined as the nominal pipe wall thickness of the connecting piping.

(b) Thickness t for heat treatment purposes is defined as the thickness of the pressure-retaining wall of the casting, excluding flanges and sections designated by the designer as nonpressure retaining.

NB-2120 PRESSURE-RETAINING MATERIAL

NB-2121 Permitted Material Specifications

(a) Pressure-retaining material shall conform to the requirements of one of the specifications for material given in Section II, Part D, Subpart 1, Tables 2A and 2B, and to all of the requirements of this Article which apply to the product form in which the material is used.

(b) The requirements of this Article do not apply to material for items not associated with the pressure-retaining function of a component, such as shafts, stems, trim, spray nozzles, bearings, bushings, springs, and wear plates, nor to seals, packing, gaskets, valve seats, and ceramic insulating material and special alloys used as seal material in electrical penetration assemblies.

(c) Material made to specifications other than those specified in Section II, Part D, Subpart 1, Tables 2A and 2B may be used for the following applications:

- (1) Safety valve disks and nozzles, when the nozzles are internally contained by the external body structure;
- (2) control valve disks and cages, when the valves function for flow control only;
- (3) line valve disks in valves whose inlet connections are NPS 2 (DN 50) and smaller.

(d) Material for instrument line fittings, 1 in. nominal pipe size (DN 25) and less, may be of material made to specifications other than those listed in Section II, Part D, Subpart 1, Tables 2A and 2B, provided that the fittings are in conformance with the requirements of NB-3671.4 and the material is determined to be adequate for the service conditions by the piping system designer.

(e) Welding and brazing material used in the manufacture of items shall comply with an SFA specification in Section II, Part C, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article. The requirements of this Article do not apply to material used as backing rings or backing strips in welded joints.

Page 16

(f) The requirements of this Article do not apply to hard surfacing or corrosion resistant weld metal overlay which is 10% or less of the thickness of the base material (NB-3122).

NB-2122 Special Requirements Conflicting With Permitted Material Specifications

Special requirements stipulated in this Article shall apply in lieu of the requirements of the material specification wherever the special requirements conflict with the material specification requirements (NCA-3856). Where the special requirements include an examination, test, or treatment which is also required by the material specification, the examination, test, or treatment need be performed only once. Required nondestructive examinations shall be performed as specified for each product form in NB-2500. Any examination, repair, test, or treatment required by the material specification or by this Article may be performed by the Material Organization or the Certificate Holder as provided in NB-4121. Any hydrostatic or pneumatic pressure test required by a material specification need not be performed, provided the material is identified as not having been pressure tested and it is subsequently pressure tested in the system in accordance with NB-6114, except where the location of the material in the component or the installation would prevent performing any nondestructive examination required by the material specification to be performed subsequent to the hydrostatic or pneumatic test.

NB-2124 Size Ranges

Material outside the limits of size or thickness given in any specification in Section II may be used if the material is in compliance with the other requirements of the specification and no size limitation is given in the rules for construction. In those specifications in which chemical composition or mechanical properties are indicated to vary with size or thickness, any material outside the specification range shall be required to conform to the composition and mechanical properties shown for the nearest specified range (NCA-3856).

NB-2125 Fabricated Hubbed Flanges

Fabricated hubbed flanges shall be in accordance with the following.

(a) Hubbed flanges may be machined from a hot rolled or forged billet. The axis of the finished flange shall be parallel to the long axis of the original billet. (This is not intended to imply that the axis of the finished flange and the original billet must be concentric.)

(b) Hubbed flanges, except as permitted in (a) above, shall not be machined from plate or bar stock material unless the material has been formed into a ring, and further provided that:

- (1) in a ring formed from plate, the original plate surfaces are parallel to the axis of the finished flange (this is not intended to imply that the original plate surface must be present in the finished flange);
- (2) the joints in the ring are welded butt joints that conform to the requirements of this Section. Thickness to be used to

determine postweld heat treatment and radiography requirements shall be the lesser of t , or $(A - B)/2$, where these symbols are as defined in XI-3130.

(c) The back of the flange and the outer surface of the hub shall be examined by the magnetic particle method or the liquid penetrant method in accordance with NB-2540 to ensure that these surfaces are free from defects.

NB-2126 Integrally Finned Tubes

Integrally finned tubes may be made from tubes that conform to one of the specifications for tubes listed in Section II, Part D, Subpart 1, Tables 2A and 2B, and to all of the special requirements of this Article which apply to that product form. In addition, the following requirements shall apply.

(a) The requirements of NB-2550 shall be met by the tube before finning.

(b) The tubes after finning shall conform to the applicable heat treatment requirements of the basic material specification.

(c) The design stress intensity values, design values of yield strength, and tensile strength values shall be those given in Section II, Part D, Subpart 1, Tables 2A and 2B, and Subpart 2, Tables Y-1, Y-2, and U, respectively, for the tube material from which the finned tube is made.

(d) After finning, each tube shall be subjected to one of the following tests:

(1) an internal pneumatic pressure test at not less than 250 psi without evidence of leakage. The test method, such as immersion of the tube underwater during the test, shall permit visual detection of any leakage.

(2) an individual tube hydrostatic test at 1.25 times the Design Pressure which permits complete examination of the tube for leakage.

Page 17

(e) A visual examination shall be performed after finning. Material having discontinuities, such as laps, seams, or cracks, is unacceptable.

NB-2127 Seal Membrane Material

Seal membrane material (NB-4360) shall conform to the requirements of one of the material specifications listed in Section II, Part D, Subpart 1, Tables 2A and 2B. The requirements of NB-2500 are applicable for the appropriate product form when the material thickness is greater than $\frac{1}{4}$ in. (6 mm).

NB-2128 Bolting Material

(a) Material for bolts and studs shall conform to the requirements of one of the specifications listed in Section II, Part D, Subpart 1, Table 4. Material for nuts shall conform to SA-194 or to the requirements of one of the specifications for nuts or bolting listed in Section II, Part D, Subpart 1, Table 4.

(b) The use of washers is optional. When used, they shall be made of wrought material with mechanical properties compatible with the nuts with which they are to be employed.

NB-2130 CERTIFICATION OF MATERIAL

All material used in construction of components shall be certified as required in NCA-3862 and NCA-3861. Certified Material Test Reports are required for pressure-retaining material except as provided by NCA-3861. A Certificate of Compliance may be provided in lieu of a Certified Material Test Report for all other material. Copies of all Certified Material Test Reports and Certificates of Compliance applicable to material used in a component shall be furnished with the material.

NB-2140 WELDING MATERIAL

For the requirements governing the material to be used for welding, see NB-2400.

NB-2150 MATERIAL IDENTIFICATION

The identification of pressure-retaining material and materials welded thereto shall meet the requirements of NCA-3856. Material for small items shall be controlled during manufacture and installation of a component so that they are identifiable as acceptable material at all times. Welding and brazing material shall be controlled during the repair of material and the manufacture and installation so that they are identifiable as acceptable until the material is actually consumed in the process (NB-4122).

NB-2160 DETERIORATION OF MATERIAL IN SERVICE

Consideration of deterioration of material caused by service is generally outside the scope of this Subsection. It is the responsibility of the Owner to select material suitable for the conditions stated in the Design Specifications (NCA-3250), with specific attention being given to the effects of service conditions upon the properties of the material. Special consideration shall be given to the influence of elements such as copper and phosphorus on the effects of irradiation on the properties of material (including welding material) in the core belt line region of the reactor vessel. Any special requirement shall be specified in the Design Specifications (NCA-3252 and NB-3124). When so specified, the check analysis shall be made in accordance with the base metal specification and in accordance with NB-2420 for the welding material.

NB-2170 HEAT TREATMENT TO ENHANCE IMPACT PROPERTIES

Carbon steels, low alloy steels, and high alloy chromium (Series 4XX) steels may be heat treated by quenching and tempering to enhance their impact properties. Postweld heat treatment of the component at a temperature of not less than 1100°F (593°C) may be considered to be the tempering phase of the heat treatment.

NB-2180 PROCEDURES FOR HEAT TREATMENT OF MATERIAL

When heat treating temperature or time is required by the material specification and the rules of this Subsection, the heat treating shall be performed in temperature-surveyed and -calibrated furnaces or the heat treating shall be controlled by measurement of material temperature by thermocouples in contact with the material or attached to blocks in contact with the material or by calibrated pyrometric instruments. Heat treating shall be performed under furnace loading conditions such that the heat treatment is in accordance with the material specification and the rules of this Subsection.

Page 18

NB-2190 NONPRESSURE-RETAINING MATERIAL

(a) Material in the component support load path and not performing a pressure-retaining function (see NB-1130) welded to pressure-retaining material shall meet the requirements of NF-2000.

(b) Material not performing a pressure-retaining function and not in the component support load path (nonstructural attachments) welded at or within $2t$ of the pressure-retaining portion of the component need not comply with NB-2000 or NF-2000 provided the requirements of NB-4430 are met.

(c) Structural steel rolled shapes, which are permitted by this Subsection to be furnished with a Certificate of Compliance, may be repaired by welding using the welders, documentation, and examination requirements specified in SA-6.

NB-2200 MATERIAL TEST COUPONS AND SPECIMENS FOR FERRITIC STEEL MATERIAL

NB-2210 HEAT TREATMENT REQUIREMENTS

NB-2211 Test Coupon Heat Treatment for Ferritic Material¹

Where ferritic steel material is subjected to heat treatment during fabrication or installation of a component, the material used for the tensile and impact test specimens shall be heat treated in the same manner as the component, except that test coupons and specimens for P-No. 1 material with a nominal thickness of 2 in. (51 mm) or less are not required to be so heat treated. The Certificate Holder shall provide the Material Organization with the temperature and heating and cooling rate to be used. In the case of postweld heat treatment, the total time at temperature or temperatures for the test material shall be at least 80% of the total time at temperature or temperatures during actual postweld heat treatment of the material,

and the total time at temperature or temperatures for the test material, coupon, or specimen may be performed in a single cycle.

1 Any postweld heat treatment time which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

NB-2212 Test Coupon Heat Treatment for Quenched and Tempered Material

NB-2212.1 Cooling Rates.

Where ferritic steel material is subjected to quenching from the austenitizing temperature, the test coupons representing that material shall be cooled at a rate similar to and no faster than the main body of the material except in the case of certain forgings and castings (NB-2223.2 and NB-2226). This rule shall apply to coupons taken directly from the material as well as to separate test coupons representing the material, and one of the general procedures described in NB-2212.2 or one of the specific procedures described in NB-2220 shall be used for each product form.

NB-2212.2 General Procedures.

One of the general procedures stipulated in (a), (b), and (c) below may be applied to quenched and tempered material or test coupons representing the material, provided the specimens are taken relative to the surface of the product in accordance with NB-2220. Further specific details of the methods to be used shall be the obligation of the Material Organization and the Certificate Holder.

(a) Any procedure may be used which can be demonstrated to produce a cooling rate in the test material which matches the cooling rate of the main body of the product at the region midway between midthickness and the surface ($\frac{1}{4}t$) and no nearer any heat-treated edge than a distance equal to the nominal thickness t being quenched within 25°F and 20 sec at all temperatures after cooling begins from the austenitizing temperature.

(b) If cooling rate data for the material and cooling rate control devices for the test specimens are available, the test specimens may be heat treated in the device to represent the material, provided that the provisions of (a) above are met.

(c) When any of the specific procedures described in NB-2220 are used, faster cooling rates at the edges may be compensated for by:

(1) taking the test specimens at least t from a quenched edge, where t equals the material thickness;

(2) attaching a steel pad at least t wide by a partial penetration weld (which completely seals the buffered surface) to the edge where specimens are to be removed; or

(3) using thermal barriers or insulation at the edge where specimens are to be removed.

It shall be demonstrated (and this information shall be included in the Certified Material Test Report) that the cooling rates are equivalent to (a) or (b) above.

Page 19

NB-2220 PROCEDURE FOR OBTAINING TEST COUPONS AND SPECIMENS FOR QUENCHED AND TEMPERED MATERIAL

NB-2221 General Requirements

The procedure for obtaining test coupons and specimens for quenched and tempered material is related to the product form. Coupon and specimen location and the number of tension test specimens shall be in accordance with the material specifications, except as required by the following paragraphs. References to dimensions signify nominal values.

NB-2222 Plates

NB-2222.1 Number of Tension Test Coupons.

The number of tension test coupons required shall be in accordance with the material specification and with SA-20,

except that from carbon steel plates weighing 42,000 lb and over and alloy steel plates weighing 40,000 lb and over, two tension test coupons shall be taken, one representing the top end of the plate and one representing the bottom end of the plate.

NB-2222.2 Orientation and Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from a rolled surface and with the midlength of the specimen at least t from any heat-treated edge, where t is the nominal thickness of the material.

NB-2222.3 Requirements for Separate Test Coupons.

Where a separate test coupon is used to represent the component material, it shall be of sufficient size to ensure that the cooling rate of the region from which the test coupons are removed represents the cooling rate of the material at least $\frac{1}{4}t$ deep and t from any edge of the product. Unless cooling rates applicable to the bulk pieces or product are simulated in accordance with NB-2212.2(b), the dimensions of the coupon shall be not less than $3t \times 3t \times t$, where t is the nominal material thickness.

NB-2223 Forgings

NB-2223.1 Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from any surface and with the midlength of the specimens at least t from any second surface, where t is the maximum heat-treated thickness. A thermal buffer as described in NB-2212.2(c) may be used to achieve these conditions, unless cooling rates applicable to the bulk forgings are simulated as otherwise provided in NB-2212.2.

NB-2223.2 Very Thick and Complex Forgings.

Test coupons for forgings which are both very thick and complex, such as contour nozzles, thick tubesheets, flanges, nozzles, pump and valve bodies, and other complex forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment may be removed from prolongations or other stock provided on the product. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service. The coupons shall be taken so that specimens shall have their longitudinal axes at a distance below the nearest heat-treated surface, equivalent at least to the greatest distance that the indicated high tensile stress surface will be from the nearest surface during heat treatment, and with the midlength of the specimens a minimum of twice this distance from a second heat-treated surface. In any case, the longitudinal axes of the specimens shall not be nearer than $\frac{3}{4}$ in. (19 mm) to any heat-treated surface and the midlength of the specimens shall be at least $1\frac{1}{2}$ in. (38 mm) from any second heat-treated surface.

NB-2223.3 Coupons From Separately Produced Test Forgings.

Test coupons representing forgings from one heat and one heat treatment lot may be taken from a separately forged piece under the conditions given in (a) through (e) below.

(a) The separate test forging shall be of the same heat of material and shall be subjected to substantially the same reduction and working as the production forging it represents.

(b) The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forging.

(c) The separate test forging shall be of the same nominal thickness as the production forging.

(d) Test coupons for simple forgings shall be taken so that specimens shall have their longitudinal axes at the region midway between midthickness and the surface, and with the midlength of the specimens no nearer any heat-treated edge than a distance equal to the forging thickness, except when the thickness-length ratio of the production forging does not permit, in which case a production forging shall be used as the test forging and the midlength of the specimens shall be at the midlength of the test forging.

NB-2223.4 Test Specimens for Forgings.

When test specimens for forgings are to be taken under the applicable specification, the Inspector shall have the option of witnessing the selection, placing an identifying stamping on them, and witnessing the testing of these specimens.

[98]

NB-2224 Bar and Bolting Material

(a) *Bars*. Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside or rolled surface and with the midlength of the specimens at least t from a heat-treated end, where t is either the bar diameter or thickness.

(b) *Bolting*. For bolting materials, tests shall be made of either full-size bolts or test coupons as required by the base specification. The gage length of the tension specimens and the area under the notch of Charpy specimens shall be at least one diameter or thickness from the heat-treated end.

[98]

NB-2225 Tubular Products and Fittings

NB-2225.1 Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the inside or outside surface and with the midlength of the specimens at least t from a heat-treated end, where t is the nominal wall thickness of the tubular product.

NB-2225.2 Separately Produced Coupons Representing Fittings.

Separately produced test coupons representing fittings may be used. When separately produced coupons are used, the requirements of NB-2223.3 shall be met.

NB-2226 Tensile Test Specimen Location (for Quenched and Tempered Ferritic Steel Castings)

NOTE: Users of this requirement should note that the hardenability of some grades may limit the usable section size.

(a) This section applies only to quenched and tempered ferritic steel castings with a thickness t exceeding 2 in. (51 mm) where t is the thickness of the pressure-retaining wall of the casting, excluding flanges and sections designated by the designer as nonpressure-retaining. The order, inquiry, and drawing shall designate what the thickness t is for the casting.

(b) One of the following shall apply.

(1) The longitudinal centering of the thickness of the tension test specimen shall be taken at least $\frac{1}{4}t$ from the t dimension surface. For cylindrical castings, the longitudinal center line of the specimens shall be taken at least $\frac{1}{4}t$ from the outside or inside surface and the gage length at least t from the as-heat-treated end.

(2) Where separately cast test coupons are used, their dimensions shall be not less than $3t \times 3t \times t$ and each specimen cut from it shall meet the requirements of (b)(1) above. The test coupon shall be of the same heat of steel and shall receive substantially the same casting practices as the production casting it represents. (Centrifugal castings may be represented by statically cast coupons.) The test coupon shall be heat treated under the same conditions as the production casting(s). The t dimension of the test coupon shall be the same maximum thickness t as defined in (a) above. Where separate test blocks require reheat treatment, thermal buffers in accordance with (b)(1) above may be used.

(3) Where specimens are to be removed from the body of the casting, a steel, thermal buffer pad $1t \times 1t \times$ at least $3t$ shall be joined to the casting surface by a partial penetration weld completely sealing the buffered surface prior to the heat treatment process. The test specimens shall be removed from the casting in a location adjacent to the center third of the buffer pad. They shall be located at a minimum distance of $\frac{1}{2}$ in. from the buffered surface and $\frac{1}{4}t$ from the other

heat-treated surfaces.

(4) Where specimens are to be removed from the body of the casting, thermal insulation or other thermal barriers shall be used during the heat treatment process adjacent to the casting edge where specimens are to be removed. It shall be demonstrated that the cooling rate of the test specimen is no faster than that of specimens taken by the method described in (b)(1) above. This information shall be included in the test reports.

(5) Where castings are cast or machined to essentially the finished product configuration prior to heat treatment, the test specimens shall be removed from a casting prolongation or other stock on the product at a location below the nearest heat-treated surface indicated on the order. The specimens shall be located with their longitudinal axes a distance below the nearest heat-treated surface equivalent to at least the greatest distance that the indicated high tensile stress surface will be from the nearest heat-treated surface and with their midlength a minimum of twice this distance from a second heat-treated surface. In any case, the longitudinal axes of the test specimens shall be no nearer than $\frac{1}{4}$ in. (6 mm) to a heat-treated surface and the midlength shall be at least $1\frac{1}{2}$ in. (38 mm) from a second heat-treated surface. The component manufacturer shall specify the surfaces of the finished product subjected to high tensile stress in service.

Page 21

NB-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL

NB-2310 MATERIAL TO BE IMPACT TESTED

NB-2311 Material for Which Impact Testing Is Required

(a) Pressure-retaining material and material welded thereto shall be impact tested in accordance with the requirements of this Subarticle, except that the material listed in (1) through (7) below is not to be impact tested as a requirement of this Subsection:

(1) material with a nominal section thickness of $\frac{5}{8}$ in. (16 mm) and less where the thicknesses shall be taken as defined in (a) through (e) below:

(a) for pumps, valves, and fittings, use the largest nominal pipe wall thickness of the connecting pipes;

(b) for vessels and tanks, use the nominal thickness of the shell or head, as applicable;

(c) for nozzles or parts welded to vessels, use the lesser of the vessel shell thickness to which the item is welded or the maximum radial thickness of the item exclusive of integral shell butt welding projections;

(d) for flat heads, tubesheets, or flanges, use the maximum shell thickness associated with the butt welding hub;

(e) for integral fittings used to attach process piping to the containment vessel or a containment vessel nozzle, use the larger nominal thickness of the pipe connections;

(2) bolting, including studs, nuts, and bolts, with a nominal size of 1 in. (25 mm) and less;

(3) bars with a nominal cross-sectional area of 1 sq in. (645 mm²) and less;

(4) all thicknesses of material for a pipe, tube, fittings, pumps, and valves with a nominal pipe size 6 in. diameter and smaller;

(5) material for pumps, valves, and fittings with all pipe connections of $\frac{5}{8}$ in. (16 mm) nominal wall thickness and less;

(6) austenitic stainless steels;

(7) nonferrous material.

(b) Drop weight tests are not required for the martensitic high alloy chromium (Series 4XX) steels and precipitation hardening steels listed in Section II, Part D, Subpart 1, Table 2A. The other requirements of NB-2332 apply for these steels. For nominal wall thicknesses greater than $2\frac{1}{2}$ in. (64 mm), the required Charpy V-notch values shall be 40 mils lateral expansion.

NB-2320 IMPACT TEST PROCEDURES

NB-2321 Types of Tests

NB-2321.1 Drop Weight Tests.

The drop weight test, when required, shall be performed in accordance with ASTM E 208-91. Specimen types P-No. 1, P-No. 2, or P-No. 3 may be used. The results, orientation, and location of all tests performed to meet the requirements of NB-2330 shall be reported in the Certified Material Test Report.

NB-2321.2 Charpy V-Notch Tests.

The Charpy V-notch test (C_v), when required, shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Fig. 11, Type A. A test shall consist of a set of three full-size 10 mm × 10 mm specimens. The lateral expansion and absorbed energy, as applicable, and the test temperature, as well as the orientation and location of all tests performed to meet the requirements of NB-2330 shall be reported in the Certified Material Test Report.

NB-2322 Test Specimens

NB-2322.1 Location of Test Specimens.

Impact test specimens for quenched and tempered material shall be removed from the locations in each product form specified in NB-2220 for tensile test specimens. For material in other heat-treated conditions, impact test specimens shall be removed from the locations specified for tensile test specimens in the material specification. For all material, the number of tests shall be in accordance with NB-2340. For bolting, the C_v impact test specimen shall be taken with the longitudinal axis of the specimen located at least one-half radius or 1 in. below the surface plus the machining allowance per side, whichever is less. The fracture plane of the specimens shall be at least one diameter or thickness from the heat-treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

NB-2322.2 Orientation of Impact Test Specimens

(a) Specimens for C_v impact tests shall be oriented as follows.

(1) Specimens for forgings, other than bolting and bars used for pressure-retaining parts of vessels, pumps, and valves, shall be oriented in a direction normal to the principal direction in which the material was worked.

Page 22

Specimens are neither required nor prohibited from the thickness direction.

(2) Specimens from material for pipe, tube, and fittings, except for those made from plate and castings, shall be oriented in the axial direction. Specimens from pipe material used for nozzles in vessels shall be oriented in a direction normal to the principal direction in which the material was worked, other than the thickness direction.

(3) Specimens from bolting material and bars shall be oriented in the axial direction.

(4) Specimens for all plate material, including that used for pipe, tube, and fittings, shall be oriented in a direction normal to the principal rolling direction, other than thickness direction.

(5) Specimens for cast material shall have their axes oriented the same as the axes of the tensile specimens (NB-2226).

(6) In cases (1) through (5) above, the notch of the C_v specimen shall be normal to the surface of the material.

(b) Specimens for drop weight tests may have their axes oriented in any direction. The orientation used shall be reported in the Certified Material Test Report.

NB-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS²

NB-2331 Material for Vessels

Pressure-retaining material for vessels, other than bolting, shall be tested as follows.

(a) Establish a reference temperature RT_{NDT} ; this shall be done as follows.

(1) Determine a temperature T_{NDT} that is at or above the nil-ductility transition temperature by drop weight tests.

(2) At a temperature not greater than $T_{NDT} + 60^{\circ}\text{F}$, each specimen of the C_v test (NB-2321.2) shall exhibit at least 35 mils lateral expansion and not less than 50 ft-lb absorbed energy. Retesting in accordance with NB-2350 is permitted. When these requirements are met, T_{NDT} is the reference temperature RT_{NDT} .

In addition to providing a basis for acceptance standards for material, the test data are designated to be used as a basis for establishing inservice operation and for use in fracture prevention evaluation [NB-3211(d) and Appendix G].

(3) In the event that the requirements of (2) above are not met, conduct additional C_v tests in groups of three specimens (NB-2321.2) to determine the temperature T_{Cv} at which they are met. In this case the reference temperature $RT_{NDT} = T_{Cv} - 60^{\circ}\text{F}$. Thus, the reference temperature RT_{NDT} is the higher of T_{NDT} and $(T_{Cv} - 60^{\circ}\text{F})$.

(4) When a C_v test has not been performed at $T_{NDT} + 60^{\circ}\text{F}$, or when the C_v test at $T_{NDT} + 60^{\circ}\text{F}$ does not exhibit a minimum of 50 ft-lb and 35 mils lateral expansion, a temperature representing a minimum of 50 ft-lb and 35 mils lateral expansion may be obtained from a full C_v impact curve developed from the minimum data points of all the C_v tests performed.

(b) Apply the procedures of (a) above to (1), (2), and (3) below:

(1) the base material;

(2) the base material, the heat affected zone, and weld metal from the weld procedure qualification tests in accordance with NB-4330;

(3) the weld metal of NB-2431.

(c) Bars having a width or diameter of 2 in. (51 mm) and less which prohibit obtaining drop weight test specimens shall be tested in accordance with NB-2332.

(d) Some nozzles or appurtenances in vessels, regardless of product form, have insufficient material for obtaining impact tests after heat treatment (except post weld heat treatment). In this case, it is not necessary to perform both the drop weight and transverse C_v impact tests as required by NB-2331(a). Instead, this material may be tested by only using axial C_v specimens. The three C_v specimens so removed shall be tested at a temperature lower than or equal to the lowest service temperature but no higher than the required $RT_{NDT} + 60^{\circ}\text{F}$ for the vessel material to which the nozzle or appurtenance is attached. Each specimen shall exhibit at least 35 mils lateral expansion and not less than 50 ft-lb absorbed energy.

(e) Consideration shall be given to the effects of irradiation (NB-3124) on material toughness properties in the core belt line region of the reactor vessel. The Design Specifications shall include additional requirements, as necessary, to ensure adequate fracture toughness for the service lifetime of the vessel. The toughness properties may be verified in service periodically by a material surveillance program using the methods of ASTM E 185-82 and the material conditions monitored by the inservice inspection requirements of Section XI.

(f) Consideration shall be given to the test temperature requirements of hydrostatic testing of the vessel (NB-6212).

NB-2332 Material for Piping, Pumps, and Valves, Excluding Bolting Material

(a) Pressure-retaining material, other than bolting, with nominal wall thickness $2\frac{1}{2}$ in. (64 mm) and less for piping (pipe and tubes) and material for pumps,

Page 23

valves, and fittings with all pipe connections of nominal wall thickness $2\frac{1}{2}$ in. (64 mm) and less shall be tested as required in (1) and (2) below.

(1) Test three C_v specimens at a temperature lower than or equal to the lowest service temperature as established in the

design specification (NB-3211). All three specimens shall meet the requirements of Table NB-2332(a)-1.

(2) Apply the procedures of (1) above to:

(a) the base material;

(b) the base material, the heat affected zone, and weld metal from the weld procedure qualification tests in accordance with NB-4330; and

(c) the weld metal of NB-2431.

(b) Pressure-retaining material, other than bolting, with nominal wall thickness over $2\frac{1}{2}$ in. (64 mm) for piping (pipe and tubes) and material for pumps, valves, and fittings with any pipe connections of nominal wall thickness greater than $2\frac{1}{2}$ in. (64 mm) shall meet the requirements of NB-2331. The lowest service temperature shall not be lower than $RT_{NDT} + 100^{\circ}\text{F}$ unless a lower temperature is justified by following methods similar to those contained in Appendix G.

NB-2333 Bolting Material

For bolting material, including studs, nuts, and bolts, test three C_v specimens at a temperature no higher than the preload temperature or the lowest service temperature, whichever is less. All three specimens shall meet the requirements of Table NB-2333-1.

NB-2340 NUMBER OF IMPACT TESTS REQUIRED

NB-2341 Plates

One test shall be made from each plate as heat treated. Where plates are furnished in the unheat-treated condition and qualified by heat-treated test specimens, one test shall be made for each plate as-rolled. The term *as-rolled* refers to the plate rolled from a slab or directly from an ingot, not to its heat-treated condition.

NB-2342 Forgings and Castings

(a) Where the weight of an individual forging or casting is less than 1000 lb (454 kg), one test shall be made to represent each heat in each heat treatment lot.

(b) When heat treatment is performed in a continuous type furnace with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a heat treatment

**TABLE NB-2332(a)-1
REQUIRED C_v VALUES FOR PIPING,
PUMPS, AND VALVES**

Nominal Wall Thickness, in. [Note (1)]	Lateral Expansion, mils
$\frac{5}{8}$ or less	No test required
Over $\frac{5}{8}$ to $\frac{3}{4}$, incl.	20
Over $\frac{3}{4}$ to $1\frac{1}{2}$, incl.	25
Over $1\frac{1}{2}$ to $2\frac{1}{2}$, incl.	40

NOTE:

- (1) For pumps, valves, and fittings, use the nominal pipe wall thickness of the connecting piping.

TABLE NB-2332(a)-1 REQUIRED C_v VALUES FOR PIPING, PUMPS, AND VALVES

charge shall be considered as the lesser of a continuous run not exceeding 8 hr duration or a total weight, so treated, not exceeding 2000 lb (907 kg).

TABLE NB-2333-1
REQUIRED C_v VALUES FOR BOLTING MATERIAL

Nominal Diameter, in.	Lateral Expansion, mils	Absorbed Energy, ft-lb
1 or less	No test required	No test required
Over 1 to 4, incl.	25	No requirements
Over 4	25	45

TABLE NB-2333-1 REQUIRED C_v VALUES FOR BOLTING MATERIAL

(c) One test shall be made for each forging or casting of 1000 lb (454 kg) to 10,000 lb (4540 kg) in weight.

(d) As an alternative to (c), a separate test forging or casting may be used to represent forgings or castings of different sizes in one heat and heat treat lot, provided the test piece is a representation of the greatest thickness in the heat treat lot. In addition, test forgings shall have been subjected to substantially the same reduction and working as the forgings represented.

(e) Forgings or castings larger than 10,000 lb (4540 kg) shall have two tests per part for Charpy V-notch and one test for drop weights. The location of drop weight or C_v impact test specimens shall be selected so that an equal number of specimens is obtained from positions in the forging or casting 180 deg. apart.

(f) As an alternative to (e) for static castings, a separately cast test coupon [NB-2226(b)(2)] may be used; one test shall be made for Charpy V-notch and one test for drop weight.

Page 24

NB-2343 Bars

One test shall be made for each lot of bars with cross-sectional area greater than 1 sq in. (645 mm²), where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed 6000 lb (2720 kg).

NB-2344 Tubular Products and Fittings

On products which are seamless or welded without filler metal, one test shall be made from each lot. On products which are welded with filler metal, one additional test with the specimens taken from the weld area shall also be made on each lot. A lot shall be defined as stated in the applicable material specification, but in no case shall a lot consist of products from more than one heat of material and of more than one diameter, with the nominal thickness of any product included not exceeding that to be impact tested by more than 1/4 in. (6 mm); such a lot shall be in a single heat treatment load or in the same continuous run in a continuous furnace controlled within a 50°F (10°C) range and equipped with recording

pyrometers.

NB-2345 Bolting Material

One test shall be made for each lot of material, where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed in weight the following:

1 ³ / ₄ in. diameter and less	1,500 lb
Over 1 ³ / ₄ in. to 2 ¹ / ₂ in. diameter	3,000 lb
Over 2 ¹ / ₂ in. to 5 in. diameter	6,000 lb
Over 5 in. diameter	10,000 lb

NB-2346 Test Definitions

Unless otherwise stated in NB-2341 through NB-2345, the term *one test* is defined to include the combination of the drop weight test and the C_v test when RT_{NDT} is required [NB-2331 and NB-2332(b)] and only the C_v test when determination of RT_{NDT} is not required [NB-2332(a) and NB-2333].

NB-2350 RETESTS

(a) For C_v tests required by NB-2330, one retest at the same temperature may be conducted provided the requirements of (1) through (3) below are met:

(1) the average value of the test results meets the minimum requirements;

(2) not more than one specimen per test is below the minimum requirements;

(3) the specimen not meeting the minimum requirements is not lower than 10 ft-lb (13.6 J) or 5 mils (0.13 mm) below the specified requirements.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retest, both specimens shall meet the minimum requirements.

NB-2360 CALIBRATION OF INSTRUMENTS AND EQUIPMENT

Calibration of temperature instruments and C_v impact test machines used in impact testing shall be performed at the frequency given in (a) and (b) below.

(a) Temperature instruments used to control test temperature of specimens shall be calibrated and the results recorded to meet the requirements of NCA-3868 at least once in each 3 month interval.

(b) C_v impact test machines shall be calibrated and the results recorded to meet the requirements of NCA-3868. The calibrations shall be performed at least once per year using methods outlined in ASTM E 23-72 and employing standard specimens obtained from the National Institute of Standards and Technology.

NB-2400 WELDING MATERIAL

NB-2410 GENERAL REQUIREMENTS

(a) All welding material used in the construction and repair of components or material, except welding material used for cladding or hard surfacing, shall conform to the requirements of the welding material specification or to the requirements for other welding material as permitted in Section IX. In addition, welding material shall conform to the requirements stated in this Subarticle and to the rules covering identification in NB-2150.

(b) The Certificate Holder shall provide the organization performing the testing with the information listed below, as applicable.

(1) welding process;

(2) SFA Specification and classification;

- (3) other identification if no SFA Specification applies;
 - (4) minimum tensile strength [NB-2431.1(e)] in the as-welded or heat-treated condition or both [NB-2431.1(c)];
 - (5) drop weight test for material as-welded or heat treated, or both (NB-2332);
-

Page 25

- (6) Charpy V-notch test for material as-welded or heat treated, or both (NB-2331); the test temperature and the lateral expansion or the absorbed energy shall be provided;
- (7) the preheat and interpass temperatures to be used during welding of the test coupon [NB-2431.1(c)];
- (8) postweld heat treatment time, temperature range, and maximum cooling rate, if the production weld will be heat treated [NB-2431.1(c)];
- (9) elements for which chemical analysis is required per the SFA Specification or Welding Procedure Specification and NB-2432;
- (10) minimum delta ferrite (NB-2433).

NB-2420 REQUIRED TESTS

The required tests shall be conducted for each lot of covered, flux cored, or fabricated electrodes; for each heat of bare electrodes, rod, or wire for use with the OFW, GMAW, GTAW, PAW, and EGW (electrogas welding) processes (Section IX, QW-492); for each heat of consumable inserts; for each combination of heat of bare electrodes and lot of submerged arc flux; for each combination of lot of fabricated electrodes and lot of submerged arc flux; for each combination of heat of bare electrodes or lot of fabricated electrodes, and dry blend of supplementary powdered filler metal, and lot of submerged arc flux; or for each combination of heat of bare electrodes and lot of electrosag flux. Tests performed on welding material in the qualification of weld procedures will satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used, provided the tests required by NB-4000 and this Subarticle are made and the results conform to the requirements of this Article. The definitions in (a) through (h) below apply.

(a) A *dry batch of covering mixture* is defined as the quantity of dry covering ingredients mixed at one time in one mixing vessel; a dry batch may be used singly or may be subsequently subdivided into quantities to which the liquid binders may be added to produce a number of wet mixes [(c) below].

(b) A *dry blend* is defined as one or more dry batches mixed in a mixing vessel and combined proportionately to produce a uniformity of mixed ingredients equal to that obtained by mixing the same total amount of dry ingredients at one time in one mixing vessel.

(c) A *wet mix* is defined as the combination of a dry batch or dry blend [(a) and (b) above, respectively], and liquid binder ingredients at one time in one mixing vessel.

(d) A *lot of covered, flux cored, or fabricated electrodes* is defined as the quantity of electrodes produced from the same combination of heat of metal and dry batch, dry blend, or chemically controlled mixes of flux or core materials. Alternatively, a lot of covered, flux cored, or fabricated electrodes may be considered one type and size of electrode, produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45,360 kg), from chemically controlled tube, wire, or strip and a dry batch, a dry blend, or chemically controlled mixes of flux, provided each container of welding material is coded for identification and traceable to the production period, the shift, line, and the analysis range of both the mix and the rod, tube, or strip used to make the electrode.

(1) *Chemically controlled tube, wire, or strip* is defined as consumable tube, wire, or strip material supplied on coils with a maximum of one splice per coil that has been chemically analyzed to ensure that the material conforms to the electrode manufacturer's chemical control limits for the specific type of electrode. Both ends of each coil shall be chemically analyzed, except that those coils which are splice free need only be analyzed on one end of the coil.

(2) *Chemically controlled mixes of flux* are defined as flux material that has been chemically analyzed to ensure that it conforms to the percent allowable variation from the electrode manufacturer's standard for each chemical element for that type electrode. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending.

(e) A *heat of bare electrode, rod, wire, or consumable insert* is defined as the material produced from the same melt of metal.

(f) Alternatively, for carbon and low alloy steel bare electrode, rod, wire, or consumable inserts for use with SAW, OFW, GMAW, GTAW, PAW, and EGW processes, a *heat* may be defined as either the material produced from the same melt of metal or the material produced from one type and size of wire when produced in a continuous period [not to exceed 24 hr and not to exceed 100,000 lb (45,360 kg)] from chemically controlled wire, subject to requirements of (1), (2), and (3) below.

(1) For the chemical control of the product of the rod mill, coils shall be limited to a maximum of one splice prior to processing the wire. Chemical analysis shall be made from a sample taken from both ends of each coil of mill coiled rod furnished by mills permitting spliced coil practice of one splice maximum per coil. A chemical analysis need be taken from only one end of rod coils furnished by mills prohibiting spliced coil practice.

Page 26

(2) Carbon, manganese, silicon, and other intentionally added elements shall be identified to ensure that the material conforms to the SFA or user's material specification.

(3) Each container of wire shall be coded for identification and traceability to the lot, production period, shift, line, and analysis of rod used to make the wire.

(g) A *lot of submerged arc or electroslag flux* is defined as the quantity of flux produced from the same combination of raw materials under one production schedule.

(h) A *dry blend of supplementary powdered filler metal* is defined as one or more mixes of material produced in a continuous period, not to exceed 24 hr and not to exceed 20,000 lb (9070 kg) from chemically controlled mixes of powdered filler metal, provided each container of powdered metal is coded for identification and traceable to the production period, the shift, and the mixing vessel. A *chemically controlled mix of powdered filler metal* is defined as powdered filler metal material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the powdered filler metal manufacturer's standard, for each chemical element, for that type of powdered filler metal. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending. The chemical analysis range of the supplemental powdered filler shall be the same as that of the welding electrode, and the ratio of powder to electrode used to make the test coupon shall be the maximum permitted for production welding.

NB-2430 WELD METAL TESTS

NB-2431 Mechanical Properties Test

Tensile and impact tests shall be made, in accordance with this paragraph, of welding materials which are used to join P-Nos. 1, 3, 4, 5, 6, 7, 9, and 11 base materials in any combination, with the exceptions listed in (a) through (d) below:

(a) austenitic stainless steel and nonferrous welding material used to join the listed P-Numbers;

(b) consumable inserts (backing filler material);

(c) welding material used for GTAW root deposits with a maximum of two layers;

(d) welding material to be used for the welding of base material exempted from impact testing by NB-2311 shall likewise be exempted from the impact testing required by NB-2330 and this paragraph.

NB-2431.1 General Test Requirements.

The welding test coupon shall be made in accordance with (a) through (f) below, using each process with which the weld material will be used in production welding.

(a) Test coupons shall be of sufficient size and thickness such that the test specimens required herein can be removed.

(b) The weld metal to be tested for all processes except electroslag welding shall be deposited in such a manner as to eliminate substantially the influence of the base material on the results of the tests. Weld metal to be used with the

electroslag process shall be deposited in such a manner as to conform to one of the applicable Welding Procedure Specifications (WPS) for production welding, Section IX, QW-2a. The base material shall conform to the requirements of Section IX, QW-403.1 or QW-403.4, as applicable.

(c) The welding of the test coupon shall be performed within the range of preheat and interpass temperatures that will be used in production welding. Coupons shall be tested in the as-welded condition, or they shall be tested in the applicable postweld heat-treated condition when the production welds are to be postweld heat treated. The postweld heat treatment holding time¹ shall be at least 80% of the maximum time to be applied to the weld metal in production application. The total time for postweld heat treatment of the test coupon may be applied in one heating cycle. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the component. In addition, weld coupons for weld metal to be used with the electroslag process, which are tested in the as-welded condition or following a postweld heat treatment within the holding temperature ranges of Tables NB-4622.1-1 or NB-4622.4(c)-1, shall have a thickness within the range of 0.5 to 1.1 times the thickness of the welds to be made in production. Electroslag weld coupons to be tested following a postweld heat treatment, which will include heating the coupon to a temperature above the Holding Temperature Range of Table NB-4622.1-1 for the type of material being tested, shall have a thickness within the range of 0.9 to 1.1 times the thickness of the welds to be made in production.

(d) Regardless of the welding process or welding material being tested, the tensile specimens, and the C_v impact specimens where required, shall be located and prepared in accordance with the requirements of SFA-5.1, Specification for Mild Steel Covered Electrodes. Drop weight impact test specimens, where required, shall be oriented so that the longitudinal axis is transverse to the weld with the notch in the weld face or in a plane parallel to the weld face. For impact

Page 27

specimen preparation and testing, the applicable parts of NB-2321.1 and NB-2321.2 shall apply. The longitudinal axis of the specimen shall be at a minimum depth of $\frac{1}{4}t$ from a surface, where t is the thickness of the test weld.

(e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the base material specification. When base materials of different specifications are to be welded, the tensile strength requirements shall conform to the specified minimum tensile strength requirements of either of the base material specifications.

(f) Impact specimens of the weld metal shall be tested where impact tests are required for either of the base materials of the production weld. The weld metal shall conform to the parts of NB-2331(a) or NB-2332 applicable to the base material. Where different requirements exist for the two base materials, the weld metal may conform to either of the two requirements.

NB-2431.2 Standard Test Requirements.

In lieu of the use of the General Test Requirements specified in NB-2431.1, tensile and impact tests may be made in accordance with this subparagraph where they are required for mild and low alloy steel covered electrodes; the material combinations to require weld material testing, as listed in NB-2431, shall apply for this Standard Test Requirements option. The limitations and testing under this Standard Test option shall be in accordance with (a) through (f) below.

(a) Testing to the requirements of this subparagraph shall be limited to electrode classifications included in Specifications SFA-5.1 or SFA-5.5.

(b) The test assembly required by SFA-5.1 or SFA-5.5, as applicable, shall be used for test coupon preparation, except that it shall be increased in size to obtain the number of C_v specimens and the drop weight test specimens required by NB-2331(a) or NB-2332, where applicable.

(c) The welding of the test coupon shall conform to the requirements of the SFA Specification for the classification of electrode being tested. Coupons shall be tested in the as-welded condition and also in the postweld heat-treated condition. The PWHT temperatures shall be in accordance with Table NB-4622.1-1 for the applicable P-Number equivalent. The time at PWHT temperature shall be 8 hr. (This qualifies PWHT of 10 hr or less.) When the PWHT of the production weld exceeds 10 hr, or the PWHT temperature is other than that required above, the general test of NB-2431.1 shall be used.

(d) The tensile and C_v specimens shall be located and prepared in accordance with the requirements of

**TABLE NB-2432.1-1
SAMPLING OF WELDING MATERIALS FOR
CHEMICAL ANALYSIS**

	GTAW/PAW	GMAW	All Other Processes
A-No. 8 filler metal	Filler metal or weld deposit	Weld deposit	Weld deposit
All other filler metal	Filler metal or weld deposit	Filler metal or weld deposit	Weld deposit

TABLE NB-2432.1-1 SAMPLING OF WELDING MATERIALS FOR CHEMICAL ANALYSIS

SFA-5.1 or SFA-5.5, as applicable. Drop weight impact test specimens, where required, shall be located and oriented as specified in NB-2431.1(d).

(e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirement of the SFA Specification for the applicable electrode classification.

(f) The requirements of NB-2431.1(f) shall be applicable to the impact testing of this option.

NB-2432 Chemical Analysis Test

Chemical analysis of filler metal or weld deposits shall be made in accordance with NB-2420 and as required by the following subparagraphs.

NB-2432.1 Test Method.

The chemical analysis test shall be performed in accordance with this subparagraph and Table NB-2432.1-1, and the results shall conform to NB-2432.2.

(a) A-No. 8 welding material to be used with GTAW and PAW processes and any other welding material to be used with any GTAW, PAW, or GMAW process shall have chemical analysis performed either on the filler metal or on a weld deposit made with the filler metal in accordance with (c) or (d) below.

(b) A-No. 8 welding material to be used with other than the GTAW and PAW processes and other welding material to

be used with other than the GTAW, PAW, or GMAW process shall have chemical analysis performed on a weld deposit of the material or combination of materials being certified in accordance with (c) or (d) below. The removal of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c) below. As an alternative, the deposit shall be made in accordance with (d) below for material that will be used for corrosion resistant overlay cladding. Where the Welding Procedure Specification or the

welding material specification specifies percentage composition limits for analysis, it shall state that the specified limits apply for the filler metal analysis, the undiluted weld deposit analysis, or *in situ* cladding deposit analysis in conformance with the above required certification testing.

(c) The preparation of samples for chemical analysis of undiluted weld deposits shall comply with the method given in the applicable SFA Specification. Where a weld deposit method is not provided by the SFA specification, the sample shall be removed from a weld pad, groove, or other test weld³ made using the welding process that will be followed when the welding material or combination of welding materials being certified is consumed. The weld for A-No. 8 material to be used with the GMAW or EGW process shall be made using the shielding gas composition specified in the Welding Procedure Specifications that will be followed when the material is consumed. The test sample for ESW shall be removed from the weld metal of the mechanical properties test coupon. Where a chemical analysis is required for a welding material which does not have a mechanical properties test requirement, a chemical analysis test coupon shall be prepared as required by NB-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of NB-2431.1(c) do not apply.

(d) The alternative method provided in (b) above for the preparation of samples for chemical analysis of welding material to be used for corrosion resistant overlay cladding shall require a test weld made in accordance with the essential variables of the Welding Procedure Specification that will be followed when the welding material is consumed. The test weld shall be made in conformance with the requirements of Section IX, QW-214.1. The removal of chemical analysis samples shall conform with QW-214.3 for the minimum thickness for which the welding procedure specification is qualified.

NB-2432.2 Requirements for Chemical Analysis.

The chemical elements to be determined, the composition requirements of the weld metal, and the recording of results of the chemical analysis shall be in accordance with (a) through (c) below.

³ The methods given in the Appendix of SFA-5.9, Specification for Corrosion Resisting Chromium and Chromium-Nickel Steel Welding Rods and Bare Electrodes, shall be used to establish a welding and sampling method for the pad, groove, or other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution.

TABLE NB-2432.2(a)-1 CHEMICAL ANALYSIS FOR REACTOR VESSEL WELDING MATERIAL

Carbon and low alloy materials	C, Cr, Mo, Ni, Mn, Si, P, S, V, Cu
Chromium and Cr–Ni stainless material	C, Cr, Mo, Ni, Mn, Si, P, S, V, Cb + Ta, Ti, Cu

TABLE NB-2432.2(a)-1 CHEMICAL ANALYSIS FOR REACTOR VESSEL WELDING MATERIAL

TABLE NB-2432.2(a)-2 CHEMICAL ANALYSIS FOR WELDING MATERIAL FOR OTHER THAN REACTOR VESSEL WELDS

Chromium–Nickel stainless steels	C, Cr, Mo, Ni, Mn, Si, Cb + Ta
---	---------------------------------------

TABLE NB-2432.2(a)-2 CHEMICAL ANALYSIS FOR WELDING MATERIAL FOR OTHER THAN REACTOR VESSEL WELDS

(a)(1) All welding material to be used in the reactor vessel shall be analyzed for the elements listed in Table NB-2432.2(a)-1.

(2) All welding material of ferrous alloys A-No. 8 and A-No. 9 (Section IX, QW-442) to be used in other components shall be analyzed for the elements listed in Table NB-2432.2(a)-2 and for any other elements specified in the welding material specification referenced by the WPS or in the WPS.

(3) All other welding material shall be analyzed for the elements specified in either the welding material specification referenced by the WPS or in the WPS.

(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition limits. Where the Welding Procedure Specification contains a

modification of the composition limits of SFA or other referenced welding material specifications, or provides limits for additional elements, these composition limits of the welding procedure specification shall apply for acceptability.

(c) The results of the chemical analysis shall be reported in accordance with NCA-3867. Elements listed in Table NB-2432.2(a)-1 or Table NB-2432.2(a)-2 but not specified in the welding material specification or WPS shall be reported for information only.

NB-2433 Delta Ferrite Determination

A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, QW-442) backing filler metal (consumable inserts); bare electrode, rod, or wire filler metal; or weld metal, except that delta

Page 29

ferrite determinations are not required for SFA-5.9 and SFA-5.4, Type 16-8-2, or A-No. 8 weld filler metal to be used for weld metal cladding.

NB-2433.1 Method.

Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of chemical analysis of NB-2432 in conjunction with Fig. NB-2433.1-1.

(a) Calibration of magnetic instruments shall conform to AWS-A4.2-91.

(b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with NB-2432.1(c).

(c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number (FN).

NB-2433.2 Acceptance Standards.

The minimum acceptable delta ferrite shall be 5FN. The results of the delta ferrite determination shall be included in the Certified Material Test Report of NB-2130 or NB-4120.

NB-2440 STORAGE AND HANDLING OF WELDING MATERIAL

Suitable storage and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by fluxes and cored, fabricated, and coated electrodes.

NB-2500 EXAMINATION AND REPAIR OF PRESSURE-RETAINING MATERIAL

NB-2510 EXAMINATION OF PRESSURE-RETAINING MATERIAL

(a) Pressure-retaining material and material welded thereto shall be examined by nondestructive methods applicable to the material and product form as required by the rules of this Subarticle, except for pumps and valves with inlet piping connections 2 in. nominal pipe size (DN 50) and less. Seamless pipe, tubes, and fittings, 1 in. nominal pipe size (DN 25) and less, need not be examined by the rules of this Subarticle. The 1 in. size exemption does not apply to heat exchanger tubing.

(b) For forged and cast pumps and valves with inlet piping connections over 2 in. (DN 50), up to and including 4 in. nominal pipe size (DN 100), magnetic particle or liquid penetrant examinations may be performed in lieu of volumetric examination, except that the welding ends for cast pumps and valves shall be radiographed for a minimum distance of t (when t is the design section thickness of the weld) from the final welding end.

(c) The requirements of this Subarticle for repair by welding, including examination of the repair welds, shall be met wherever repair welds are made to pressure-retaining material and material welded thereto. The exceptions in (a) and (b) above do not apply to repair welds.

NB-2520 EXAMINATION AFTER QUENCHING AND TEMPERING

Ferritic steel products that have their properties enhanced by quenching and tempering shall be examined by the methods specified in this Subarticle for each product form after the quenching and tempering phase of the heat treatment.

NB-2530 EXAMINATION AND REPAIR OF PLATE

NB-2531 Required Examination

All plates 2 in. (51 mm) nominal thickness and less used for piping, pumps, and valves shall be examined by the angle beam ultrasonic method in accordance with NB-2532.2. All plates for vessels and all plates greater than 2 in. (51 mm) thickness shall be examined by the straight beam ultrasonic method in accordance with NB-2532.1.

NB-2532 Examination Procedures

NB-2532.1 Straight Beam Examination.

The requirements for straight beam examination shall be in accordance with SA-578, Specification for Straight Beam Wave Ultrasonic Testing and Inspection of Plain and Clad Steel Plates for Special Applications, as shown in Section V, except that the extent of examination and the acceptance standards to be applied are given in (a) and (b) below.

(a) Extent of Examination. One hundred percent of one major plate surface shall be covered by moving the search unit in parallel paths with not less than a 10% overlap.

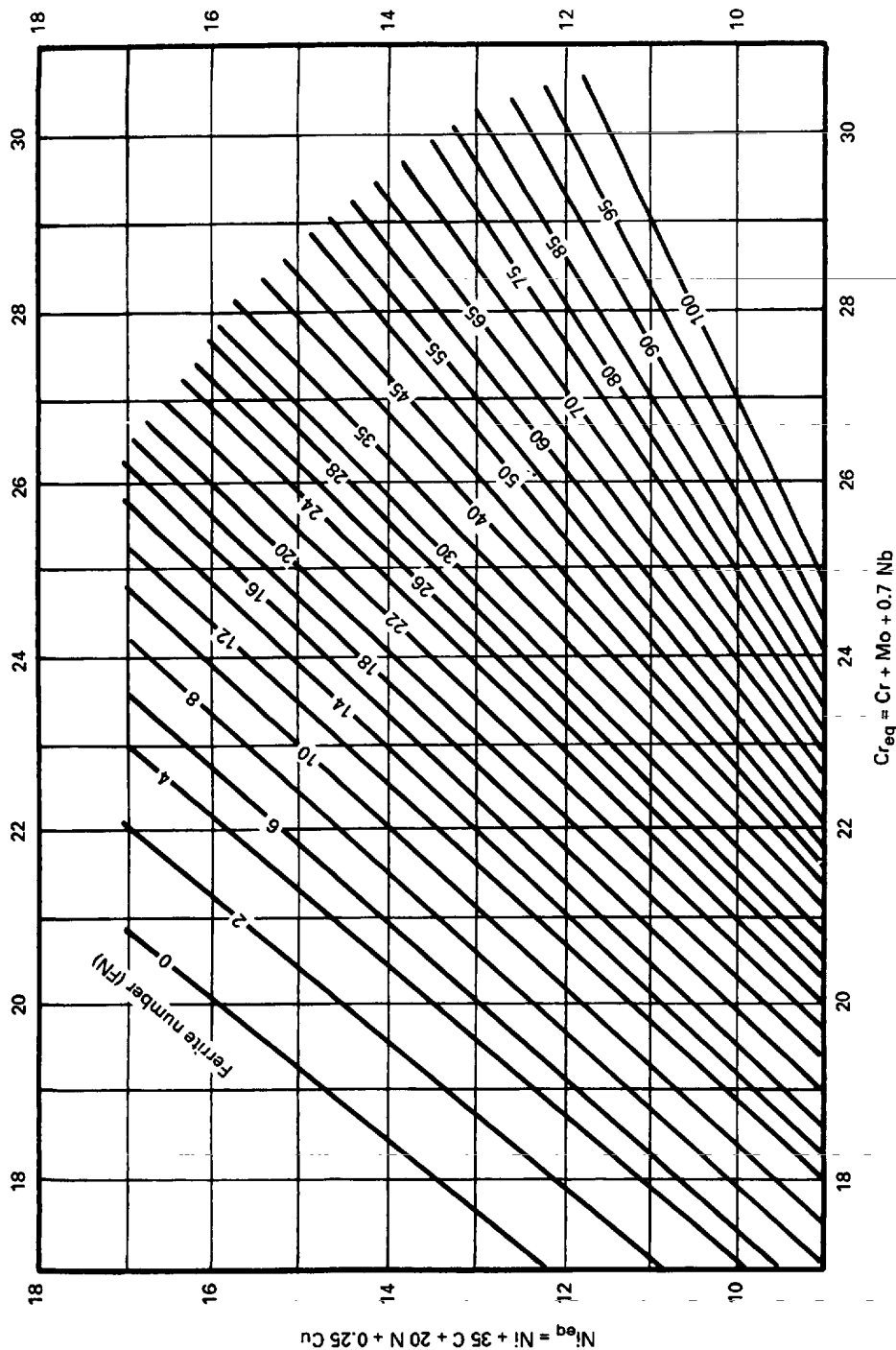
(b) Acceptance Standards

(1) Any area where one or more imperfections produce a continuous total loss of back reflection accompanied

Page 30

Page 31

by continuous indications on the same plane that cannot be encompassed within a circle whose diameter is 3 in. (76 mm) or one-half of the plate thickness, whichever is greater, is unacceptable.



GENERAL NOTES:

- (a) The actual nitrogen content is preferred. If this is not available, the following applicable nitrogen value shall be used:
 (1) GMAW welds - 0.08%, except that when self shielding flux cored electrodes are used - 0.12%.
 (2) Welds made using other processes - 0.06%.
- (b) This diagram is identical to the WRC-1992 Diagram, except that the solidification mode lines have been removed for ease of use.

FIG. NB-2433.1-1 WELD METAL DELTA FERRITE CONTENT

FIG. NB-2433.1-1 WELD METAL DELTA FERRITE CONTENT

(2) In addition, two or more imperfections smaller than described in (1) above shall be unacceptable unless separated by a minimum distance equal to the greatest diameter of the larger imperfection, or unless they may be collectively encompassed by the circle described in (1) above.

NB-2532.2 Angle Beam Examination.

The requirements for angle beam examination shall be in accordance with SA-577, Specification for Ultrasonic Beam Wave Inspection of Steel Plates, as shown in Section V and supplemented by (a) and (b) below. The calibration notch, extent of examination, and acceptance standards to be applied are given in (a) through (c) below.

(a) *Calibration.* Angle beam examination shall be calibrated from a notch.

(b) *Extent of Examination.* One hundred percent of one major plate surface shall be covered by moving the search unit in parallel paths with not less than 10% overlap.

(c) *Acceptance Standards.* Material which shows one or more imperfections which produce indications exceeding in amplitude the indication from the calibration notch is unacceptable unless additional exploration by the straight beam method shows the imperfections are laminar in nature and are acceptable in accordance with NB-2532.1(b).

NB-2537 Time of Examination

Acceptance examinations shall be performed at the time of manufacture as required in (a) through (c) below.

(a) *Ultrasonic examination* shall be performed after rolling to size and after heat treatment, except for postweld heat treatment.

(b) *Radiographic examination* of repair welds, when required, may be performed prior to any required postweld heat treatment.

(c) *Magnetic particle or liquid penetrant examination* of repair welds shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment of P-No.1 material 2 in. and less nominal thickness.

NB-2538 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (d) below are met.

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) After defect elimination, the area is examined by the magnetic particle method in accordance with NB-2545 or the liquid penetrant method in accordance with NB-2546 to ensure that the defect has been removed or reduced to an imperfection of acceptable size.

(c) Areas ground to remove oxide scale or other mechanically caused impressions for appearance or to facilitate proper ultrasonic testing need not be examined by the magnetic particle or liquid penetrant test method.

(d) When the elimination of the defect reduces the thickness of the section below the minimum required to satisfy NB-3000, the product shall be repaired in accordance with NB-2539.

NB-2539 Repair by Welding

The Material Organization may repair by welding material from which defects have been removed, provided the depth of the repair cavity does not exceed one-third the nominal thickness and the requirements of the following subparagraphs are met. Prior approval of the Certificate Holder shall be obtained for the repair of plates to be used in the manufacture of vessels.

NB-2539.1 Defect Removal.

The defect shall be removed or reduced to an imperfection of acceptable size by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair (NB-4211.1).

NB-2539.2 Qualification of Welding Procedures and Welders.

The welding procedure and welders or welding operators shall be qualified in accordance with NB-4000 and Section

IX.

NB-2539.3 Blending of Repaired Areas.

After repair, the surface shall be blended uniformly into the surrounding surface.

NB-2539.4 Examination of Repair Welds.

Each repair weld shall be examined by the magnetic particle method (NB-2545) or by the liquid penetrant method (NB-2546). In addition, when the depth of the repair cavity exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness, the repair weld shall be radiographed after repair in accordance with NB-5110 and to the acceptance standards of NB-5320. The penetrameter and the acceptance standards for radiographic examination

Page 32

of repair welds shall be based on the section thickness at the repair area.

NB-2539.5 Heat Treatment After Repairs.

The product shall be heat treated after repair in accordance with the heat treatment requirements of NB-4620.

NB-2539.6 Material Report Describing Defects and Repairs.

Each defect repair exceeding in depth the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart which shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographic film.

NB-2539.7 Repair of Cladding by Welding.

The Material Organization may repair defects in cladding by welding, provided the requirements of (a) through (d) below are met.

(a) Qualification of Welding Procedures and Welders. The welding procedure and the welders or welding operators shall be qualified in accordance with NB-4000 and with Section IX.

(b) Defect Removal and Examination of Cavity. The defect shall be removed, and the cavity prepared for repair shall be examined by the liquid penetrant method (NB-2546).

(c) Examination of Repaired Areas. The repaired area shall be examined by a liquid penetrant method (NB-2546).

(d) Report of Repairs. Each defect repair shall be described in the Certified Material Test Report for each piece, including a chart which shows the location and size of the repair, the welding material identification, welding procedure, heat treatment, and examination results.

NB-2540 EXAMINATION AND REPAIR OF FORGINGS AND BARS

NB-2541 Required Examinations

(a) Forgings and bars shall be examined by the ultrasonic method in accordance with NB-2542, except forgings or sections of forgings which have coarse grains, or configurations which do not yield meaningful examination results by ultrasonic methods, shall be examined by radiographic methods in accordance with Section V, Article 2, using the acceptance standards of NB-5320. In addition, all external surfaces and accessible internal surfaces shall be examined by a magnetic particle method (NB-2545) or a liquid penetrant method (NB-2546).

(b) Forged flanges and fittings, such as elbows, tees, and couplings, shall be examined in accordance with the requirements of NB-2550.

(c) Bar material used for bolting shall be examined in accordance with NB-2580.

(d) Forgings and forged or rolled bars which are to be bored to form tubular products or fittings shall be examined in

accordance with the requirements of NB-2550 after boring.

(e) Forgings and forged or rolled bars which will subsequently be bored to form pump and valve parts shall be examined in accordance with NB-2541 after boring.

NB-2542 Ultrasonic Examination

NB-2542.1 Examination Procedure.

All forgings in the rough-forged or finished condition, and bars, shall be examined in accordance with Article 5 of Section V and the following supplemental requirements. The techniques of (a) through (d) below are required, as applicable.

(a) Forgings may be examined by the use of alternative ultrasonic methods which utilize distance amplitude corrections, provided the acceptance standards are shown to be equivalent to those listed in NB-2542.2.

(b) Cylindrical section bars shall be scanned from the entire external circumference.

(c) Noncylindrical section bars shall be scanned in two perpendicular directions to the maximum extent possible (through each pair of parallel sides).

(d) Bar products do not require recording and reporting of indications smaller than the acceptance standard, except when so specified for specialized applications.

NB-2542.2 Acceptance Standards

(a) Straight Beam General Rule. A forging shall be unacceptable if the results of straight beam examinations show one or more reflectors which produce indications accompanied by a complete loss of back reflection not associated with or attributable to geometric configurations. Complete loss of back reflection is assumed when the back reflection falls below 5% of full calibration screen height.

(b) Straight Beam Special Rule for Vessel Shell Sections

(1) A ring forging made to fine grain melting practice and used for vessel shell sections shall be unacceptable if the results of the straight beam radial examination show one or more reflectors producing a

Page 33

continuous complete loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed with a circle whose diameter is 3 in. or one-half of the wall thickness, whichever is greater.

(2) In addition, two or more reflectors smaller than described in (1) above shall be unacceptable unless separated by a minimum distance equal to the greatest diameter of the larger reflector or unless they may be collectively encompassed by the circle described in (1) above.

(c) Angle Beam Rule. A forging shall be unacceptable if the results of angle beam examinations show one or more reflectors which produce indications exceeding in amplitude the indication from the appropriate calibration notches.

NB-2545 Magnetic Particle Examination

NB-2545.1 Examination Procedure.

The procedure for magnetic particle examination shall be in accordance with the methods of Article 7, Section V.

NB-2545.2 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication in excess of the NB-2545.3 acceptance standards, which is believed to be nonrelevant, shall be

reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NB-2545.3 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for material less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for material 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 sq in. (3871 mm²) of area whose major dimension is no more than 6 in. (152 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

NB-2546 Liquid Penetrant Examination

NB-2546.1 Examination Procedure.

The procedure for liquid penetrant examination shall be in accordance with the methods of Section V, Article 6.

NB-2546.2 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities, such as may occur from machining marks, surface conditions, or an incomplete bond between base metal and cladding, may produce similar indications which are not relevant.

(b) Any indication in excess of the NB-2546.3 acceptance standards, which is believed to be nonrelevant, shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation, which would mask defects, are unacceptable.

(c) Relevant indications are indications which result from imperfections. *Linear indications* are indications in which the length is more than three times the width. *Rounded indications* are indications which are circular or elliptical with the length equal to or less than three times the width.

NB-2546.3 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for material less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for material 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and

greater than $\frac{1}{16}$ in. (4.8 mm) for thicknesses $\frac{1}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 sq in. (3871 mm²) of area whose major dimension is no more than 6 in. (152 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

NB-2547 Time of Examination

Acceptance examinations, including those for repair welds, shall be performed at the time of manufacture as required in (a) through (e) below.

(a) Ultrasonic examination may be performed at any time after forging [NB-2541(d)], and the maximum practical volume, including weld repairs, if required, shall be examined after final heat treatment, excluding postweld heat treatment.

(b) Radiographic examination of repair welds, if required, may be performed prior to any required postweld heat treatment.

(c) Magnetic particle or liquid penetrant examination shall be performed in the finished condition, except repair welds of P-No. 1 material, 2 in. (51 mm) nominal thickness and less, may be examined prior to postweld heat treatment.

(d) Forgings and rolled bars which are to be bored or turned to form tubular parts or fittings shall be examined after boring or turning, except for threading.

(e) Forgings and forged or rolled bars which will subsequently be bored or turned to form pump and valve parts shall be examined after boring or turning, except for threading.

NB-2548 Elimination of Surface Defects

Elimination of surface defects shall be made in accordance with NB-2538.

NB-2549 Repair by Welding

Repair by welding shall be in accordance with NB-2539, except that:

(a) the depth of repair that is permitted is not limited; and

(b) for ferritic steel forgings, the completed repair may be examined by the ultrasonic method in accordance with the requirements of NB-2542 in lieu of radiography.

NB-2550 EXAMINATION AND REPAIR OF SEAMLESS AND WELDED (WITHOUT FILLER METAL) TUBULAR PRODUCTS AND FITTINGS

NB-2551 Required Examination

In addition to the requirements of the material specification and of this Article, seamless and welded (without filler metal) tubular products (including pipe flanges and fittings machined from forgings and bars) shall comply with the following.

(a) Wrought seamless and welded (without filler metal) pipe and tubing shall be examined over the entire volume⁴ of the material in accordance with (1), (2), (3), or (4), as follows. Tubular products may require both outside and inside surface conditioning prior to examination.

(1) Pipe and Tubing

(a) Pipe and tubing smaller than $2\frac{1}{2}$ in. (64 mm) O.D. shall be examined by the ultrasonic method in accordance with NB-2552(a)(1) in two opposite circumferential directions⁵ and by the eddy current method in accordance with NB-2554, provided the product is limited to sizes, materials, and thicknesses for which meaningful results can be obtained by eddy current examination as evidenced by detection of required standards.

(b) As an alternative to the eddy current examination or when the eddy current examination does not yield meaningful results, an axial scan ultrasonic examination in two opposite axial directions,⁵ in accordance with NB-2552(a)(2), shall be made.

(2) Pipe and tubing $2\frac{1}{2}$ in. (64 mm) O.D. and larger shall be examined by the ultrasonic method in accordance with NB-2552(a)(1) in two opposite circumferential directions, and in accordance with NB-2552(a)(2) in two opposite axial directions. Alternatively, for welded without filler metal pipe larger than $6\frac{3}{4}$ in. (171 mm) O.D., the plate shall be examined by the ultrasonic method in accordance with NB-2530 prior to forming and the weld shall be examined by the radiographic method in accordance with NB-2553. Radiographic examination of welds, including repair welds, shall be performed after final rolling and forming and may be performed prior to any required postweld heat treatment.

4 The volumetric examinations required by this paragraph need only be conducted from one surface.

5 The direction of ultrasonic examinations referenced is the direction of sound propagation.

Page 35

(3) Copper-nickel alloy and nickel alloy seamless pipe and tubing shall be examined as follows.

(a) Except as provided in (d) below, each pipe and tube, all sizes shall be ultrasonically examined in accordance with NB-2552(a)(1) in two opposite circumferential directions.

(b) Except as provided in (d) below, pipe and tubing smaller than $2\frac{1}{2}$ in. (64 mm) O.D. shall be examined by the eddy current method in accordance with NB-2554 if meaningful indications can be obtained from the reference specimen notches. If meaningful indications cannot be obtained from the reference specimen, an axial scan ultrasonic examination in two opposite axial directions, in accordance with NB-2552(a)(2), shall be made.

(c) Except as provided in (d) below, pipe and tubing $2\frac{1}{2}$ in. (64 mm) O.D. and larger shall be examined by an axial scan ultrasonic examination in two opposite axial directions in accordance with NB-2552(a)(2).

(d) For pipe and tubing which is specified to be coarse grain structure, radiographic examination in accordance with NB-2553 may be performed in lieu of ultrasonic examination.

(4) Tubing used in steam generator fabrication shall be examined as follows:

(a) each tube shall be ultrasonically examined in accordance with NB-2552(a)(1) in two opposite circumferential directions, and

(b) by eddy current in accordance with NB-2554 if meaningful indications can be obtained from the reference specimen notches. If meaningful results cannot be obtained from the reference specimen, an axial scan ultrasonic examination in two opposite axial directions, in accordance with NB-2552(a)(2), shall be made.

(b) Wrought seamless and welded without filler metal fittings (including pipe flanges and fittings machined from forgings and bars) shall be examined in accordance with the material specification, and in addition by the magnetic particle method in accordance with NB-2555, or the liquid penetrant method in accordance with NB-2556 on all external surfaces and all accessible internal surfaces (excluding bolt holes and threads). Additionally, for fittings over 6 in. (152 mm) nominal size, the entire volume shall be examined by the ultrasonic method, if feasible, in accordance with NB-2552, or the radiographic method in accordance with NB-2553. Alternatively, the plate shall be examined by the ultrasonic method in accordance with NB-2530 prior to forming and the weld shall be examined by the radiographic method in accordance with NB-2553. Radiographic examination of welds, including repair welds, shall be performed after final rolling and forming, and may be performed prior to any required postweld heat treatment.

(c) Tubular products used for vessel nozzles shall be examined over the entire volume of material by either the ultrasonic method in two opposite circumferential directions in accordance with NB-2552(b) or the radiographic method in accordance with NB-2553, and shall be examined on all external and all accessible internal surfaces by either the magnetic particle method in accordance with NB-2555 or the liquid penetrant method in accordance with NB-2556.

NB-2552 Ultrasonic Examination⁴

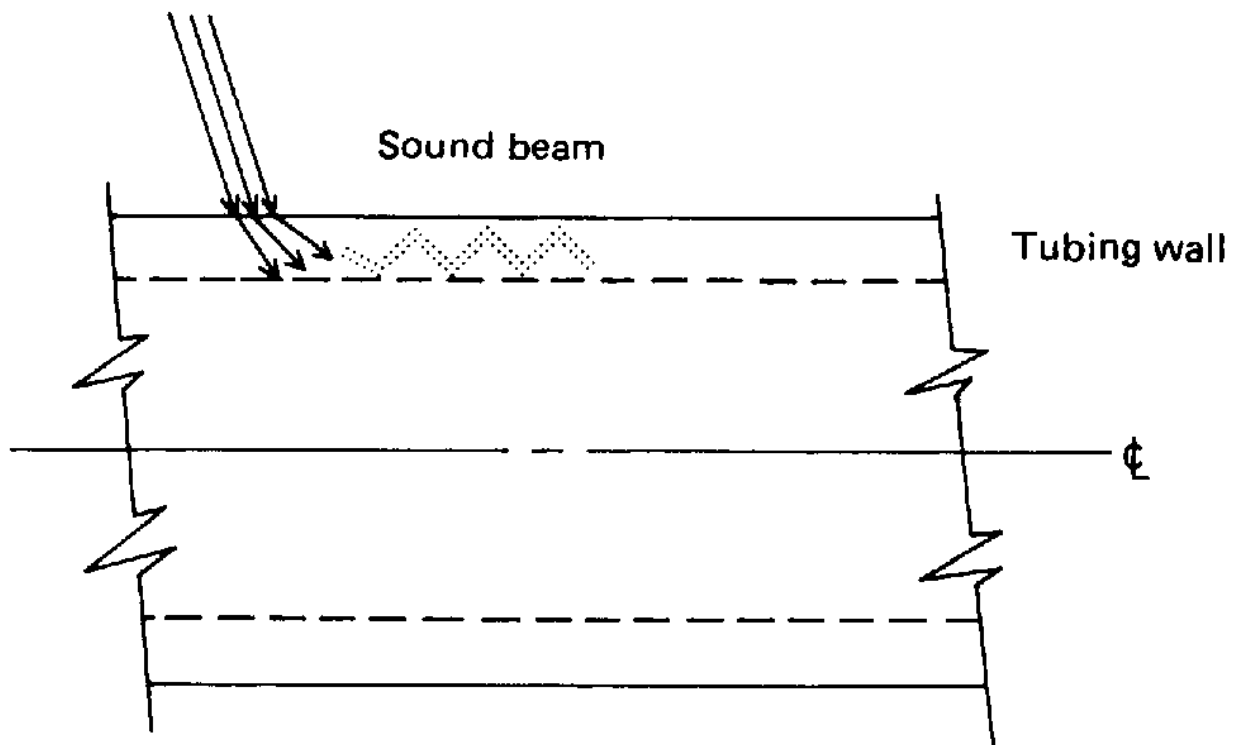
(a) *Examination Procedure for Pipe and Tubing.* Independent channels or instruments shall be employed for circumferential and axial scans.

(1) *Circumferential Direction.* The procedure for ultrasonic examination of pipe and tubing in the circumferential direction shall be in accordance with SE-213. The procedure shall provide a sensitivity which will consistently detect defects that produce indications equal to, or greater than, the indications produced by the standard defects specified in (c).

(2) *Axial Direction.* When required by NB-2551, the ultrasonic examination of pipe and tubing shall include angle beam scanning in the axial direction. The procedure for the axial scans shall be in accordance with SE-213, except that the propagation of sound in the tube or pipe wall shall be in the axial direction instead of the circumferential direction. Figure NB-2552-1 illustrates the characteristic oblique entry of

Page 36

sound into the pipe or tube wall and the axial direction of ultrasonic energy propagation to detect transverse notches or similar surface discontinuities.



**FIG. NB-2552-1 AXIAL PROPAGATION
OF SOUND IN TUBE WALL**

FIG. NB-2552-1 AXIAL PROPAGATION OF SOUND IN TUBE WALL

(3) *Acceptance Standards.* Products with defects that produce indications in excess of the indications produced by the standard defects in the reference specimen are unacceptable unless the defects are eliminated or repaired in accordance

with NB-2558 or NB-2559.

(b) Examination Procedure for Fittings

(1) Procedure. The procedure for ultrasonic examination of fittings shall be in accordance with the requirements of SA-388 for straight beam examination and, where feasible, angle-beam examination in two circumferential directions.

(2) Acceptance Standards. Fittings shall be unacceptable if straight beam examination shows one or more reflectors which produce indications accompanied by complete loss of back reflection not associated with or attributable to the geometric configuration, or if angle beam examination results show one or more reflectors which produce indications exceeding in amplitude the indications from the calibrated notch. Complete loss of back reflection is assumed when the back reflection falls below 5% of full calibration screen height.

(c) Reference Specimens

(1) The reference specimen shall be of the same nominal diameter and thickness, and of the same nominal composition and heat-treated condition as the product which is being examined. For circumferential scanning, the standard defects shall be axial notches or grooves on the outside and inside surfaces of the reference specimen, and shall have a length of approximately 1 in. (25 mm) or less, a width not to exceed $\frac{1}{16}$ in. (1.6 mm) for a square notch or U-notch, a width proportional to the depth for a V-notch, and a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the nominal wall thickness. For axial scanning in accordance with SE-213, a transverse (circumferential) notch shall be introduced on the inner and outer surfaces of the standard. Dimensions of the transverse notch shall not exceed those of the longitudinal notch. The reference specimen may be the product being examined.

(2) The reference specimen shall be long enough to simulate the handling of the product being examined through the examination equipment. When more than one standard defect is placed in a reference specimen, the defects shall be located so that indications from each defect are separate and distinct without mutual interference or amplification. All upset metal and burrs adjacent to the reference notches shall be removed.

(d) Checking and Calibration of Equipment. The proper functioning of the examination equipment shall be checked and the equipment shall be calibrated by the use of the reference specimens, as a minimum:

(1) at the beginning of each production run of a given size and thickness of a given material;

(2) after each 4 hr or less during the production run;

(3) at the end of the production run;

(4) at any time that malfunctioning is suspected. If, during any check, it is determined that the examination equipment is not functioning properly, all of the product that has been examined since the last valid equipment calibration shall be reexamined.

NB-2553 Radiographic Examination

(a) General. When radiographic examination is performed as an alternative for ultrasonic examination of the entire volume of the material, it shall apply to the entire volume of the pipe, tube, or fitting material. Acceptance standards specified for welds shall apply to the entire volume of material examined.

(b) Examination Procedure. The radiographic examination shall be performed in accordance with Article 2 of Section V, as modified by NB-5111.

(c) Acceptance Standard. Welds that are shown by radiography to have any of the following types of discontinuities are unacceptable:

(1) any type of crack or zone of incomplete fusion or penetration;

(2) any other elongated indication which has a length greater than:

(a) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive

(b) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (57 mm), inclusive

(c) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm) where t is the thickness of the thinner portion of the weld;

(3) any group of aligned indications having an aggregate length greater than t in a length of $12t$, unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication;

(4) rounded indications in excess of that shown as acceptable in Appendix VI.

NB-2554 Eddy Current Examination

(a) *General.* This examination method is restricted to materials with uniform magnetic properties and of sizes for which meaningful results can be obtained.

(b) *Examination Procedure.* The procedure for eddy current examination shall be in accordance with SE-426

Page 37

or SE-571. The procedure shall provide a sensitivity that will consistently detect defects by comparison with the standard defects included in the reference specimen in (d).

(c) *Acceptance Standards.* Products with defects that produce indications in excess of the reference standards are unacceptable.

(d) *Reference Specimens.* The reference specimen shall be of the same nominal diameter and thickness, and of the same nominal composition and heat-treated condition as the product that is being examined. The standard shall contain axial notches on the outside surface plus a $\frac{1}{16}$ in. (1.6 mm) diameter hole drilled through the wall. For copper-nickel alloy and nickel alloy materials, the standard shall have one notch extending axially on the outside surface and one notch extending axially on the inside surface plus a $\frac{1}{16}$ in. (1.6 mm) diameter hole drilled through the wall. These shall be used to establish the rejection level for the product to be tested. The reference notches shall have a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the wall thickness. The width of the notch shall not exceed $\frac{1}{16}$ in. (1.6 mm). The length shall be approximately 1 in. (25 mm) or less. The size of reference specimens shall be as specified in NB-2552(c).

(e) *Checking and Calibration of Equipment.* The checking and calibration of examination equipment shall be the same as in NB-2552(d).

NB-2555 Magnetic Particle Examination

Magnetic particle examination shall be performed in accordance with the requirements of NB-2545.

NB-2556 Liquid Penetrant Examination

Liquid penetrant examination shall be performed in accordance with the requirements of NB-2546.

NB-2557 Time of Examination

(a) Products that are quenched and tempered shall be examined, as required, after the quenching and tempering heat treatment.

(b) Products that are not quenched and tempered shall receive the required examinations as follows.

(1) Ultrasonic or eddy current examination, when required, shall be performed after final heat treatment, except postweld heat treatment.

(2) Radiographic examination, when required, may be performed prior to any required postweld heat treatment.

(3) Magnetic particle or liquid penetrant examination, including repair welds, shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment for P-No. 1 (Section IX of the Code) materials of 2 in. (51 mm) and less nominal thickness.

(4) Forgings and rolled bars which are to be bored and/or turned to form tubular parts or fittings shall be examined after boring and/or turning, except for threading. Fittings shall be examined after final forming.

NB-2558 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (c) below are met.

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) After defect elimination, the area is examined by the method which originally disclosed the defect to assure that the defect has been removed or reduced to an imperfection of acceptable size.

(c) If the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of NB-3000, the product shall be repaired in accordance with NB-2559.

NB-2559 Repair by Welding

Repair of defects shall be in accordance with NB-2539, except repair by welding is not permitted on copper-nickel alloy and nickel alloy heat exchanger tubes.

NB-2560 EXAMINATION AND REPAIR OF TUBULAR PRODUCTS AND FITTINGS WELDED WITH FILLER METAL

NB-2561 Required Examinations

(a) Welded tubular products (with filler metal) such as pipe made in accordance with SA-358, SA-409, SA-671, SA-672, and SA-691, and fittings made in accordance with the WPW grades of SA-234, SA-403, and SA-420, which are made by welding with filler metal, shall be treated as material; however, inspection by an Inspector and stamping with an NPT symbol shall be in accordance with Section III requirements. In addition to the NPT symbol, a numeral 1 shall be stamped below and outside the official Code Symbol.

Page 38

(b) In addition to the requirements of the material specification and of the Article, pipe and fittings shall comply with the following.

(1) The plate shall be examined in accordance with NB-2530 prior to forming, or alternatively, the finished product shall be examined by the ultrasonic method in accordance with NB-2562.

(2) All welds shall be examined 100% by radiography in accordance with the method and acceptance requirements of the base material specification, and by either the magnetic particle method in accordance with NB-2564 or the liquid penetrant method in accordance with NB-2565. If radiographic examination of welds is not specified in the basic material specification, the welds shall be examined by the radiographic method in accordance with NB-2563. The radiographic film and a radiographic report showing film locations shall be provided with the Certified Material Test Report.

NB-2562 Ultrasonic Examination

The ultrasonic examination shall be performed in accordance with the requirements of NB-2552.

NB-2563 Radiographic Examination

The radiographic examination shall be performed in accordance with the requirements of NB-2553.

NB-2565 Magnetic Particle Examination

The magnetic particle examination shall be performed in accordance with the requirements of NB-2545.

NB-2566 Liquid Penetrant Examination

The liquid penetrant examination shall be performed in accordance with the requirements of NB-2546.

NB-2567 Time of Examination

The time of examination shall be in accordance with the requirements of NB-2557, except that for magnetic particle or liquid penetrant examination of welds, including repair welds, for P-No. 1 (Section IX of the Code), examination may be performed prior to postweld heat treatment.

NB-2568 Elimination of Surface Defects

Unacceptable surface defects shall be removed in accordance with the requirements of NB-2558.

NB-2569 Repair by Welding

When permitted by the basic material specification, base material defects shall be repair welded in accordance with the requirements of NB-2559. Repair welding of weld seam defects shall be in accordance with NB-4450.

NB-2570 EXAMINATION AND REPAIR OF STATICALLY AND CENTRIFUGALLY CAST PRODUCTS

In addition to the requirements of the material specification and of this Article, statically and centrifugally cast products shall comply with the following subparagraphs.

NB-2571 Required Examination

Cast products shall be examined by the radiographic method, except cast ferritic steels which shall be examined by either the radiographic or ultrasonic method, or a combination of both methods, as required for the product form by Table NB-2571-1.

In addition, all cast products shall be examined on all external surfaces and all accessible internal surfaces by either the magnetic particle or liquid penetrant method. Machined surfaces, except threaded surfaces, of a cast product shall be examined by either the liquid penetrant or magnetic particle method after machining.

NB-2572 Time of Nondestructive Examination

NB-2572.1 Acceptance Examinations.

Acceptance examinations shall be performed at the time of manufacture as stipulated in the following and Table NB-2571-1.

(a) *Ultrasonic Examination.* Ultrasonic examination, if required, shall be performed at the same stage of manufacture as required for radiography.

(b) *Radiographic Examination.* Radiography may be performed prior to heat treatment and may be performed prior to or after finish machining at the following limiting thicknesses.

(1) For finished thicknesses under $2\frac{1}{2}$ in. (64 mm), castings shall be radiographed within 20% of the finished thickness when Type 2 radiographic film is used or within $\frac{1}{2}$ in. (13 mm) of the finished thickness when Type 1 radiographic film is used. The penetrameter and the acceptance reference radiographs shall be based on the finished thickness.

(2) For finished thickness from $2\frac{1}{2}$ in. (64 mm) up to 6 in. (152 mm), castings shall be radiographed

within 20% of the finished thickness. The penetrameter and the acceptance reference radiographs shall be based on the finished thickness. Pages 40-40

TABLE NB-2571-1 REQUIRED EXAMINATIONS

Nominal Pipe Size	Item	Applicable Special Requirements for Class 1 Castings
Inlet piping connections of 2 in. and less	Cast products other than pumps and valves	Cast products shall be examined by the radiographic method, except cast ferritic steels, which shall be examined by either the radiographic or ultrasonic method, or a combination of both methods. Castings or sections of castings that have coarse grains or configurations that do not yield meaningful examination results by the ultrasonic method shall be examined by the radiographic method. In addition, all cast products shall be examined on all external surfaces and all accessible internal surfaces by either the magnetic particle or the liquid penetrant method. Machined surfaces, except threaded surfaces, of a cast product shall be examined by either the liquid penetrant or the magnetic particle method after machining.
	Cast pumps and valves	None
	Repair welds in pumps and valves of P-No. 1 or P-No. 8 material	None
	Repair welds in cast products, excluding repair welds in pumps and valves of P-No. 1 or P-No. 8 material	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, repair welds in cavities the depth of which exceed the lesser of $\frac{3}{8}$ in. or 10% of the section thickness shall be radiographed in accordance with NB-2575.
Inlet piping connections over 2 in. up to and including 4 in.	Cast products — See <i>Cast pumps and valves</i> below for exceptions	Cast products shall be examined by the radiographic method, except cast ferritic steels, which shall be examined by either the radiographic or the ultrasonic method, or a combination of both methods. Castings or sections of castings that have coarse grains or configurations that do not yield meaningful examination results by the ultrasonic method shall be examined by the radiographic method. In addition, all cast products shall be examined on all external surfaces and all accessible internal surfaces by either the magnetic particle or the liquid penetrant method. Machined surfaces, except threaded surfaces, of a cast product shall be examined by either the liquid penetrant or the magnetic particle method after machining.
	Cast pumps and valves	Magnetic particle or liquid penetrant examination may be performed, in lieu of volumetric examination, except the welding ends of cast pumps and valves shall be radiographed for a minimum distance of t (when t is the design section thickness of the weld) from the final weld end.
	Repair welds	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, repair welds in cavities the depth of which exceed the lesser of $\frac{3}{8}$ in. or 10% of the section thickness shall be radiographed in accordance with NB-2575.

(continued)

TABLE NB-2571-1 REQUIRED EXAMINATIONS

TABLE NB-2571-1 REQUIRED EXAMINATIONS (CONT'D)

Nominal Pipe Size	Item	Applicable Special Requirements for Class 1 Castings
Inlet piping connections over 4 in.	Cast products	Cast products shall be examined by the radiographic method, except cast ferritic steels, which shall be examined by either the radiographic or the ultrasonic method, or a combination of both methods. Castings or sections of castings that have coarse grains or configurations that do not yield meaningful examination results by the ultrasonic method shall be examined by the radiographic method. In addition, all cast products shall be examined on all external surfaces and all accessible internal surfaces by either the magnetic particle or the liquid penetrant method. Machined surfaces, except threaded surfaces, of a cast product shall be examined by either the liquid penetrant or the magnetic particle method after machining.
	Repair welds	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, repair welds in cavities the depth of which exceed the lesser of $\frac{3}{8}$ in. or 10% of the section thickness shall be radiographed in accordance with NB-2575.

TABLE NB-2571-1 REQUIRED EXAMINATIONS (CONT'D)

(3) For finished thicknesses over 6 in. (152 mm), castings shall be radiographed with $\frac{1}{2}$ in. (13 mm) or 15% of the finished thickness, whichever is greater. The penetrometer and the acceptance reference radiographs shall be based on the finished thickness.

(c) Radiography of castings for pumps and valves may be performed in as-cast or rough machined thickness exceeding the limits of (b)(1), (b)(2), or (b)(3) above, subject to the following conditions.

(1) When the thickness of the as-cast or rough machined section exceeds 2 in. (51 mm), acceptance shall be based on reference radiographs for the next lesser thickness; e.g., if the section being radiographed exceeds $4\frac{1}{2}$ in. (114 mm), use reference radiographs of ASTM E 186-75 (reapproved 1979). The penetrometer shall be based on the thickness of the section being radiographed.

(2) When the thickness of the as-cast or rough machined section is 2 in. (51 mm) or less, the reference radiographs of ASTM E 446-78 shall be used and the penetrometer shall be based on the final section thickness.

(3) Weld ends for a minimum distance of t or $\frac{1}{2}$ in. (13 mm), whichever is less (where t is the design section thickness of the weld), from the final welding end shall be radiographed at a thickness within the limits given in (b)(1), (b)(2), or (b)(3) above as applicable. As an alternative, the weld ends may be radiographed in the as-cast or rough machined thickness in accordance with (c)(1) and (c)(2) above, and the penetrometer shall be based on the final section thickness.

(d) *Magnetic Particle or Liquid Penetrant Examination.* Magnetic particle or liquid penetrant examination shall be performed after the final heat treatment required by the material specification. Repair weld areas shall be examined after postweld heat treatment when a postweld heat treatment is performed, except that repair welds in P-No. 1 (see Section IX of the Code) material 2 in. (51 mm) nominal thickness and less may be examined prior to postweld heat treatment. For cast products with machined surfaces, all finished machined surfaces, except threaded surfaces and small deep holes, shall also be examined by the magnetic particle or the liquid penetrant method.

NB-2573 Provisions for Repair of Base Material by Welding

The Material Organization may repair, by welding, products from which defects have been removed, provided the requirements of this Article are met.

NB-2573.1 Defect Removal.

The defects shall be removed or reduced to an imperfection of acceptable size by suitable mechanical or thermal cutting or gouging methods, and the cavity prepared for repair. When thermal cutting is performed, consideration shall be given to preheating the material.

Page 41

NB-2573.2 Repair by Welding.

The Material Organization may repair castings by welding after removing the material containing unacceptable defects. The depth of the repair is not limited. A cored hole or access hole may be closed by the Material Organization by welding in accordance with the requirements of this paragraph, provided the hole is closed by filler metal only. If the hole is closed by welding in a metal insert, the welding shall be performed by a holder of a Certificate of Authorization in accordance with the requirements of the Code.

NB-2573.3 Qualification of Welding Procedures and Welders.

Each manufacturer is responsible for the welding done by his organization and shall establish the procedures and conduct the tests required by NB-4000 and by Section IX of the Code in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures. He is also responsible for the welding performed by his subcontractors and shall assure himself that the subcontractors conduct the tests required by NB-4000 and by Section IX of the Code in order to qualify their welding procedures and the performance of their welders and welding operators.

NB-2573.4 Blending of Repaired Areas.

After repair, the surface shall be blended uniformly into the surrounding surface.

NB-2573.5 Examination of Repair Welds

(a) Each repair weld shall be examined by the magnetic particle method in accordance with the requirements of NB-2577 or by the liquid penetrant method in accordance with the requirements of NB-2576. In addition, when radiography is specified in the order for the original casting, repair cavities, the depth of which exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the nominal wall thickness, shall be radiographed after repair except that weld slag, including elongated slag, shall be considered as inclusions under Category B of the applicable reference radiographs. The total area of all inclusions, including slag inclusions, shall not exceed the limits of the applicable severity level of Category B of the reference radiographs. The penetrameter and the acceptance standards for radiographic examination of repair welds shall be based on the actual section thickness at the repair area.

(b) Examination of repair welds in P-No. 1 and P-No. 8 material is not required for pumps and valves with inlet piping connections NPS 2 (DN 50) and less.

NB-2573.6 Heat Treatment After Repairs.

The material shall be heat treated after repair in accordance with the heat treatment requirements of NB-4620, except that the heating and cooling rate limitations of NB-4623 do not apply.

NB-2573.7 Elimination of Surface Defects.

Surface defects shall be removed by grinding or machining provided the requirements of (a) through (c) below are met.

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) After defect elimination, the area is reexamined by the magnetic particle method in accordance with NB-2577 or the liquid penetrant method in accordance with NB-2576 to assure that the defect has been removed or reduced to an imperfection of acceptable size.

(c) If the elimination of the defect reduces the section thickness below the minimum required by the specification or

drawing, the casting shall be repaired in accordance with NB-2539.

NB-2573.8 Material Report Describing Defects and Repairs.

Each defect repair exceeding in depth the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the nominal wall thickness shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart that shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographic film, when radiography is specified in the order for the original casting.

NB-2574 Ultrasonic Examination of Ferritic Steel Castings

Ultrasonic examination shall be performed in accordance with T-541.4 of Article 5 of Section V. Each manufacturer shall certify that the procedure is in accordance with the requirements of NB-2574 and shall make the procedure available for approval upon request.

NB-2574.1 Acceptance Standards

(a) The Quality Levels of SA-609 as shown in Section V shall apply for the casting thicknesses indicated:

- (1) Quality Level 1 for thicknesses up to 2 in. (51 mm);
- (2) Quality Level 3 for thicknesses 2 in. (51 mm) to 4 in. (102 mm);
- (3) Quality Level 4 for thicknesses greater than 4 in. (102 mm).

(b) In addition to the Quality Level requirements stated in (a) above, the requirements in (1) through (5) below shall apply for both straight beam and angle beam examination.

Page 42

(1) Areas giving indications exceeding the Amplitude Reference Line with any dimension longer than those specified in the following tabulation are unacceptable:

UT Quality Level	Longest Dimension of Area^{6, 7, 8}
1	1.5 in.
2	2.0 in.
3	2.5 in.
4	3.0 in.

(2) Quality Level 1 shall apply for the volume of castings within 1 in. (25 mm) of the surface regardless of the overall thickness.

(3) Discontinuities indicated to have a change in depth equal to or greater than one-half the wall thickness or 1 in. (25 mm) (whichever is less) are unacceptable.

(4) Two or more imperfections producing indications in the same plane with amplitudes exceeding the Amplitude Reference Line and separated by a distance less than the longest dimension of the larger of the adjacent indications are unacceptable if they cannot be encompassed within an area less than that of the Quality Level specified in (b)(1) above.

(5) Two or more imperfections producing indications greater than permitted for Quality Level 1 for castings less than 2 in. (51 mm) in thickness, greater than permitted for Quality Level 2 for thicknesses 2 in. (51 mm) through 4 in. (102 mm), and greater than permitted for Level 3 for thicknesses greater than 4 in. (102 mm), separated by a distance less than the longest dimension of the larger of the adjacent indications are unacceptable, if they cannot be encompassed in an area less than that of the Quality Level requirements stated in (a) above.

NB-2575 Radiographic Examination

6 The areas for the Ultrasonic Quality Levels in SA-609 refer to the surface area on the casting over which continuous indication, exceeding the transfer corrected distance amplitude curve, is maintained.

7 Areas are to be measured from dimensions of the movement of the search unit, using the center of the search unit as the reference point.

8 In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases, other criteria which incorporate a consideration of beam angles or beam spread must be used for realistic evaluation of the discontinuity.

NB-2575.1 Examination.

Cast pressure-retaining materials shall be examined by the radiographic method when specified in the order for the original castings, except that cast ferritic steels may be examined by either the radiographic or ultrasonic method, or a combination of both methods. Castings or sections of castings that have coarse grains or configurations that do not yield meaningful examination results by ultrasonic methods shall be examined by the radiographic method.

NB-2575.2 Extent.

Radiographic examination shall be performed on pressure-retaining castings such as vessel heads and flanges, valve bodies, bonnets and disks, pump casings and covers, and piping and fittings. The extent of radiographic coverage shall be of the maximum feasible volume and, when the shape of the casting precludes complete coverage, the coverage shall be at least as exemplified in the typical sketches as shown in Fig. NB-2575.2-1.

NB-2575.3 Examination Procedure.

The radiographic examination shall be performed in accordance with Article 2 of Section V, with the following modifications.

(a) *Film Selection.* Only Types 1, 2, and 3 are permitted.

(b) *Radiographic Density.* The transmitted film density through the radiographic image of the body of the appropriate penetrameter and the area of interest shall be 1.3 minimum for single film viewing. For composite viewing of multiple film exposures, each film of the composite set shall have a minimum density of 1.0. The maximum density shall be 4.0 for either single or composite viewing. A tolerance of 0.05 in density is allowed for variations between densitometer readings.

(c) The requirements of T-274 and T-285 of Article 2 of Section V need not be met.

(d) *Image Quality Indicator (IQI) Design.* Penetrameters shall be manufactured and identified in accordance with the requirements or alternates allowed in SE-142 and Appendices.

(e) *Image Quality Indicator (IQI) Selection.* The radiographic quality level shall be 2-4 *T* for section thicknesses up to and including $\frac{3}{4}$ in. (19 mm) and 2-2 *T* for section thicknesses greater than $\frac{3}{4}$ in. (19 mm). Radiographic quality is defined in Note 2 of SE-94.

(f) When radiographing weld ends of cast valves, NPS 4 and less, double-wall radiography may be used subject to the conditions of (1) and (2) below.

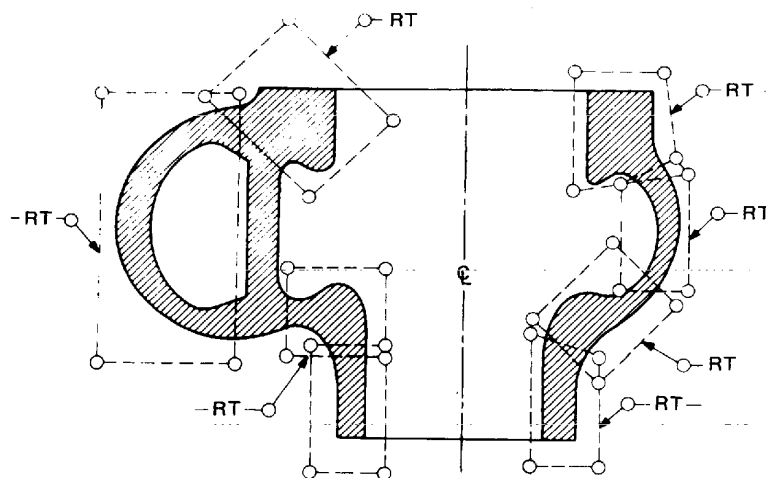
(1) The penetrameter thickness shall be based on the design section thickness of the double wall, excluding the weld preparation lip.

(2) Acceptance standards shall be based on nominal single-wall thickness.

Page 43

Page 45

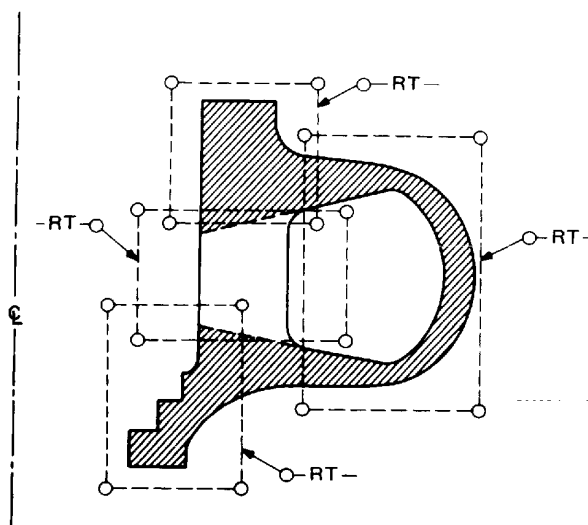
Pages 44-44



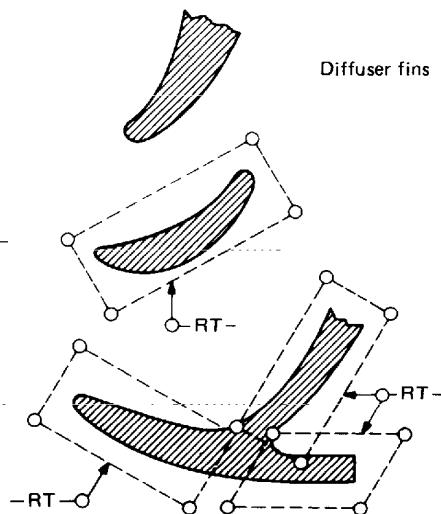
(a) Typical Volute-Type Pump Case

GENERAL NOTES:

- (a) Radiographic examination areas shall be indicated by a circle at each change of direction. The examination symbol for radiography shall be indicated as RT.
- (b) For nondestructive examination areas of revolution, the area shall be indicated by the examine-all-around symbol: — RT — ⌀
- (c) The sketches are typical and are to be used as a guide for minimum required coverage. Even though a sketch may be titled, "pump" or "valve," the coverage shown by the configurations may be applied interchangeably.



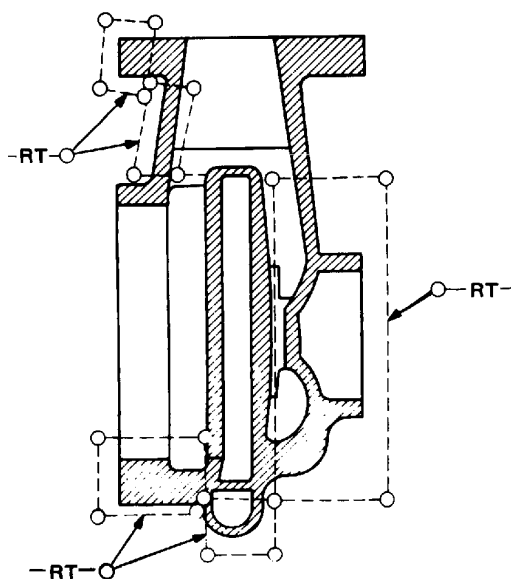
(b) Typical Diffuser-Type Pump Case



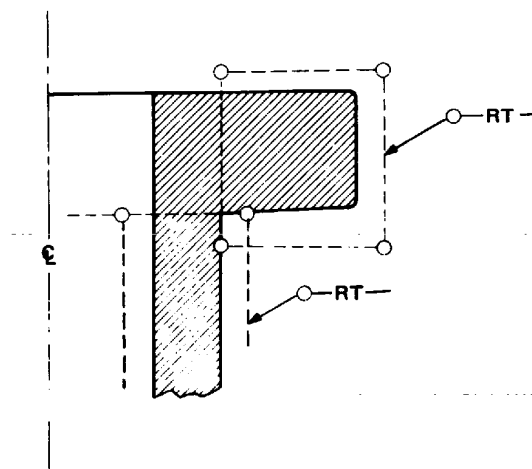
(c) Typical Diffuser-Type Pump Case Detail

FIG. NB-2575.2-1 TYPICAL PRESSURE-RETAINING PARTS OF PUMPS AND VALVES

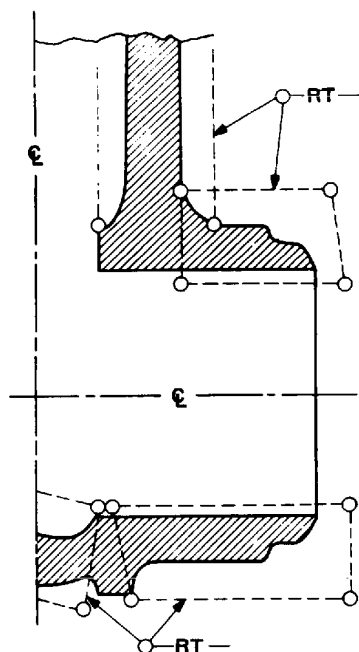
FIG. NB-2575.2-1 TYPICAL PRESSURE-RETAINING PARTS OF PUMPS AND VALVES



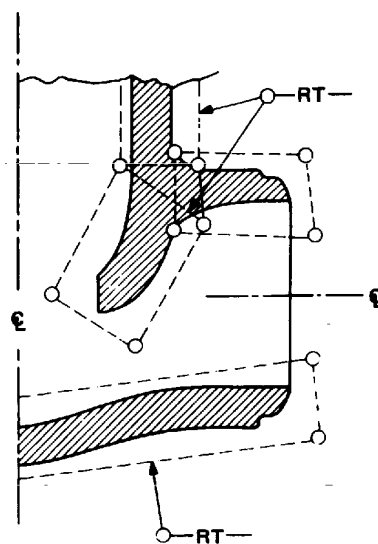
(d) Typical Single Stage Pump Case



(e) Typical Flange



(f) Typical Gate Valve



(g) Typical Globe Valve

FIG. NB-2575.2-1 TYPICAL PRESSURE-RETAINING PARTS OF PUMPS AND VALVES (CONT'D)

FIG. NB-2575.2-1 TYPICAL PRESSURE-RETAINING PARTS OF PUMPS AND VALVES (CONT'D)

NB-2575.4 Procedure Requirements.

Radiographic examination shall be performed in accordance with a written procedure. Each manufacturer shall certify that the procedure is in accordance with the requirements of NB-2575. The procedure shall be available for the interpretation of the films and shall be submitted together with the radiographs. Each procedure shall include at least the following information:

- (a) the type of material to be radiographed;
- (b) the material thickness ranges to be radiographed;
- (c) the type of radiation source, actual or maximum source size or focal spot, X-ray equipment voltage rating and manufacturer. The equipment manufacturer's or supplier's publications, such as technical manuals, decay curves, or written statements documenting the actual or maximum source size or focal spot, shall be acceptable as source size verification. For X-ray machines 320 kV and less, the focal spot size may be determined by the pinhole method;⁹
- (d) type and thickness of intensifying screens and filters;
- (e) minimum source-to-film distance.

NB-2575.5 Radiographic Setup Information.

To aid in proper interpretation of radiographs, details of the radiographic examination setup used shall accompany each group of radiographs. As a minimum, the information shall include:

- (a) film brand and the type and number of films in the cassette;
- (b) for multiple film technique, state whether viewing is to be single or superimposed;
- (c) blocking or masking technique, if used;
- (d) isotope or X-ray voltage used;
- (e) source-to-film distance used;
- (f) distance between film and object when film/cassette is not in contact with object;
- (g) geometric arrangement for the radiograph(s) (sketch);
- (h) orientation of location markers;
- (i) description of how internal markers, when used, locate area of interest;

⁹ Nondestructive Testing Handbook, Volume I, First Edition, pp. 14.32, 14.33, "Measuring Focal-Spot Size." Also, pp. 20, 21 of Radiography in Modern Industry, Fourth Edition.

(j) location markers, such as lead numbers or letters, which shall appear as radiographic images on the film, shall be permanently stamped on the surface of the casting being radiographed in a manner permitting the area of interest on a radiograph to be accurately located on the casting and providing evidence on the radiograph that the extent of coverage required by NB-2575.2 has been obtained. On castings or sections of castings where stamping is not feasible, the radiographic procedure shall so state, in which case a radiographic film location map shall be provided.

NB-2575.6 Acceptance Criteria.

Castings shall meet the acceptance requirements of Severity Level 2 of ASTM E 446-72, E 446-75, or E 446-78, Reference Radiographs for Steel Castings up to 2 In. in Thickness, ASTM E 186-67, E 186-73, or E 186-75, Reference Radiographs for Heavy-Walled (2 to 4 $\frac{1}{2}$ in.) Steel Castings, or ASTM E 280-68, E 280-72, or E 280-75, Reference Radiographs for Heavy-Walled (4 $\frac{1}{2}$ to 12 in.) Steel Castings, as applicable for the thickness being radiographed except that Category D, E, F, or G defects are not acceptable. The requirements of ASTM E 280-68, E 280-72, or E 280-75 shall apply for castings over 12 in. in thickness.

NB-2576 Liquid Penetrant Examination

(a) Castings shall be examined, if required, on all accessible surfaces by the liquid penetrant method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by bleeding out of the penetrant; however, localized surface discontinuities as may occur from machining marks, scale, or dents, may produce indications which are not relevant. Any indication in excess of the acceptance standards believed to be nonrelevant shall be reexamined to verify whether actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation that would mask indications of defects are unacceptable. Relevant indications are those which result from imperfections and have a major dimension greater than $\frac{1}{16}$ in. (1.6 mm). Linear indications are those whose length is more than three times the width. Rounded indications are those which are circular or elliptical with the length less than three times the width.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for materials less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for materials from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for materials 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

Page 46

(4) ten or more indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

NB-2577 Magnetic Particle Examination (for Ferritic Steel Products Only)

(a) Castings of magnetic material shall be examined, if required, on all accessible surfaces by a magnetic particle method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by retention of the examination medium. All indications are not necessarily defects since certain metallurgical discontinuities and magnetic permeability variations may produce indications that are not relevant. Any indication in excess of the acceptance standards believed to be nonrelevant shall be reexamined to verify whether actual defects are present. Nonrelevant indications which would mask indications of defects are unacceptable. Surface conditioning may precede the reexamination. Relevant indications are those which result from imperfections and have a major dimension greater than $\frac{1}{16}$ in. Linear indications are those whose length is more than three times the width. Rounded indications are those which are circular or elliptical with the length less than three times the width.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for materials less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for materials from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for materials 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

NB-2580 EXAMINATION OF BOLTS, STUDS, AND NUTS

NB-2581 Required Examination

All bolting material shall be visually examined in accordance with NB-2582. Nominal sizes greater than 1 in. (25 mm) shall be examined by either the magnetic particle or the liquid penetrant method. In addition, nominal sizes greater than 2 in. (51 mm) but not over 4 in. (102 mm) shall be examined by the ultrasonic method as required by NB-2585 and nominal sizes greater than 4 in. (102 mm) shall be examined by the ultrasonic method as required by NB-2586.

NB-2582 Visual Examination

The areas of threads, shanks, and heads of final machined parts shall be visually examined. Harmful discontinuities such as laps, seams, or cracks that would be detrimental to the intended service are unacceptable.

NB-2583 Magnetic Particle Examination (for Ferritic Steel Bolting Material Only)

NB-2583.1 Examination Procedure.

All bolts, studs, and nuts greater than 1 in. (25 mm) nominal bolt size shall be examined by the magnetic particle method in accordance with ASTM A 275-78. If desired, the supplier may perform liquid penetrant examination in accordance with NB-2584 instead of magnetic particle examination. Such examination shall be performed on the finished component after threading or on the materials stock at approximately the finished diameter before threading and after heading (if involved). This examination shall be performed on all accessible surfaces.

NB-2583.2 Evaluation of Indications

(a) All indications shall be evaluated in terms of the acceptance standards. Linear indications are those indications in which the length is more than three times the width. Rounded indications are those which are circular or elliptical with the length equal to or less than three times the width.

(b) All indications are not necessarily relevant: leakage of magnetic fields and permeability variations may produce indications that are not relevant to the detection of unacceptable discontinuities. Indications with major dimensions of $\frac{1}{16}$ in. (1.6 mm) or less are not relevant.

(c) Any indication that is believed to be nonrelevant, and that is larger than acceptable, shall be considered to be a defect and shall be reexamined after light surface conditioning.

Page 47

(d) Any indication observed during such reexamination shall be considered relevant and shall be evaluated in terms of the acceptance standards.

(e) As an alternative to magnetic particle reexamination, other nondestructive examination means (such as liquid penetrant examination for surface discontinuities) may be used to determine relevancy.

NB-2583.3 Acceptance Standard.

Linear nonaxial indications are unacceptable. Linear axial indications greater than 1 in. (25 mm) in length are unacceptable.

NB-2584 Liquid Penetrant Examination

NB-2584.1 Examination Procedure.

All bolts, studs, and nuts greater than 1 in. (25 mm) nominal bolt size shall be examined by a liquid penetrant method in accordance with the methods of Article 6, Section V. Such examination shall be performed on the finished component after threading or on the materials stock at approximately the finished diameter before threading and after heading (if involved).

NB-2584.2 Evaluation of Indications.

All indications shall be evaluated in terms of the acceptance standards. Linear indications are those indications in which the length is more than three times the width. Rounded indications are those which are circular to elliptical with the length equal to or less than three times the width. All penetrant indications are not necessarily relevant. Surface imperfections such as machining marks and scratches may produce indications that are nonrelevant to the detection of unacceptable discontinuities. Broad areas of pigmentation, which could mask indications of defects, are unacceptable. Indications with major dimensions of $\frac{1}{16}$ in. (1.6 mm) or less are not relevant. Any indication that is believed to be nonrelevant, and that is larger than acceptable, shall be considered to be a defect and shall be reexamined after light surface conditioning. Any area of pigmentation also shall be reexamined after recleaning or light surface conditioning, as appropriate. Any indication observed during such reexamination shall be considered relevant and shall be evaluated in terms of the acceptance standards.

NB-2584.3 Acceptance Standard.

Linear nonaxial indications are unacceptable. Linear axial indications greater than 1 in. (25 mm) long are unacceptable.

NB-2585 Ultrasonic Examination for Sizes Greater Than 2 in. (51 mm)

All bolts, studs, and nuts greater than 2 in. nominal bolt size shall be ultrasonically examined over the entire surface prior to threading in accordance with the following requirements.

NB-2585.1 Ultrasonic Method.

Examination shall be carried out by the straight beam, radial-scan method in accordance with SA-388 of Article 23 of Section V.

NB-2585.2 Examination Procedure.

Examination shall be performed at a nominal frequency of 2.25 MHz with a search unit not to exceed 1 sq in. (645 mm²).

NB-2585.3 Calibration of Equipment.

Calibration sensitivity shall be established by adjustment of the instrument so that the first back reflection is 75% to 90% of full-screen height.

NB-2585.4 Acceptance Standard.

Any discontinuity that causes an indication in excess of 20% of the height of the first back reflection or any discontinuity that prevents the production of a first back reflection of 50% of the calibration amplitude is not acceptable.

NB-2586 Ultrasonic Examination for Sizes Over 4 in. (102 mm)

In addition to the requirements of NB-2585, all bolts, studs, and nuts over 4 in. (102 mm) nominal bolt size shall be ultrasonically examined over the entire end surface before or after threading in accordance with the following requirements.

NB-2586.1 Ultrasonic Method.

Examination shall be carried out by the straight beam, longitudinal-scan method.

NB-2586.2 Examination Procedure.

Examination shall be performed at a nominal frequency of 2.25 MHz with a search unit having a circular cross section with a diameter not less than $\frac{1}{2}$ in. (13 mm) nor more than $1\frac{1}{8}$ in. (29 mm).

NB-2586.3 Calibration of Equipment.

Calibration shall be established on a test bar of the same nominal composition and diameter as the production part and a minimum of one-half of the length. A $\frac{3}{8}$ in. (10 mm) diameter by 3 in. (76 mm) deep flat-bottom hole shall be drilled in one end of the bar and plugged to full depth. A distance-amplitude curve shall be established by scanning from both ends of the test bar.

NB-2586.4 Acceptance Standard.

Any discontinuity that causes an indication in excess of that produced

Page 48

by the calibration hole in the reference specimen as corrected by the distance-amplitude curve is not acceptable.

NB-2587 Time of Examination

Acceptance examinations shall be performed after the final heat treatment required by the basic material specification.

NB-2588 Elimination of Surface Defects

Unacceptable surface defects on finished bolts, studs, and nuts are not permitted, and are cause for rejection.

NB-2589 Repair by Welding

Weld repairs of bolts, studs, and nuts are not permitted.

NB-2600 MATERIAL ORGANIZATIONS' QUALITY SYSTEM PROGRAMS

NB-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS

(a) Except as provided in (b) below, Material Organizations shall have a Quality System Program or an Identification and Verification Program, as applicable, which meets the requirements of NCA-3800.

(b) The requirements of NCA-3862 and NCA-3856 shall be met as required by NB-2130 and NB-2150, respectively. The other requirements of NCA-3800 need not be used by Material Organizations for small products, as defined in (c) below, for brazing material, and for material which is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Assurance Program (NCA-4000) shall include measures to provide assurance that the material is furnished in accordance with the material specification and with the applicable requirements of this Subsection.

(c) For the purpose of this paragraph, small products are defined as given in (1) through (5) below:

- (1) pipe, tube (except heat exchanger tube), pipe fittings, and flanges 2 in. nominal pipe size (DN 50) and less;
- (2) bolting material, including studs, nuts, and bolts of 1 in. (25 mm) nominal diameter and less;
- (3) bars with a nominal cross-sectional area of 1 sq in. (645 mm²) and less;
- (4) material for pumps and valves with inlet pipe connections of 2 in. nominal pipe size (DN 50) and less;
- (5) material exempted by NB-2121(c).

NB-2700 DIMENSIONAL STANDARDS

Dimensions of standard items shall comply with the standards and specifications listed in Table NB-3132-1.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NB-3000

NB-3100 GENERAL DESIGN

NB-3110 LOADING CRITERIA

NB-3111 Loading Conditions

The loadings that shall be taken into account in designing a component include, but are not limited to, those in (a) through (g) below:

- (a) internal and external pressure;
- (b) impact loads, including rapidly fluctuating pressures;
- (c) weight of the component and normal contents under operating or test conditions, including additional pressure due to static and dynamic head of liquids;
- (d) superimposed loads such as other components, operating equipment, insulation, corrosion resistant or erosion resistant linings, and piping;
- (e) wind loads, snow loads, vibrations, and earthquake loads where specified;
- (f) reactions of supporting lugs, rings, saddles, or other types of supports;
- (g) temperature effects.

NB-3112 Design Loadings

The Design Loadings shall be established in accordance with NCA-2142.1 and the following subparagraphs.

NB-3112.1 Design Pressure

(a) The specified internal and external Design Pressures to be used in this Subsection shall be established in accordance with NCA-2142.1(a). They shall be used in the computations made to show compliance with the stress intensity limits of NB-3221, NB-3227.1, NB-3227.2, NB-3227.4, NB-3228.1, NB-3228.2, and NB-3231. The specified service pressure at the appropriate time shall be used in the computations made to show compliance with the stress intensity limits of NB-3222, NB-3228.3, and NB-3232. When the occurrence of different pressures during operation can be predicted for different zones of a component, the Design Pressure of the different zones may be based on their predicted pressures.

(b) All pressures referred to in this Article are to be taken as pounds per square inch, psi, above atmospheric pressure, unless otherwise stated.

NB-3112.2 Design Temperature

(a) The specified Design Temperature shall be established in accordance with NCA-2142.1(b). It shall be used in computations involving the Design Pressure and coincidental Design Mechanical Loads. The actual metal temperature at the point under consideration shall be used in all computations where the use of the specified service pressure is required.

(b) All temperatures referred to in this Subsection are the metal temperatures expressed in degrees Fahrenheit (°F) unless otherwise stated.

(c) Where a component is heated by tracing, induction coils, jacketing, or internal heat generation, the effect of such heating shall be incorporated in the establishment of the Design Temperature.

NB-3112.3 Design Mechanical Loads.

The specified Design Mechanical Loads shall be established in accordance with NCA-2142.1(c). They shall be used in conjunction with the Design Pressure.

NB-3112.4 Design Stress Intensity Values.

Design stress intensity values for materials are listed in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4. The material shall not be used at metal and design temperatures above those for which stress intensity values are listed. The values in the Table may be interpolated for intermediate temperatures.

NB-3113 Service Conditions

Each service condition to which the components may be subjected shall be classified in accordance with NCA-2142 and Service Limits [NCA-2142.4(b)] designated in the Design Specifications in such detail as will provide a complete basis for design, construction, and inspection

Page 62

in accordance with this Article. The requirements of (a) and (b) below shall also apply.

(a) *Level B Conditions.* The estimated duration of service conditions for which Level B Limits are specified shall be included in the Design Specifications.

(b) *Level C Conditions.* The total number of postulated occurrences for all specified service conditions for which Level C Limits are specified shall not cause more than 25 stress cycles having an S_a value greater than that for 10^6 cycles from the applicable fatigue design curves of Figs. I-9.0.

NB-3120 SPECIAL CONSIDERATIONS

NB-3121 Corrosion

Material subject to thinning by corrosion, erosion, mechanical abrasion, or other environmental effects shall have provision made for these effects during the design or specified life of the component by a suitable increase in or addition to the thickness of the base metal over that determined by the design formulas. Material added or included for these purposes need not be of the same thickness for all areas of the component if different rates of attack are expected for the various areas. It should be noted that the tests on which the design fatigue curves (Figs. I-9.0) are based did not include tests in the presence of corrosive environments which might accelerate fatigue failure.

NB-3122 Cladding

The rules of the following subparagraphs apply to the analysis of clad components constructed of material permitted in Section II, Part D, Subpart 1, Tables 2A and 2B.

NB-3122.1 Primary Stresses.

No structural strength shall be attributed to the cladding in satisfying NB-3221.

NB-3122.2 Design Dimensions.

The dimensions given in (a) and (b) below shall be used in the design of the component:

(a) for components subjected to internal pressure, the inside diameter shall be taken at the nominal inner face of the cladding;

(b) for components subjected to external pressure, the outside diameter shall be taken at the outer face of the base metal.

NB-3122.3 Secondary and Peak Stresses.

In satisfying NB-3222.2 and NB-3222.4, the presence of the cladding shall be considered with respect to both the thermal analysis and the stress analysis. The stresses in both materials shall be limited to the values specified in

NB-3222.2 and NB-3222.4. However, when the cladding is of the integrally bonded type and the nominal thickness of the cladding is 10% or less of the total thickness of the component, the presence of the cladding may be neglected.

NB-3122.4 Bearing Stresses.

In satisfying NB-3227.1, the presence of cladding shall be included.

NB-3123 Welding

NB-3123.1 Dissimilar Welds.

In satisfying the requirements of this Subarticle, caution should be exercised in design and construction involving dissimilar metals having different coefficients of thermal expansion in order to avoid difficulties in service.

NB-3123.2 Fillet Welded Attachments.

Fillet welds conforming to Fig. NB-4427-1 may be used for attachments to components except as limited by NB-4433. Evaluation for cyclic loading shall be made in accordance with the appropriate Subarticle of NB-3000, and shall include consideration of temperature differences between the component and the attachment, and of expansion or contraction of the component produced by internal or external pressure.

NB-3124 Environmental Effects

Changes in material properties may occur due to environmental effects. In particular, fast neutron irradiation (>1 MeV) above a certain level may result in significant increase in the brittle fracture transition temperature and deterioration in the resistance to fracture at temperatures above the transition range (upper shelf energy). Therefore, nozzles or other structural discontinuities in ferritic vessels should preferably not be placed in regions of high neutron flux.

NB-3125 Configuration

Accessibility to permit the examinations required by the Edition and Addenda of Section XI as specified in the Design Specification for the component shall be provided in the design of the component.

NB-3130 GENERAL DESIGN RULES

NB-3131 Scope

Design rules generally applicable to all components are provided in the following paragraphs. The design Subarticle for the specific component provides rules

Page 63

applicable to that particular component. In case of conflict between NB-3130 and the design rules for a particular component, the component design rules govern.

NB-3132 Dimensional Standards for Standard Products

Dimensions of standard products shall comply with the standards and specifications listed in Table NB-3132-1 when the standard or specification is referenced in the specific design Subarticle. However, compliance with these standards does not replace or eliminate the requirements for stress analysis when called for by the design Subarticle for a specific component.

NB-3133 Components Under External Pressure

NB-3133.1 General.

Rules are given in this paragraph for determining the stresses under external pressure loading in spherical and cylindrical shells with or without stiffening rings, and tubular products consisting of pipes, tubes, and fittings. Charts for determining the stresses in shells, hemispherical heads, and tubular products are given in Section II, Part D, Subpart 3.

NB-3133.2 Nomenclature.

The symbols used in this paragraph are defined as follows:

A	= factor determined from Fig. G in Section II, Part D, Subpart 3 and used to enter the applicable material chart in Section II, Part D, Subpart 3. For the case of cylinders having D_o/T values less than 10, see NB-3133.3(b). Also, factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a stiffening ring, corresponding to the factor B and the design metal temperature for the shell under consideration.
A_s	= cross-sectional area of a stiffening ring, sq in.
B	= factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a shell or stiffening ring at the design metal temperature, psi
D_o	= outside diameter of the cylindrical shell course or tube under consideration, in.
E	= modulus of elasticity of material at Design Temperature, psi. For external pressure and axial compression design in accordance with this Section, the modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 3. (Interpolation may be made between lines for intermediate temperatures.) The modulus of elasticity values shown in Section II, Part D, Subpart 3 for material groups may differ from those values listed in Section II, Part D, Subpart 2, Tables TM for specific materials. Section II, Part D, Subpart 3 values shall be applied only to external pressure and axial compression design.
I	= available moment of inertia of the combined ring-shell section about its neutral axis, parallel to the axis of the shell, in. ⁴ The width of the shell which is taken as contributing to the combined moment of inertia shall not be greater than $1.10\sqrt{D_o T}$ and shall be taken as lying one-half on each side of the centroid of the ring. Portions of shell plates shall not be considered as contributing area to more than one stiffening ring.
I_s	= required moment of inertia of the combined ring-shell section about its neutral axis parallel to the axis of the shell, in. ⁴
L	= total length, in., of a tube between tubesheets, or the design length of a vessel section, taken as the largest of the following: (1) the distance between head tangent lines plus one-third of the depth of each head if there are no stiffening rings; (2) the greatest center-to-center distance between any two adjacent stiffening rings; or (3) the distance from the center of the first stiffening ring to the head tangent line plus one-third of the depth of the head,

all measured parallel to the axis of the vessel, in.

L_s

= one-half the distance, in., from the center line of the stiffening ring to the next line of support on one side, plus one-half of the center line distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the component. A line of support is:

(1) a stiffening ring that meets the requirements of this paragraph;

(2) a circumferential line on a head at one-third the depth of the head from the head tangent line; or

(3) circumferential connection to a jacket for a jacketed section of a cylindrical shell.

P

= external design pressure, psi (gage or absolute, as required)

P_a

= allowable external pressure, psi (gage or absolute, as required)

R

= inside radius of spherical shell, in.

S

= the lesser of 1.5 times the stress intensity at design metal temperature from Section II, Part D, Subpart 1, Tables 2A and 2B, or 0.9 times the tabulated yield strength at design metal temperature from Section II, Part D, Subpart 1, Table Y-1, psi

Page 64

Page 65

T

= minimum required thickness of cylindrical shell or tube, or spherical shell, in.

T_n

= nominal thickness used, less corrosion allowance, of cylindrical shell or tube, in.

[98]

**TABLE NB-3132-1
DIMENSIONAL STANDARDS**

Standard	Designation
Pipe and Tubes	
Welded and Seamless Wrought Steel Pipe	ANSI B36.10-1985
Stainless Steel Pipe	ANSI B36.19-1985
Fittings, Flanges, and Gaskets	
Steel Pipe Flanges and Flanged Fittings	ANSI B16.5-1988
Factory Made Wrought Steel Butt welding Fittings	ANSI B16.9-1986 [Note (1)]
Forged Steel Fittings, Socket-Welding and Threaded	ANSI B16.11-1980
Ring-Joint Gaskets and Grooves for Steel Pipe Flanges	ANSI B16.20-1984
Nonmetallic Gaskets for Pipe Flanges	ANSI B16.21-1978
Butt welding Ends	ANSI B16.25-1986
Wrought Steel Butt welding Short Radius Elbows and Returns	ANSI B16.28-1986 [Note (2)]
Refrigeration Flare Type Fittings	SAE J513 F-1981
Stainless Steel Butt welding Fittings	MSS SP-43-1982(R1986)
Steel Pipeline Flanges	MSS SP-44-1985
Factory Made Butt welding Fittings for Class 1	
Nuclear Piping Applications	MSS SP-87-1982 [Note (3)]
Large Diameter Carbon Steel Flanges	API 605-1980
Standard for Steel Pipe Flanges	AWWA C207-1978
Bolting	
Square and Hex Bolts and Screws, Including Askew Head Bolts,	
Hex Cap Screws, and Lag Screws	ANSI B18.2.1-1981
Square and Hex Nuts	ANSI B18.2.2-1987
Socket Cap, Shoulder, and Set Screws	ANSI B18.3-1986
Threads	
Unified Inch Screw Threads (UN and UNR Thread Form)	ANSI B1.1-1982
Pipe Threads (Except Dryseal)	ANSI B1.20.1-1983
Dryseal Pipe Threads	ANSI B1.20.3-1976(R1982)
Gaging for Dryseal Piping Threads	ANSI B1.20.5-1978
Valves	
Valves — Flanged and Butt welding End	ANSI B16.34-1988
NOTES:	
(1) Analysis per ANSI B16.9, paragraph 2.2, is acceptable only for caps and reducers.	
(2) Analysis per ANSI B16.28, paragraph 2.2, is not acceptable.	
(3) Analysis per MSS-SP-87 is acceptable only for caps and reducers.	

TABLE NB-3132-1 DIMENSIONAL STANDARDS

NB-3133.3 Cylindrical Shells and Tubular Products

(a) The minimum thickness of cylindrical shells or tubular products under external pressure having D_o/T values equal to or greater than 10 shall be determined by the procedure given in Steps 1 through 8 below.

Step 1: Assume a value for T . Determine the ratios L/D_o and D_o/T .

Step 2: Enter Fig. G in Section II, Part D, Subpart 3 at the value of L/D_o determined in Step 1. For values of L/D_o greater than 50, enter the chart at a value of L/D_o of 50. For values of L/D_o less than 0.05, enter the chart at a value of L/D_o of 0.05.

Step 3: Move horizontally to the line for the value of D_o/T determined in Step 1. Interpolation may be made for intermediate values of D_o/T . From this intersection move vertically downward and read the value of factor A .

Step 4: Using the value of A calculated in Step 3, enter the applicable material chart in Section II, Part D, Subpart 3 for the material/temperature under consideration. Move vertically to an intersection with the material/temperature line for the design temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material line, see Step 7.

Step 5: From the intersection obtained in Step 4 move horizontally to the right and read the value of B .

Step 6: Using this value of B , calculate the maximum allowable external pressure P_a using the following formula:

$$P_a = \frac{4B}{3D_o/T}$$

Step 7: For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following formula:

$$P_a = \frac{2AE}{3D_o/T}$$

Step 8: Compare P_a with P . If P_a is smaller than P , select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P .

(b) The minimum thickness of cylindrical shells or tubular products under external pressure having D_o/T values less than 10 shall be determined by the procedure given in Steps 1 through 4 below.

Step 1: Using the same procedure as given in (a) above, obtain the value of B . For values of D_o/T less than 4, the value of factor A can be calculated using the following formula:

$$A = \frac{1.1}{(D_o/T)^2}$$

For values of A greater than 0.10 use a value of 0.10.

Step 2: Using the value of B obtained in Step 1, calculate a value P_{al} using the following formula:

$$P_{a1} = \left(\frac{2.167}{D_o/T} - 0.0833 \right) B$$

Step 3: Calculate a value P_{a2} using the following formula:

$$P_{a2} = \frac{2S}{D_o/T} \left(1 - \frac{1}{D_o/T} \right)$$

Step 4: The smaller of the values of P_{a1} calculated in Step 2 or P_{a2} calculated in Step 3 shall be used for the maximum allowable external pressure P_a . Compare P_a with P . If P_a is smaller than P , select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P .

NB-3133.4 Spherical Shells.

The minimum required thickness of a spherical shell under external pressure, either seamless or of built-up construction with butt joints, shall be determined by the procedure given in Steps 1 through 6 below.

Page 66

Step 1: Assume a value for T and calculate the value of factor A using the following formula:

$$A = \frac{0.125}{R/T}$$

Step 2: Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values at A falling to the left of the material/temperature line, see Step 5.

Step 3: From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B .

Step 4: Using the value of B obtained in Step 3, calculate the value of the maximum allowable external pressure P_a using the following formula:

$$P_a = \frac{B}{R/T}$$

Step 5: For values of A falling to the left of the applicable material/temperature line for the Design Temperature, the value of P_a can be calculated using the following formula:

$$P_a = \frac{0.0625E}{(R/T)^2}$$

Step 6: Compare P_a obtained in Step 4 or 5 with P . If P_a is smaller than P , select a larger value for T , and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P .

NB-3133.5 Stiffening Rings for Cylindrical Shells

(a) The required moment of inertia of the combined ring-shell section is given by the formula:

$$I_s = \frac{D_o^2 L_s (T + A_s / L_s) A}{10.9}$$

The available moment of inertia I for a stiffening ring shall be determined by the procedure given in Steps 1 through 6 below.

Step 1: Assuming that the shell has been designed and D_o , L_s , and T_n are known, select a member to be used for the stiffening ring and determine its area A and the value of I defined in NB-3133.2. Then calculate B by the formula:

$$B = \frac{3}{4} \left(\frac{PD_o}{T_n + A_s / L_s} \right)$$

Step 2: Enter the right-hand side of the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration at the value of B determined in Step 1. If different materials are used for the shell and stiffening ring, then use the material chart resulting in the larger value for factor A in Steps 4 or 5 below.

Step 3: Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5.

Step 4: Move vertically to the bottom of the chart and read the value of A .

Step 5: For values of B falling below the left end of the material/temperature line for the design temperature, the value of A can be calculated using the following formula:

$$A = 2B/E$$

Step 6: If the required I_s is greater than the computed moment of inertia I for the combined-ring shell section selected in Step 1, a new section with a larger moment of inertia must be selected and a new I_s determined. If the required I_s is smaller than the computed I for the section selected in Step 1, that section should be satisfactory.

(b) Stiffening rings may be attached to either the outside or the inside of the component by continuous welding.

NB-3133.6 Cylinders Under Axial Compression.

The maximum allowable compressive stress to be used in the design of cylindrical shells and tubular products subjected to loadings that produce longitudinal compressive stresses in the shell or wall shall be the lesser of the values given in (a) or (b) below:

Page 67

(a) the S_m value for the applicable material at design temperature given in Section II, Part D, Subpart 1, Tables 2A and 2B;

(b) the value of the factor B determined from the applicable chart contained in Section II, Part D, Subpart 3, using the following definitions for the symbols on the charts:

R	= inside radius of the cylindrical shell or tubular product, in.
T	= minimum required thickness of the shell or tubular product, exclusive of the corrosion allowance, in.

The value of B shall be determined from the applicable chart contained in Section II, Part D, Subpart 3 as given in Steps 1 through 5 below.

Step 1: Using the selected values of T and R , calculate the value of factor A using the following formula:

$$A = \frac{0.125}{R/T}$$

Step 2: Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 4.

Step 3: From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B . This is the maximum allowable compressive stress for the values of T and R used in Step 1.

Step 4: For values of A falling to the left of the applicable material/temperature line, the value of B shall be calculated using the following formula:

$$B = \frac{AE}{2}$$

Step 5: Compare the value of B determined in Step 3 or 4 with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of T and R . If the value of B is smaller than the computed compressive stress, a greater value of T must be selected and the design procedure repeated until a value of B is obtained which is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

NB-3134 Leak Tightness

Where a system leak tightness greater than that required or demonstrated by a hydrostatic test is required, the leak

tightness requirements for each component shall be set forth in the Design Specifications.

NB-3135 Attachments

(a) Except as permitted in (d), (e), or (f) below, attachments and connecting welds within the jurisdictional boundary of the component as defined in NB-1130 shall meet the stress limits of the component or NB-3200.

(b) The design of the component shall include consideration of the localized interaction effects and loads transmitted through the attachment to and from the pressure-retaining portion of the component. Localized interaction effects include thermal stresses, stress concentrations, and restraint of the pressure-retaining portion of the component.

(c) The first welded structural attachment within $2t$ of the pressure-retaining portion of the component, where t is the nominal thickness of the pressure-retaining material, shall be evaluated for cyclic loading. Evaluation shall be in accordance with the appropriate Subarticle of NB-3000 and shall be made at the juncture of the attachment to the component.

(d) Beyond $2t$ the appropriate design rules of NF-3000 may be used as a substitute for the design rules of NB-3000 for cast and forged portions of attachments which are in the component support load path.

(e) Nonstructural attachments shall meet the requirements of NB-4435.

(f) Beyond $2t$ the appropriate design rules of NG-3000 may be used as a substitute for the design rules of NB-3000 for portions of cast or forged attachments which are core support structures.

NB-3137 Reinforcement for Openings

The requirements applicable to vessels and piping are contained in NB-3330 and NB-3643, respectively.

Page 68

NB-3200 DESIGN BY ANALYSIS

NB-3210 DESIGN CRITERIA

NB-3211 Requirements for Acceptability

The requirements for the acceptability of a design by analysis are given in (a) through (d) below.

(a) The design shall be such that stress intensities will not exceed the limits described in this Subarticle and in NB-3100 and tabulated in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4.

(b) The design details shall conform to the rules given in NB-3100 and those given in the Subarticle applicable to the specific component.

(c) For configurations where compressive stresses occur, in addition to the requirements in (a) and (b) above, the critical buckling stress shall be taken into account. For the special case of external pressure, NB-3133 applies.

(d) Protection against nonductile fracture shall be provided by satisfying one of the following provisions:

(1) performing an evaluation of service and test conditions by methods similar to those contained in Appendix G; or

(2) for piping, pump, and valve material thickness greater than $2\frac{1}{2}$ in. (64 mm) establishing a lowest service temperature¹ that is not lower than RT_{NDT} (NB-2331) + 100°F;

(3) for piping, pump, and valve material thickness equal to or less than $2\frac{1}{2}$ in. (64 mm), the requirements of NB-2332(a) shall be met at or below the lowest service temperature as established in the design specification.

NB-3212 Basis for Determining Stresses

The theory of failure, used in the rules of this Subsection for combining stresses, is the maximum shear stress theory. The maximum shear stress at a point is equal to one-half the difference between the algebraically largest and the algebraically

smallest of the three principal stresses at the point.

NB-3213 Terms Relating to Stress Analysis

Terms used in this Subsection relating to stress analysis are defined in the following subparagraphs.

1 Lowest service temperature is the minimum temperature of the fluid retained by the component or, alternatively, the calculated volumetric average metal temperature expected during normal operation, whenever pressure within the component exceeds 20% of the pre-operational system hydrostatic test pressure.

NB-3213.1 Stress Intensity.²

Stress intensity is the equivalent intensity of combined stress, or, in short, the stress intensity is defined as twice the maximum shear stress. In other words, the stress intensity is the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tensile stresses are considered positive and compressive stresses are considered negative.

NB-3213.2 Gross Structural Discontinuity.

Gross structural discontinuity is a geometric or material discontinuity which affects the stress or strain distribution through the entire wall thickness of the pressure retaining member. Gross discontinuity type stresses are those portions of the actual stress distributions that produce net bending and membrane force resultants when integrated through the wall thickness. Examples of gross structural discontinuities are head-to-shell and flange-to-shell junctions, nozzles (NB-3331), and junctions between shells of different diameters or thicknesses.

NB-3213.3 Local Structural Discontinuity.

Local structural discontinuity is a geometric or material discontinuity which affects the stress or strain distribution through a fractional part of the wall thickness. The stress distribution associated with a local discontinuity causes only very localized types of deformation or strain and has no significant effect on the shell type discontinuity deformations. Examples are small fillet radii, small attachments, and partial penetration welds.

NB-3213.4 Normal Stress.

Normal stress is the component of stress normal to the plane of reference. This is also referred to as direct stress. Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to be made up in turn of two components, one of which is uniformly distributed and equal to the average value of stress across the thickness under consideration, and the other of which varies from this average value with the location across the thickness.

NB-3213.5 Shear Stress.

Shear stress is the component of stress tangent to the plane of reference.

NB-3213.6 Membrane Stress.

Membrane stress is the component of normal stress which is uniformly distributed and equal to the average value of stress across the thickness of the section under consideration.

2 This definition of stress intensity is not related to the definition of stress intensity applied in the field of Fracture Mechanics.

NB-3213.7 Bending Stress.

Bending stress is the variable component of normal stress described in NB-3213.4.

The variation may or may not be linear across the thickness.

NB-3213.8 Primary Stress.

Primary stress is any normal stress or a shear stress developed by an imposed loading which is necessary to satisfy the

Primary stress is any normal stress or a shear stress developed by an imposed loading which is necessary to satisfy the laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses which considerably exceed the yield strength will result in failure or, at least, in gross distortion. A thermal stress is not classified as a primary stress. Primary membrane stress is divided into general and local categories. A general primary membrane stress is one which is so distributed in the structure that no redistribution of load occurs as a result of yielding. Examples of primary stresses are:

- (a) general membrane stress in a circular cylindrical or a spherical shell due to internal pressure or to distributed live loads;
- (b) bending stress in the central portion of a flat head due to pressure.

NB-3213.9 Secondary Stress.

Secondary stress is a normal stress or a shear stress developed by the constraint of adjacent material or by self-constraint of the structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions which cause the stress to occur and failure from one application of the stress is not to be expected. Examples of secondary stresses are:

- (a) general thermal stress [NB-3213.13(a)];
- (b) bending stress at a gross structural discontinuity.

NB-3213.10 Local Primary Membrane Stress.

Cases arise in which a membrane stress produced by pressure or other mechanical loading and associated with a discontinuity would, if not limited, produce excessive distortion in the transfer of load to other portions of the structure. Conservatism requires that such a stress be classified as a local primary membrane stress even though it has some characteristics of a secondary stress. A stressed region may be considered local if the distance over which the membrane stress intensity exceeds $1.1S_m$ does not extend in the meridional direction more than $1.0\sqrt{Rt}$, where R is the minimum midsurface radius of curvature and t is the minimum thickness in the region considered. Regions of local primary stress intensity involving axisymmetric membrane stress distributions which exceed $1.1S_m$ shall not be closer in the meridional direction than $2.5\sqrt{Rt}$, where R is defined as $(R_1 + R_2)/2$ and t is defined as $(t_1 + t_2)/2$ (where t_1 and t_2 are the minimum thicknesses at each of the regions considered, and R_1 and R_2 are the minimum midsurface radii of curvature at these regions where the membrane stress intensity exceeds $1.1S_m$). Discrete regions of local primary membrane stress intensity, such as those resulting from concentrated loads acting on brackets, where the membrane stress intensity exceeds $1.1S_m$, shall be spaced so that there is no overlapping of the areas in which the membrane stress intensity exceeds $1.1S_m$.

NB-3213.11 Peak Stress.

Peak stress is that increment of stress which is additive to the primary plus secondary stresses by reason of local discontinuities or local thermal stress [NB-3213.13(b)] including the effects, if any, of stress concentrations. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture. A stress which is not highly localized falls into this category if it is of a type which cannot cause noticeable distortion. Examples of peak stresses are:

- (a) the thermal stress in the austenitic steel cladding of a carbon steel component;
- (b) certain thermal stresses which may cause fatigue but not distortion;
- (c) the stress at a local structural discontinuity;
- (d) surface stresses produced by thermal shock.

NB-3213.12 Load Controlled Stresses.

Load controlled stresses are the stresses resulting from application of a loading, such as internal pressure, inertial loads, or the effects of gravity, whose magnitude is not reduced as a result of displacement.

NB-3213.13 Thermal Stress.

Thermal stress is a self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally should under a change in temperature. For the purpose of establishing allowable stresses, two types of thermal stress are recognized, depending on the volume or area in which distortion takes place, as described in (a) and (b) below.

(a) General thermal stress is associated with distortion of the structure in which it occurs. If a stress of this type, neglecting stress concentrations, exceeds twice the yield strength of the material, the elastic analysis may be invalid and successive thermal cycles may produce incremental distortion. Therefore this type is classified as secondary stress in Table NB-3217-1. Examples of general thermal stresses are:

(1) stress produced by an axial temperature distribution in a cylindrical shell;

Page 70

(2) stress produced by the temperature difference between a nozzle and the shell to which it is attached;

(3) the equivalent linear stress³ produced by the radial temperature distribution in a cylindrical shell.

(b) Local thermal stress is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses shall be considered only from the fatigue standpoint and are therefore classified as local stresses in Table NB-3217-1. In evaluating local thermal stresses the procedures of NB-3227.6(b) shall be used. Examples of local thermal stresses are:

(1) the stress in a small hot spot in a vessel wall;

(2) the difference between the actual stress and the equivalent linear stress resulting from a radial temperature distribution in a cylindrical shell;

(3) the thermal stress in a cladding material which has a coefficient of expansion different from that of the base metal.

NB-3213.14 Total Stress.

Total stress is the sum of the primary, secondary, and peak stress contributions. Recognition of each of the individual contributions is essential to establishment of appropriate stress limitations.

NB-3213.15 Operational Cycle.

Operational cycle is defined as the initiation and establishment of new conditions followed by a return to the conditions which prevailed at the beginning of the cycle. The types of operating conditions which may occur are further defined in NB-3113.

NB-3213.16 Stress Cycle.

Stress cycle is a condition in which the alternating stress difference [NB-3222.4(e)] goes from an initial value through an algebraic maximum value and an algebraic minimum value and then returns to the initial value. A single operational cycle may result in one or more stress cycles. Dynamic effects shall also be considered as stress cycles.

NB-3213.17 Fatigue Strength Reduction Factor.

Fatigue strength reduction factor is a stress intensification factor which accounts for the effect of a local structural discontinuity (stress concentration) on the fatigue strength. Values for some specific cases, based on experiment, are given in NB-3338 and NB-3339. In the absence of experimental data, the theoretical stress concentration factor may be used.

³ Equivalent linear stress is defined as the linear stress distribution which has the same net bending moment as the actual stress distribution.

NB-3213.18 Free End Displacement.

Free end displacement consists of the relative motions that would occur between a fixed attachment and connected piping if the two members were separated and permitted to move.

NB-3213.19 Expansion Stresses.

Expansion stresses are those stresses resulting from restraint of free end displacement of the piping system.

NB-3213.20 Deformation.

Deformation of a component part is an alteration of its shape or size.

NB-3213.21 Inelasticity.

Inelasticity is a general characteristic of material behavior in which the material does not return to its original shape and size after removal of all applied loads. Plasticity and creep are special cases of inelasticity.

NB-3213.22 Creep.

Creep is the special case of inelasticity that relates to the stress-induced, time-dependent deformation under load. Small time-dependent deformations may occur after the removal of all applied loads.

NB-3213.23 Plasticity.

Plasticity is the special case of inelasticity in which the material undergoes time-independent nonrecoverable deformation.

NB-3213.24 Plastic Analysis.

Plastic analysis is that method which computes the structural behavior under given loads considering the plasticity characteristics of the materials, including strain hardening and the stress redistribution occurring in the structure.

NB-3213.25 Plastic Analysis - Collapse Load.

A plastic analysis may be used to determine the collapse load for a given combination of loads on a given structure. The following criterion for determination of the collapse load shall be used. A load-deflection or load-strain curve is plotted with load as the ordinate and deflection or strain as the abscissa. The angle that the linear part of the load-deflection or load-strain curve makes with the ordinate is called θ . A second straight line, hereafter called the collapse limit line, is drawn through the origin so that it makes an angle $\phi = \tan^{-1} (2 \tan \theta)$ with the ordinate. The collapse load is the load at the intersection of the load-deflection or load-strain curve and the collapse limit line. If this method is used, particular care should be given to ensure that the strains or deflections that are used are indicative of the load carrying capacity of the structure.

NB-3213.26 Plastic Instability Load.

The plastic instability load for members under predominantly tensile or compressive loading is defined as that load at which unbounded plastic deformation can occur without an increase in load. At the plastic tensile instability load,

Page 71

the true stress in the material increases faster than strain hardening can accommodate.

NB-3213.27 Limit Analysis.

Limit analysis is a special case of plastic analysis in which the material is assumed to be ideally plastic (nonstrain-hardening). In limit analysis, the equilibrium and flow characteristics at the limit state are used to calculate the collapse load. The two bounding methods which are used in limit analysis are the lower bound approach, which is associated with a statically admissible stress field, and the upper bound approach, which is associated with a kinematically admissible velocity field. For beams and frames, the term *mechanism* is commonly used in lieu of *kinematically admissible velocity* field.

NB-3213.28 Limit Analysis - Collapse Load.

The methods of limit analysis are used to compute the maximum load that a structure assumed to be made of ideally plastic material can carry. At this load, which is termed the collapse load, the deformations of the structure increase without bound.

NB-3213.29 Collapse Load - Lower Bound.

If, for a given load, any system of stresses can be found which everywhere satisfies equilibrium, and nowhere exceeds the material yield strength, the load is at or below the collapse load. This is the lower bound theorem of limit analysis which permits calculations of a lower bound to the collapse load.

NB-3213.30 Plastic Hinge.

A plastic hinge is an idealized concept used in Limit Analysis. In a beam or a frame, a plastic hinge is formed at the point where the moment, shear, and axial force lie on the yield interaction surface. In plates and shells, a plastic hinge is formed where the generalized stresses lie on the yield surface.

NB-3213.31 Strain Limiting Load.

When a limit is placed upon a strain, the load associated with the strain limit is called the strain limiting load.

NB-3213.32 Test Collapse Load.

Test collapse load is the collapse load determined by tests according to the criteria given in II-1430.

NB-3213.33 Ratcheting.

Ratcheting is a progressive incremental inelastic deformation or strain which can occur in a component that is subjected to variations of mechanical stress, thermal stress, or both.

NB-3213.34 Shakedown.

Shakedown of a structure occurs if, after a few cycles of load application, ratcheting ceases. The subsequent structural response is elastic, or elastic-plastic, and progressive incremental inelastic deformation is absent. Elastic shakedown is the case in which the subsequent response is elastic.

NB-3213.35 Reversing Dynamic Loads.

Reversing dynamic loads (Fig. NB-3213-1) are those loads which cycle about a mean value and include building filtered loads, earthquake, and the reflected waves in a piping system due to flow transients resulting from sudden opening or closure of valves.

NB-3213.36 Nonreversing Dynamic Loads.

Nonreversing dynamic loads (Fig. NB-3213-1) are those loads which do not cycle about a mean value and include the initial thrust force due to sudden opening or closure of valves and waterhammer resulting from entrapped water in two-phase flow systems.

NB-3214 Stress Analysis

A detailed stress analysis of all major structural components shall be prepared in sufficient detail to show that each of the stress limitations of NB-3220 and NB-3230 is satisfied when the component is subjected to the loadings of NB-3110. As an aid to the evaluation of these stresses, formulas and methods for the solution of certain recurring problems have been placed in Appendix A.

NB-3215 Derivation of Stress Intensities

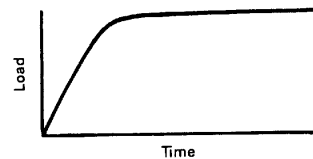
One requirement for the acceptability of a design (NB-3210) is that the calculated stress intensities shall not exceed specified allowable limits. These limits differ depending on the stress category (primary, secondary, etc.) from which the stress intensity is derived. This paragraph describes the procedure for the calculation of the stress intensities which are subject to the specified limits. The steps in the procedure are stipulated in (a) through (e) below.

(a) At the point on the component which is being investigated, choose an orthogonal set of coordinates, such as tangential, longitudinal, and radial, and designate them by the subscripts t , l , and r . The stress components in these directions are then designated σ_t , σ_l , and σ_r for direct stresses and τ_{lt} , τ_{lr} , and τ_{rt} for shear stresses.

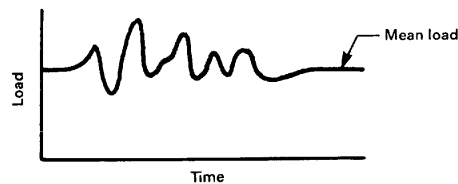
(b) Calculate the stress components for each type of loading to which the part will be subjected, and assign each set of stress values to one or a group of the following categories:⁴

(1) general primary membrane stress P_m (NB-3213.8);

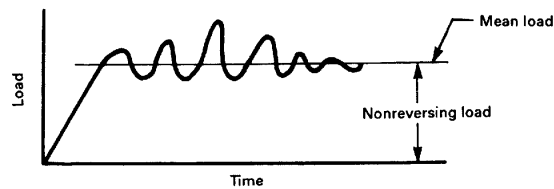
⁴ See Tables NB-3217-1 and NB-3217-2 and Note(2) of Fig. NB-3221-1.



(a) Nonreversing Dynamic Load
(Relief/Safety Valve Open End Discharge)



(b) Reversing Dynamic Load
(Earthquake Load Cycling About Normal Operating Condition)



(c) Nonreversing Followed By Reversing
(Initial Water Slug Followed By Reflected Pressure Pulses)

FIG. NB-3213-1 EXAMPLES OF REVERSING AND NONREVERSING DYNAMIC LOADS

FIG. NB-3213-1 EXAMPLES OF REVERSING AND NONREVERSING DYNAMIC LOADS

- (2) local primary membrane stress P_L (NB-3213.10);
 - (3) primary bending stress P_b (NB-3213.7 and NB-3213.8);
 - (4) expansion stress P_e (NB-3213.19);
 - (5) secondary stress Q (NB-3213.9);
 - (6) peak stress F (NB-3213.11). NB-3217 provides guidance for this step.
- (c) For each category, calculate the algebraic sum of the σ_i values which result from the different types of loadings and similarly for the other five stress components. Certain combinations of the categories must also be considered.
- (d) Translate the stress components for the t , l , and r directions into principal stresses σ_1 , σ_2 , and σ_3 . In many pressure component calculations, the t , l , and r directions may be so chosen that the shear stress components are zero and σ_1 , σ_2 , and σ_3 are identical to σ_t , σ_l , and σ_r .
- (e) Calculate the stress differences S_{12} , S_{23} , and S_{31} from the relations:

$$S_{12} = \sigma_1 - \sigma_2$$

$$S_{23} = \sigma_2 - \sigma_3$$

$$S_{31} = \sigma_3 - \sigma_1$$

The stress intensity S is the largest absolute value of S_{12} , S_{23} , and S_{31} .

NOTE: Membrane stress intensity is derived from the stress components averaged across the thickness of the section. The averaging shall be performed at the component level in (b) or (c) above.

NB-3216 Derivation of Stress Differences

If the specified operation of the component does not meet the conditions of NB-3222.4(d), the ability of the component to withstand the specified cyclic service without fatigue failure shall be determined as provided in NB-3222.4(e). The determination shall be made on the basis of the stresses at a point of the component, and the allowable stress cycles shall be adequate for the specified service at every point. Only the stress differences due to cyclic service loadings as specified in the Design Specification need be considered.

NB-3216.1 Constant Principal Stress Direction.

For any case in which the directions of the principal stresses at the point being considered do not change during the cycle, the steps stipulated in (a) through (c) below shall be taken to determine the alternating stress intensity.

(a) *Principal Stresses.* Consider the values of the three principal stresses at the point versus time for the complete stress cycle taking into account both the gross and local structural discontinuities and the thermal effects which vary during the cycle. These are designated as σ_1 , σ_2 , and σ_3 for later identification.

(b) *Stress Differences.* Determine the stress differences $S_{12} = \sigma_1 - \sigma_2$, $S_{23} = \sigma_2 - \sigma_3$, and $S_{31} = \sigma_3 - \sigma_1$ versus time for the complete cycle. In what follows, the symbol S_{ij} is used to represent any one of these three stress differences.

(c) *Alternating Stress Intensity.* Determine the extremes of the range through which each stress difference S_{ij} fluctuates and find the absolute magnitude of this range for each S_{ij} . Call this magnitude S_{rij} and let $S_{alt\ ij} = 0.5S_{rij}$. The alternating stress intensity S_{alt} is the largest $S_{alt\ ij}$ value.

NB-3216.2 Varying Principal Stress Direction.

For any case in which the directions of the principal stresses at the point being considered do change during the stress cycle, it is necessary to use the more general procedure of (a) through (e) below.

(a) Consider the values of the six stress components σ_p , σ_b , σ_r , τ_{lp} , τ_{lr} , and τ_{rt} versus time for the complete stress cycle,

taking into account both the gross and local structural discontinuities and the thermal effects which vary during the cycle.

(b) Choose a point in time when the conditions are one of the extremes for the cycle (either maximum or minimum, algebraically) and identify the stress components at this time by the subscript i . In most cases it will be possible to choose at least one time during the cycle when the conditions are known to be extreme. In some cases it may be necessary to try different points in time to find the one which results in the largest value of alternating stress intensity.

(c) Subtract each of the six stress components σ_{iP} , σ_{iR} , etc., from the corresponding stress components σ_P , σ_R , etc., at each point in time during cycle and call the resulting components σ'_P , σ'_R , etc.

(d) At each point in time during the cycle, calculate the principal stresses σ'_1 , σ'_2 , and σ'_3 derived from the six stress components σ'_P , σ'_R , etc. Note that the directions of the principal stresses may change during the cycle but each principal stress retains its identity as it rotates.

(e) Determine the stress differences $S_{12} = \sigma'_1 - \sigma'_2$, $S_{23} = \sigma'_2 - \sigma'_3$, and $S_{31} = \sigma'_3 - \sigma'_1$ versus time for the complete cycle and find the largest absolute magnitude of any stress difference at any time. The alternating stress intensity S_{alt} is one-half of this magnitude.

NB-3217 Classification of Stresses

Tables NB-3217-1 and NB-3217-2 provide assistance in the determination of the category to which a stress should be assigned.

NB-3220 STRESS LIMITS FOR OTHER THAN BOLTS

NB-3221 Design Loadings

The stress intensity limits which must be satisfied for the Design Loadings (NB-3112) stated in the Design Specifications are the four limits of this paragraph and the Special Stress Limits of NB-3227. The provisions of NB-3228 may provide relief from certain of these stress limits if plastic analysis techniques are applied. The design stress intensity values S_m are given by NB-3229. The limits are summarized by Fig. NB-3221-1.

NB-3221.1 General Primary Membrane Stress Intensity.

(Derived from P_m in Fig. NB-3221-1.) This stress intensity is derived from the average value across the thickness of a section of the general primary stresses (NB-3213.8) produced by design internal pressure and other specified Design Mechanical Loads, but excluding all secondary and peak stresses. Averaging is to be applied to the stress components prior to determination of the stress intensity values. The allowable value of this stress intensity is S_m at the Design Temperature.

NB-3221.2 Local Membrane Stress Intensity.

(Derived from P_L in Fig. NB-3221-1.) This stress intensity is derived from the average value across the thickness of a section of the local primary stresses (NB-3213.10) produced by Design Pressure and specified Design Mechanical Loads, but excluding all thermal and peak stresses. Averaging is to be applied to the stress components prior to the determination of the stress intensity values. The allowable value of this stress intensity is $1.5S_m$.

NB-3221.3 Primary Membrane (General or Local) Plus Primary Bending Stress Intensity.

(Derived from $P_L \pm P_b$ in Fig. NB-3221-1.) This stress intensity is derived from the highest value across the thickness of a section of the general or local primary membrane stresses plus primary bending stresses produced by Design Pressure and other specified Design Mechanical Loads, but excluding all secondary and peak stresses. For solid rectangular sections, the allowable value of this stress intensity is $1.5S_m$. For other than solid rectangular sections, a value of α times the limit established in NB-3221.1 may be used, where the factor α is defined as the ratio of the load set producing a fully plastic section to the load set producing initial yielding in the extreme fibers of the section. In the evaluation of the initial yield and fully plastic section capacities, the ratios of each individual load in the respective load set to each other

initial yield and fully plastic section capacities, the ratios of each individual load in the respective load set to each other load in that load set shall be the same as the respective ratios of the individual loads in the specified design load set. The value of α shall not exceed the value calculated for bending only ($P_m = 0$). In no case shall the value of α exceed 1.5. The propensity for buckling of the part of the section that is in compression shall be investigated. The α factor is not permitted for Level D Service Limits when inelastic component analysis is used as permitted in Appendix F.

NB-3221.4 External Pressure.

The provisions of NB-3133 apply.

NB-3222 Level A Service Limits

Level A Service Limits must be satisfied for the Service Conditions [NCA-2142.4(b)(1)] for which these limits are designated in the Design Specifications and are the four limits of this paragraph and the Special Stress Limits of NB-3227. The provisions of NB-3228 may provide relief from certain of these stress limits if plastic analysis techniques are applied. The design stress intensity values S_m are given by NB-3229. The limits are summarized by Fig. NB-3222-1.

NB-3222.1 Primary Membrane and Bending Stress Intensities.

There are no specific limits established on the primary stresses in the Level A Limits. However, the stresses due to primary loads presented during normal service must be computed and combined with the effects of other loadings in satisfying the remaining limits.

NB-3222.2 Primary Plus Secondary Stress Intensity.⁵

This stress intensity is derived from the highest value at any point across the thickness of a section of the general or local primary membrane stresses, plus primary bending stresses plus secondary stresses, produced by the specified service pressure and other specified mechanical loads and by general thermal effects associated with normal Service Conditions. The allowable value of the maximum range of this stress intensity is $3S_m$.

⁵ The concept of stress differences discussed in NB-3216 is essential to determination to the maximum range, since algebraic signs must be retained in the computation. Note that this limitation on range is applicable to the entire history of normal Service Conditions, not just to the stresses resulting from each individual transient.

**TABLE NB-3217-1
CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES¹**

Vessel Part	Location	Origin of Stress	Type of Stress	Classification
Cylindrical or spherical shell	Shell plate remote from discontinuities	Internal pressure	General membrane Gradient through plate thickness	P_m Q
		Axial thermal gradient	Membrane Bending	Q Q
	Junction with head or flange	Internal pressure	Membrane Bending	P_L Q [Note (2)]
Any shell or head	Any section across entire vessel	External load or moment, or internal pressure	General membrane averaged across full section	P_m
		External load or moment	Bending across full section	P_m
	Near nozzle or other opening	External load or moment, or internal pressure	Local membrane Bending Peak (fillet or corner)	P_L Q F
	Any location	Temperature difference between shell and head	Membrane Bending	Q Q
Dished head or conical head	Crown	Internal pressure	Membrane Bending	P_m P_b
	Knuckle or junction to shell	Internal pressure	Membrane Bending	P_L [Note (3)] Q
Flat head	Center region	Internal pressure	Membrane Bending	P_m P_b
	Junction to shell	Internal pressure	Membrane Bending	P_L Q [Note (2)]
Perforated head or shell	Typical ligament in a uniform pattern	Pressure	Membrane (averaged through cross section) Bending (averaged through width of ligament, but gradient through plate) Peak	P_m P_b F
	Isolated or atypical ligament	Pressure	Membrane Bending Peak	Q F F
Nozzle (NB-3227.5)	Within the limits of reinforcement defined by NB-3334	Pressure and external loads and moments, including those attributable to restrained free end displacements of attached piping	General membrane Bending (other than gross structural discontinuity stresses) averaged through nozzle thickness	P_m P_m

(continued)

TABLE NB-3217-1 CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES¹

**TABLE NB-3217-1 (CONT'D)
CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES¹**

Vessel Part	Location	Origin of Stress	Type of Stress	Classification
Nozzle (NB-3227.5)	Outside the limits of reinforcement defined by NB-3334	Pressure and external axial, shear, and torsional loads other than those attributable to restrained free end displacements of attached piping	General membrane stresses	P_m
		Pressure and external loads and moments other than those attributable to restrained free end displacements of attached piping	Membrane Bending	P_L P_b
		Pressure and all external loads and moments	Membrane Bending Peak	P_L Q F
	Nozzle wall	Gross structural discontinuities	Local membrane Bending Peak	P_L Q F
		Differential expansion	Membrane Bending Peak	Q Q F
Cladding	Any	Differential expansion	Membrane Bending	F F
Any	Any	Radial temperature distribution [Note (4)]	Equivalent linear stress [Note (5)]	Q
			Nonlinear portion of stress distribution	F
Any	Any	Any	Stress concentration (notch effect)	F

NOTES:

- (1) Q & F classification of stresses refers to other than design condition (Fig. NB-3222-1).
- (2) If the bending moment at the edge is required to maintain the bending stress in the middle to acceptable limits, the edge bending is classified as P_b . Otherwise, it is classified as Q .
- (3) Consideration shall also be given to the possibility of wrinkling and excessive deformation in vessels with a large diameter-thickness ratio.
- (4) Consider possibility of thermal stress ratchet.
- (5) Equivalent linear stress if defined as the linear stress distribution which has the same net bending moment as the actual stress distribution.

TABLE NB-3217-1 (CONT'D) CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES¹

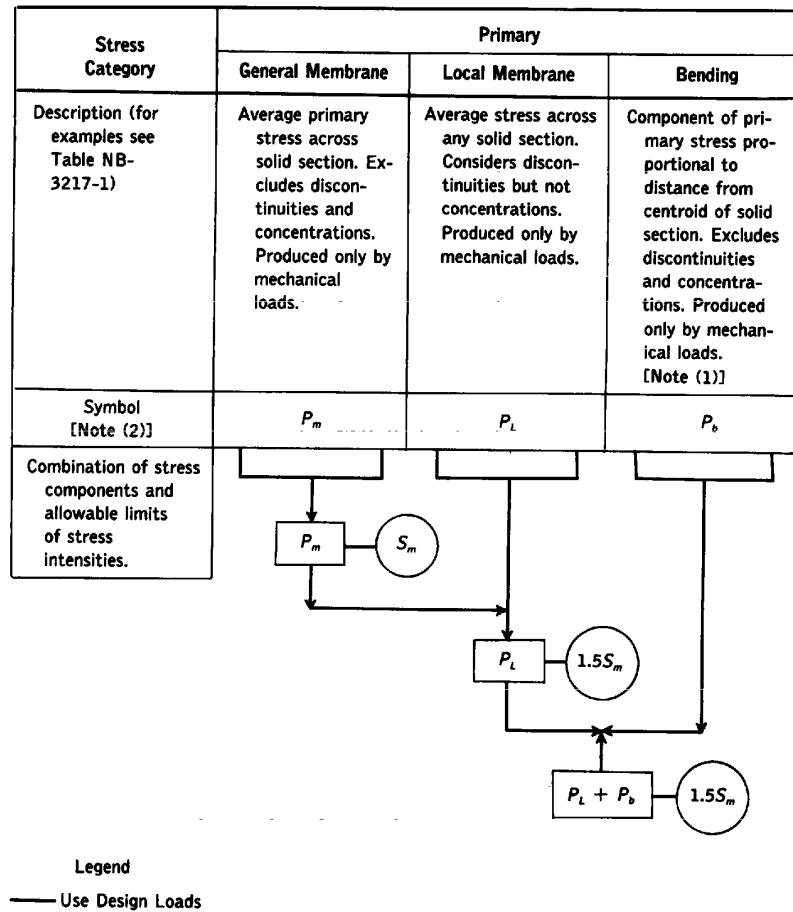
TABLE NB-3217-2
CLASSIFICATION OF STRESS INTENSITY IN PIPING, TYPICAL CASES

Piping Component	Locations	Origin of Stress	Classification	Discontinuities Considered	
				Gross	Local
Pipe or tube, elbows, and reducers. Intersections and branch connections, except in crotch regions	Any, except crotch regions of intersections	Internal pressure	P_m P_L and Q F	No Yes Yes	No No Yes
		Sustained mechanical loads, including weight Nonreversing dynamic loads	P_o P_L and Q F	No Yes Yes	No No Yes
		Expansion	P_e F	Yes Yes	No Yes
		Axial thermal gradient Reversing dynamic loads	Q F [Note (1)]	Yes Yes Yes	No No Yes
Intersections, including tees and branch connections	In crotch region	Internal pressure, sustained mechanical loads, expansion, and nonreversing dynamic loads	P_L and Q [Note (2)] F	Yes Yes	No Yes
		Axial thermal gradient	Q F	Yes Yes	No Yes
		Reversing dynamic loads	[Note (1)]		
Bolts and flanges	Any	Internal pressure, gasket compression, and bolt load	P_m Q F	No Yes Yes	No No Yes
		Thermal gradient	Q F	Yes Yes	No Yes
		Expansion	P_e F	Yes Yes	No Yes
Any	Any	Nonlinear radial thermal gradient	F	Yes	Yes
		Linear radial thermal gradient	F	Yes	No
		Anchor point motions, including those resulting from earthquake	Q	Yes	No

NOTES:

- (1) The stress intensity resulting from this loading has special requirements that must be satisfied. For Level B Service Limits, these are provided in NB-3223(b)(2) and for Level D Service Limits in NB-3228.6.
(2) Analysis is not required when reinforced in accordance with NB-3643.

TABLE NB-3217-2 CLASSIFICATION OF STRESS INTENSITY IN PIPING, FOR SOME TYPICAL CASES



NOTES:

- (1) Bending component of primary stress for piping shall be the stress proportional to the distance from centroid of pipe cross section.
- (2) The symbols P_m , P_L , and P_b do not represent single quantities, but rather sets of six quantities representing the six stress components σ_x , σ_y , σ_z , τ_{xy} , τ_{yz} , and τ_{zx} .

FIG. NB-3221-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR DESIGN CONDITIONS

FIG. NB-3221-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR DESIGN CONDITIONS

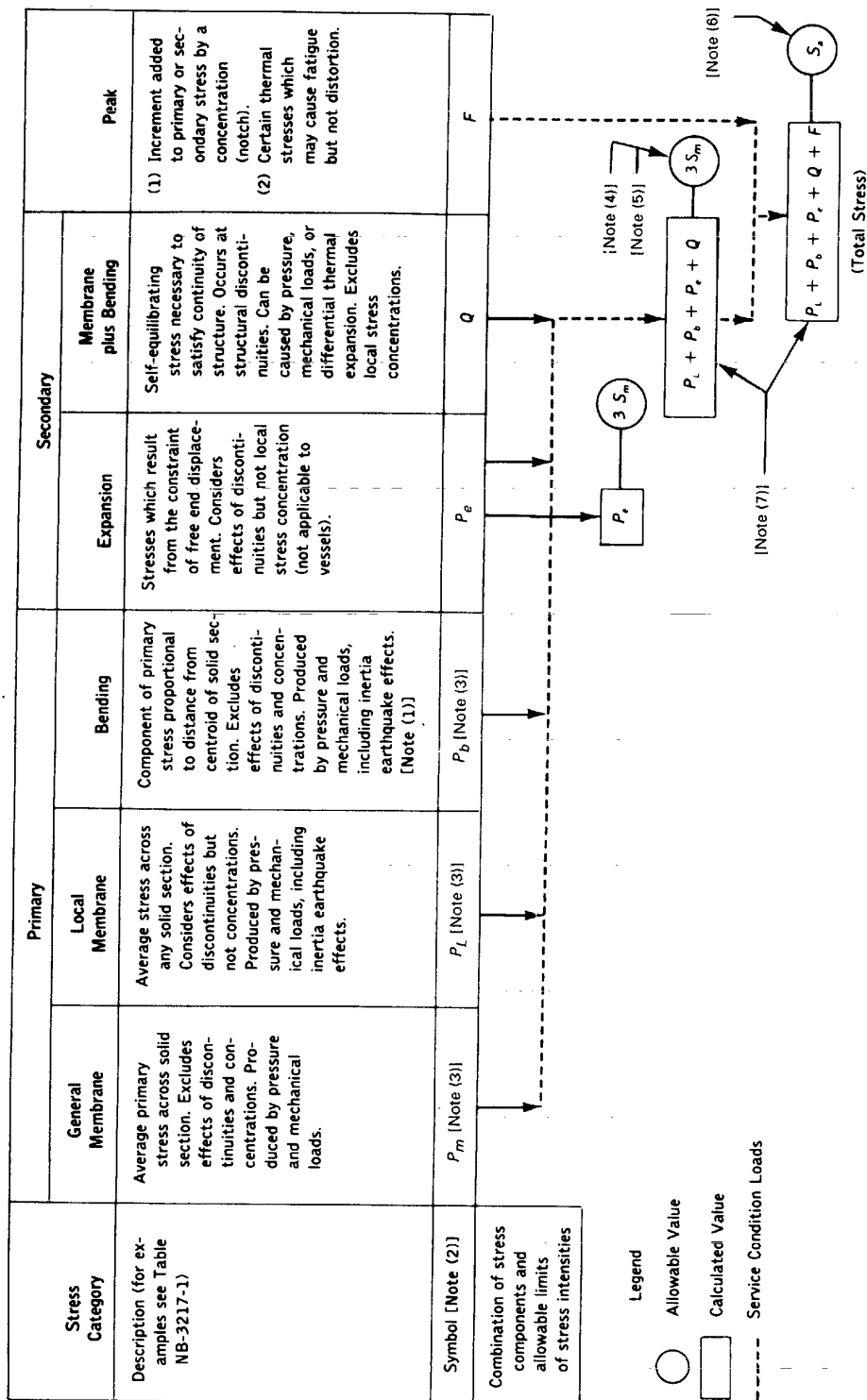


FIG. NB-3222-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR LEVEL A AND LEVEL B SERVICE LIMITS

NOTES:

- (1) Bending component of primary stress due to mechanical loads for piping shall be the stress proportional to the distance from centroid of pipe cross section. For piping, the calculation of P_b stresses is not required for reversing dynamic loads (including inertia earthquake effects). See NB-3223(b)(2). The symbols P_m , P_L , P_b , P_e , Q , and F do not represent single quantities, but sets of six quantities representing the six stress components σ_x , σ_y , σ_z , τ_{xy} , τ_{yz} , and τ_{zx} .
- (3) For Level B Service Limits for primary stress intensities generated by Level B Service Loadings, see NB-3223(a)(1).
- (4) When the secondary stress is due to a temperature transient at the point at which the stresses are being analyzed or to restraint of free end deflection, the value of S_m shall be taken as the average of the tabulated S_m values for the highest and the lowest temperatures of the metal during the transient. When part or all of the secondary stress is due to mechanical load, the value of S_m shall not exceed the value for the highest temperature during the transient.
- (5) Special rules for exceeding $3S_m$ are provided in NB-3228.5.
- (6) S_a is obtained from the fatigue curves, Figs. I-9.0. The allowable stress intensity for the full range of fluctuation is $2S_a$.
- (7) The stresses in category Q are those parts of the total stress that are produced by thermal gradients, structural discontinuities, etc., and they do not include primary stresses that may also exist at the same point. However, it should be noted that a detailed stress analysis frequently gives the combination of primary and secondary stresses directly and, when appropriate, the calculated value represents the total of $P_m + P_b + Q$, and not Q alone. Similarly, if the stress in category F is produced by a stress concentration, the quantity F is the additional stress produced by the notch over and above the nominal stress. For example, if a point has a nominal stress intensity P_m and has a notch with a stress concentration factor K , then $P_m \leq S_m$, $P_b = Q = 0$, $F = P_m (K - 1)$, and the peak stress intensity equals $P_m + P_m (K - 1) = KP_m$. However, P_L is the total membrane stress that results from mechanical loads, including discontinuity effects, rather than a stress increment. Therefore, the P_L value always includes the P_m contribution.

FIG. NB-3222-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR LEVEL A AND LEVEL B SERVICE LIMITS (CONT'D)

[98]

FIG. NB-3222-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR LEVEL A AND LEVEL B SERVICE LIMITS (CONT'D)

NB-3222.3 Expansion Stress Intensity.

(Not applicable to vessels; P_e in Fig. NB-3222-1.) This stress intensity is the highest value of stress, neglecting local structural discontinuities, produced at any point across the thickness of a section by the loadings that result from restraint of free end displacement. The allowable value of the maximum range of this stress intensity is $3S_m$.

NB-3222.4 Analysis for Cyclic Operation

(a) *Suitability for Cyclic Condition.* The suitability of a component for specified service loadings involving cyclic application of loads and thermal conditions shall be determined by the methods described herein, except that the suitability of high strength bolts shall be determined by the methods of NB-3232.3(b) and the possibility of thermal stress ratchet shall be investigated in accordance with NB-3222.5. If the specified Service Loadings of the component meet all of the conditions of (d) below, no analysis for cyclic service is required, and it may be assumed that the limits on peak stress intensities as governed by fatigue have been satisfied by compliance with the applicable requirements for material, design, fabrication, examination, and testing of this Subsection. If the Service Loadings do not meet all the conditions of (d) below, a fatigue analysis shall be made in accordance with (e) below or a fatigue test shall be made in accordance with II-1500.

(b) *Peak Stress Intensity.* This stress intensity is derived from the highest value at any point across the thickness of a section of the combination of all primary, secondary, and peak stresses produced by specified service pressures and other mechanical loads, and by general and local thermal effects associated with normal service conditions, and including the effects of gross and local structural discontinuities.

(c) *Conditions and Procedures.* The conditions and procedures of NB-3222.4 are based on a comparison of peak stresses with strain cycling fatigue data. The strain cycling fatigue data are represented by design fatigue strength curves of Figs. I-9.0. These curves show the allowable amplitude S_a of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles. This stress intensity amplitude is calculated on the assumption of elastic behavior and, hence, has the dimensions of stress, but it does not represent a real stress when the elastic range is exceeded. The fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable stress intensity amplitude directly comparable.⁶ Where necessary, the curves have been adjusted to include the maximum effects of mean stress, which is the condition where the stress fluctuates about a mean value that is different from zero. As a consequence of this procedure, it is essential that the requirements of NB-3222.2 be satisfied at all times with transient stresses included, and that the calculated value of the alternating stress intensity be proportional to the actual strain amplitude. To evaluate the effect of alternating stresses of varying amplitudes, a linear damage relation is assumed in (e)(4) below.

(d) *Components Not Requiring Analysis for Cyclic Service.* An analysis for cyclic service is not required, and it may be assumed that the limits on peak stress intensities as governed by fatigue have been satisfied for a component by compliance with the applicable requirements for material, design, fabrication, examination, and testing of this Subsection, provided the specified Service Loading⁷ of the component or portion thereof meets all the conditions stipulated in (1) through (6) below.

(1) *Atmospheric to Service Pressure Cycle.* The specified number of times (including startup and shutdown) that the pressure will be cycled from atmospheric pressure to service pressure and back to atmospheric pressure during normal service does not exceed the number of cycles on the applicable fatigue curve of Figs. I-9.0 corresponding to an S_a value of three times the S_m value for the material at service temperature.

⁶ As an exception to the use of strain controlled test data, Fig. I-9.2.2, Curves B and C are based on load controlled fatigue data.

⁷ As is stated in NB-3223, for components operating within the temperature limits of this Subsection, Service Loadings for which Level B Limits are designed must be considered as though Level A Limits were designated in evaluating exemptions from fatigue analysis.

(2) *Normal Service Pressure Fluctuation.* The specified full range of pressure fluctuations during normal service does not exceed the quantity $\frac{1}{3} \times \text{Design Pressure} \times (S_d/S_m)$, where S_d is the value obtained from the applicable design fatigue curve for the total specified number of significant pressure fluctuations and S_m is the allowable stress intensity for the material at service temperature. If the total specified number of significant pressure fluctuations exceeds the maximum number of cycles defined on the applicable design fatigue curve, the S_d value corresponding to the maximum number of cycles defined on the curve may be used. Significant pressure fluctuations are those for which the total excursion exceeds the quantity:

$$\text{Design Pressure} \times \frac{1}{3} \times (S/S_m)$$

where S is defined as follows.

(a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_d obtained from the applicable design fatigue curve for 10^6 cycles.

(b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_d obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(3) *Temperature Difference - Startup and Shutdown.* The temperature difference, °F, between any two adjacent points⁸ of the component during normal service does not exceed $S_d/2E\alpha$, where S_d is the value obtained from the applicable design fatigue curves for the specified number of startup-shutdown cycles, α is the value of the instantaneous coefficient of thermal expansion and E at the mean value of the temperatures at the two points as given by Section II, Part D, Subpart 2, Tables TE and TM.

(4) *Temperature Difference - Normal Service.*⁹ The temperature difference, °F, between any two adjacent points⁸ does not change¹⁰ during normal service by more than the quantity $S_d/2E\alpha$, where S_d is the value obtained from the applicable design fatigue curve of Figs. I-9.0 for the total specified number of significant temperature difference fluctuations. A temperature difference fluctuation shall be considered to be significant if its total algebraic range exceeds the quantity $S/2E\alpha$, where S is defined as follows.

(a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_d obtained from the applicable design fatigue curve for 10^6 cycles.

(b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_d obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

⁸ Adjacent points are defined in (a), (b), and (c) below.

(a) For surface temperature differences on surfaces of revolution in the meridional direction, adjacent points are defined as points that are less than the distance $2\sqrt{Rt}$, where R is the radius measured normal to the surface from the axis of rotation to the midwall and t is the thickness of the part at the point under consideration. If the product Rt varies, the average value of the points shall be used.

(b) For surface temperature differences on surfaces of revolution in the circumferential direction and on flat parts, such as flanges and flat heads, adjacent points are defined as any two points on the same surface.

(c) For through-thickness temperature differences, adjacent points are defined as any two points on a line normal to any surface.

⁹ Normal service is defined as service, other than startup and shutdown, resulting in specified Service Loadings for which Level A Limits, Level B Limits, or Testing Limits are designated.

¹⁰ The algebraic range of the difference shall be used.

(5) *Temperature Difference - Dissimilar Materials.* For components fabricated from materials of differing moduli of elasticity or coefficients of thermal expansion, the total algebraic range of temperature fluctuation, °F, experienced by the component during normal service does not exceed the magnitude $S_d/2(E_1\alpha_1 - E_2\alpha_2)$, where S_d is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature fluctuations, E_1 and E_2 are the moduli of elasticity, and α_1 and α_2 are the values of the instantaneous coefficients of thermal expansion at the mean temperature value involved for the two materials of construction given in Section II, Part D, Subpart 2, Tables TE and TM. A temperature fluctuation shall be considered to be significant if its total excursion exceeds the quantity $S/2(E_1\alpha_1 - E_2\alpha_2)$, where S is defined as follows.

(a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_d obtained from the

applicable design fatigue curve for 10^6 cycles.

(b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve. If the two materials used have different applicable design fatigue curves, the lower value of S_a shall be used in applying the rules of this paragraph.

(6) *Mechanical Loads.* The specified full range of mechanical loads, excluding pressure but including pipe reactions, does not result in load stresses whose range exceeds the S_a value obtained from the applicable design fatigue curve of Figs. I-9.0 for the total specified number of significant load fluctuations. If the total specified number of significant load fluctuations exceeds the maximum number of cycles defined on the applicable design fatigue curve, the S_a value corresponding to the maximum number of cycles defined on the curve may be used. A load fluctuation shall be considered to be significant if the total excursion of load stress exceeds the quantity S , where S is defined as follows.

(a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(e) *Procedure for Analysis for Cyclic Loading.* If the specified Service Loadings for the component do not meet the conditions of NB-3222.4(d), the ability of the component to withstand the specified cyclic service without fatigue failure shall be determined as provided in this subsubparagraph. The determination shall be made on the basis of the stresses at a point, and the allowable stress cycles shall be adequate for the specified Service Loadings at every point. Only

Page 83

the stress differences due to service cycles as specified in the Design Specifications need be considered. Compliance with these requirements means only that the component is suitable from the standpoint of possible fatigue failure; complete suitability for the specified Service Loadings is also dependent on meeting the general stress limits of NB-3222 and any applicable special stress limits of NB-3227.

(1) *Stress Differences.* For each condition of normal service, determine the stress differences and the alternating stress intensity S_a in accordance with NB-3216.

(2) *Local Structural Discontinuities.* These effects shall be evaluated for all conditions using stress concentration factors determined from theoretical, experimental, or photoelastic studies, or numerical stress analysis techniques. Experimentally determined fatigue strength reduction factors may be used when determined in accordance with the procedures of II-1600, except for high strength alloy steel bolting for which the requirements of NB-3232.3(c) shall apply when using the design fatigue curve of Fig. I-9.4. Except for the case of crack-like defects and specified piping geometries for which specific values are given in NB-3680, no fatigue strength reduction factor greater than five need be used.

(3) *Design Fatigue Curves.* Figures I-9.0 contain the applicable fatigue design curves for the materials permitted by this Subsection. When more than one curve is presented for a given material, the applicability of each is identified. Where curves for various strength levels of a material are given, linear interpolation may be used for intermediate strength levels of these materials. The strength level is the specified minimum room temperature value. The design fatigue curves of Figs. I-9.0 are defined over a cyclic range of 10 to 10^6 cycles, except that for austenitic steels, nickel-chromium-iron alloys, and nickel-iron-chromium alloys, nickel-chromium-molybdenum-iron alloys, and nickel-copper alloys, the design fatigue curve is extended to 10^{11} cycles in Figs. I-9.2.2 and I-9.5. Criteria for the use of the latter curve are given in Fig. I-9.2.2 and are also presented graphically by the flow chart given in Fig. I-9.2.3.

(4) *Effect of Elastic Modulus.* Multiply S_{alt} (as determined in NB-3216.1 or NB-3216.2) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve of Figs. I-9.0 at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the service cycle being considered is the only one which produces significant fluctuating stresses, this is the allowable number of cycles.

(5) *Cumulative Damage.* If there are two or more types of stress cycle which produce significant stresses, their cumulative effect shall be evaluated as stipulated in Steps 1 through 6 below.

Step 1: Designate the specified number of times each type of stress cycle of types 1, 2, 3, ..., n , will be repeated during the life of the component as $n_1, n_2, n_3, \dots, n_n$ respectively.

NOTE: In determining $n_1, n_2, n_3, \dots, n_n$ consideration shall be given to the superposition of cycles of various origins which produce a total stress difference range greater than the stress difference ranges of the individual cycles. For example, if one type of stress cycle produces 1000 cycles of a stress difference variation from zero to +60,000 psi and another type of stress cycle produces 10,000 cycles of a stress difference variation from zero to -50,000 psi, the two types of cycle to be considered are defined by the following parameters:

(a) for type 1 cycle, $n_1 = 1000$ and $S_{alt 1} = (60,000 + 50,000)/2 = 55,000$ psi;

(b) for type 2 cycle, $n_2 = 9000$ and $S_{alt 2} = (50,000 + 0)/2 = 25,000$ psi.

Step 2: For each type of stress cycle, determine the alternating stress intensity S_{alt} by the procedures of NB-3216.1 or NB-3216.2 above. Call these quantities $S_{alt 1}, S_{alt 2}, S_{alt 3}, \dots, S_{alt n}$

Step 3: For each value $S_{alt 1}, S_{alt 2}, S_{alt 3}, \dots, S_{alt n}$ use the applicable design fatigue curve to determine the maximum number of repetitions which would be allowable if this type of cycle were the only one acting. Call these values $N_1, N_2, N_3, \dots, N_n$

Step 4: For each type of stress cycle, calculate the usage factors $U_1, U_2, U_3, \dots, U_n$ from $U_1 = n_1/N_1, U_2 = n_2/N_2, U_3 = n_3/N_3, \dots, U_n = n_n/N_n$

Step 5: Calculate the cumulative usage factor U from $U = U_1 + U_2 + U_3 + \dots + U_n$

Step 6: The cumulative usage factor U shall not exceed 1.0.

NB-3222.5 Thermal Stress Ratchet.

It should be noted that under certain combinations of steady state and cyclic loadings there is a possibility of large distortions developing as the result of ratchet action; that is, the deformation increases by a nearly equal amount for each cycle. Examples of this phenomenon are treated in this subparagraph and in NB-3227.3.

(a) The limiting value of the maximum cyclic thermal stress permitted in a portion of an axisymmetric shell loaded by steady state internal pressure in order to prevent cyclic growth in diameter is as follows. Let

x	= maximum general membrane stress due to pressure divided by the yield strength S_y
-----	---

Page 84

y'	= maximum allowable range of thermal stress computed on an elastic basis divided by the yield strength ¹¹ S_y
------	--

Case 1: Linear variation of temperature through the wall: for $0 < x < 0.5, y' = 1/x$ and, for $0.5 < x < 1.0, y' = 4(1-x)$.

Case 2: Parabolic constantly increasing or constantly decreasing variation of temperature through the wall: for $0.615 < x < 1.0, y' = 5.2(1-x)$ and, approximately for $x < 0.615, y' = 4.65, 3.55, \text{ and } 2.70$ for $x = 0.3, 0.4, \text{ and } 0.5$, respectively.

(b) Use of yield strength S_y in the above relations instead of the proportional limit allows a small amount of growth during each cycle until strain hardening raises the proportional limit to S_y . If the yield strength of the material is higher than the endurance limit¹² for the material, the latter value shall be used if there is to be a large number of cycles because strain softening may occur.

NB-3222.6 Deformation Limits.

Any deformation limits prescribed by the Design Specifications shall be satisfied.

[98]

NB-3223 Level B Service Limits

(a) For components other than piping operating within the temperature limits of this Subsection, the requirements of (1), (2), and (3) below shall apply.

(1) The values of Level A Service Limits shall apply for Level B Service Limits, except that for primary stress intensities generated by Level B Service Loadings, allowable stress intensity values of 110% of those given in Fig. NB-3221-1 shall apply.

(2) In evaluating possible exemption from fatigue analysis by the methods of NB-3222.4(d), Service Loadings for which Level B Limits are designated shall be considered as though Level A Limits were designated.

(3) Any deformation limits prescribed by the Design Specifications shall be satisfied.

(b) For piping components operating within the temperature limits of this Subsection, the requirements of (1) or (2) below shall apply.

11 It is permissible to use $1.5S_m$ whenever it is greater than S_y .

12 The endurance limit shall be taken as two times the S_a value at 10^7 cycles in the applicable fatigue curve of Figs. I-9.0, except that for the curves of Figs. I-9.2.1 and I-9.2.2 the endurance limit shall be taken as two times the S_a value at 10^{11} cycles obtained from Curve A.

(1) For Level B Service Limits which do not include reversing dynamic loads (NB-3213.35) or have reversing dynamic loads combined with nonreversing dynamic loads (NB-3213.36), the requirements of (a)(1), (a)(2), and (a)(3) above shall be satisfied.

(2) For Level B Service Limits which include reversing dynamic loads that are not required to be combined with nonreversing dynamic loads, the requirements of NB-3222.2 and NB-3222.4(e) shall be satisfied in lieu of (b)(1) above. In addition, any deflection limits prescribed by the Design Specification must be satisfied.

[98]

NB-3224 Level C Service Limits

If the Design Specifications specify any Service Loadings for which Level C Service Limits are designated [NCA-2142.4(b)(3) and NB-3113(b)] for components other than piping, the rules used in evaluating these loadings shall be those used for other loadings, except as modified by the following subparagraphs and as summarized in Fig. NB-3224-1. For piping, special requirements are provided in NB-3224.7.

NB-3224.1 Primary Stress Limits.

The primary stress limits of NB-3221 shall be satisfied using an S_m value equal to the greater of 120% of the tabulated S_m value or 100% of the tabulated yield strength, with both values taken at the appropriate temperature. In addition, for ferritic material, the P_m elastic analysis limits for pressure loadings alone shall be equal to the greater of $1.1S_m$ or $0.9S_y$.

NB-3224.2 External Pressure.

The permissible external pressure shall be taken as 120% of that given by the rules of NB-3133.

NB-3224.3 Special Stress Limits.

The permissible values for special stress limit shall be taken as 120% of the values given in NB-3227.4 and NB-3228.

NB-3224.4 Secondary and Peak Stresses.

The requirements of NB-3222.2, NB-3222.4, NB-3222.5, and NB-3227.3 need not be satisfied.

NB-3224.5 Fatigue Requirements.

Service Loadings for which Level C Service Limits are designated need not be considered when applying the procedures of NB-3222.4(a) to determine whether or not a fatigue analysis is required.

NB-3224.6 Deformation Limits.

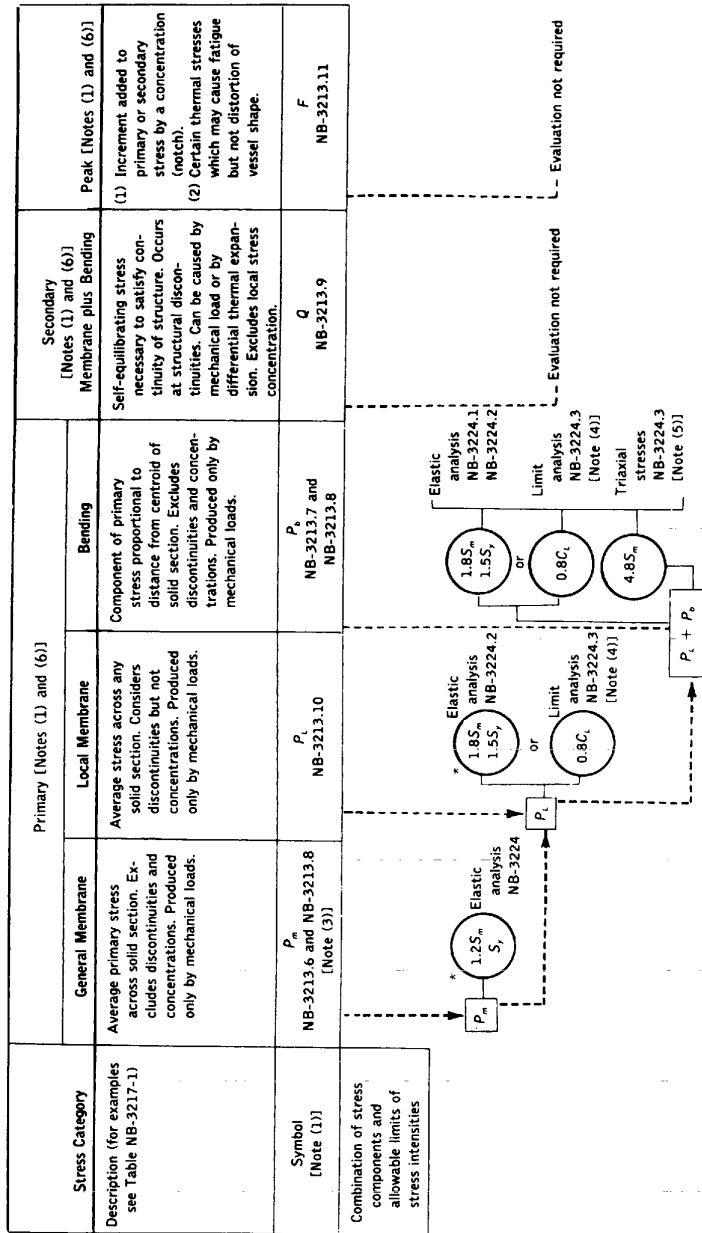
Any deformation limits prescribed by the Design Specifications shall be considered.

NB-3224.7 Piping Requirements

(a) For Level C Service Limits which do not include reversing dynamic loads or have reversing dynamic load combined with nonreversing dynamic loads, the

Page 85

requirements of NB-3224.1 through NB-3224.6 above shall be satisfied.



NOTES:

- (1) The symbols P_m , P_l , P_b , Q , and F do not represent single quantities, but rather sets of six quantities representing the six stress components σ_1 , σ_2 , σ_3 , τ_{xy} , τ_{yz} , and τ_{zx} .
- (2) For configurations where compressive stresses occur, the stress limits shall be revised to take into account critical buckling stresses [NB-3211(c)].
- (3) The limits shown are for stresses resulting from pressure in combination with other mechanical loads. For ferritic materials, the P_1 elastic analysis limits for pressure loadings alone shall be equal to the greater of $1.15S_m$ or $0.9S_v$.
- (4) C_1 the collapse load calculated on the basis of the lower bound theorem of limit analysis and yield strength values specified in Section II, Part D, Subpart 2, Table Y-1.
- (5) The triaxial stresses represent the algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) for the combination of stress components.
- (6) For piping, alternative requirements are provided in NB-3224.7.

* Use the greater of the values specified.

FIG. NB-3224-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR LEVEL C SERVICE LIMITS

FIG. NB-3224-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR LEVEL C SERVICE LIMITS

(b) As an alternative to (a) above, for Level C Service Limits which include reversing dynamic loads that are not required to be combined with nonreversing dynamic loads, the requirements of NB-3228.6 may be satisfied using 70% of the specified allowable strain values.

NB-3225 Level D Service Limits

(a) For components other than piping, if the Design Specifications specify any Service Loadings for which Level D Limits are designated [NCA-2142.4(b)(4)], the rules contained in Appendix F may be used in evaluating these loadings, independently of all other Design and Service Loadings.

(b) For piping fabricated from material designated P-No. 1 through P-No. 9 in Table 2A, Section II, Part D, if the Design Specifications specify any Service Loading for which Level D Limits are designated [NCA-2142.4(b)(4)], the rules contained in NB-3228.6 may be used as an alternative to those contained in Appendix F. For other piping materials, the rules of Appendix F may be used in evaluating these loadings, independently of all other Design and Service Loadings.

NB-3226 Testing Limits

The evaluation of pressure test loadings (NCA-2142.3) shall be in accordance with (a) through (e) below, except that these rules do not apply to the items in NB-3500.

(a) The general primary membrane stress intensity P_m shall not exceed 90% of the tabulated yield strength S_y at test temperature.

(b) The primary membrane plus bending stress intensity $P_m + P_b$ shall not exceed the applicable limits given in (1) or (2) below.

(1) For $P_m \leq 0.67S_y$

$$P_m + P_b \leq 1.35S_y$$

(2) For $0.67S_y < P_m \leq 0.90S_y$

$$P_m + P_b \leq (2.15S_y - 1.2P_m)$$

where S_y is the tabulated yield strength at test temperature.

(c) The external pressure shall not exceed 135% of the value determined by the rules of NB-3133. Alternatively, an external hydrostatic test pressure may be applied up to a maximum of 80% of the lower of the collapse or elastic instability pressures determined by analysis or experimental procedures (NB-3228 and Appendix II) including consideration of allowable tolerances. If a collapse analysis is performed, it shall be a lower bound limit analysis assuming ideally elastic-plastic (nonstrain-hardening) material having a yield strength equal to its tabulated yield strength at test temperature.

(d) For the 1.25 Design Pressure hydrostatic test of NB-6221, or the 1.20 to 1.25 Design Pressure pneumatic tests of NB-6321, the stresses shall be calculated and compared to the limits of (a), (b), and (c) above. This calculation and the fatigue evaluation of (e) below need not be revised unless the actual hydrostatic test pressure of NB-6221 exceeds the 1.25 Design Pressure by more than 6%, or the actual pneumatic test pressure of NB-6321 exceeds 1.25 Design Pressure.

(e) Tests, with the exception of either the first 10 hydrostatic tests in accordance with NB-6220, the first 10 pneumatic tests in accordance with NB-6320, or any combination of 10 such tests, shall be considered in the fatigue evaluation of the component. In this fatigue evaluation, the limits on the primary plus secondary stress intensity range (NB-3222.2) may be taken as the larger of $3S_m$ or $2S_y$ when at least one extreme of the stress intensity range is determined by the Test Loadings.

NB-3227 Special Stress Limits

The following deviations from the basic stress limits are provided to cover special Service Loadings or configurations. Some of these deviations are more restrictive, and some are less restrictive, than the basic stress limits. In cases of conflict between these requirements and the basic stress limits, the rules of NB-3227 take precedence for the particular situations to

which they apply.

NB-3227.1 Bearing Loads

(a) The average bearing stress for resistance to crushing under the maximum load, experienced as a result of Design Loadings, Test Loadings, or any Service Loadings, except those for which Level D Limits are designated, shall be limited to S_y at temperature, except that when the distance to a free edge is larger than the distance over which the bearing load is applied, a stress of $1.5S_y$ at temperature is permitted. For clad surfaces, the yield strength of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area

Page 87

or the area of the base metal supporting the contact surface.

(b) When bearing loads are applied near free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. In the case of load stress only (NB-3213.12) the average shear stress shall be limited to $0.6S_m$. In the case of load stress plus secondary stress (NB-3213.10) the average shear stress shall not exceed (1) or (2) below:

(1) for materials to which Note (2) of Section II, Part D, Subpart 1, Tables 2A and 2B applies, the lower of $0.5S_y$ at 100°F (38°C) and $0.675S_y$ at temperature;

(2) for all other materials, $0.5S_y$ at temperature.

For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

(c) When considering bearing stresses in pins and similar members, the S_y at temperature value is applicable, except that a value of $1.5S_y$ may be used if no credit is given to bearing area within one pin diameter from a plate edge.

NB-3227.2 Pure Shear

(a) The average primary shear stress across a section loaded in pure shear, experienced as a result of Design Loadings, Test Loadings, or any Service Loadings, except those for which Level D Limits are designated (for example, keys, shear rings, screw threads), shall be limited to $0.6S_m$.

(b) The maximum primary shear that is experienced as a result of Design Loadings, Test Loadings, or any Service Loadings (except those for which Level D Limits are designated), exclusive of stress concentration, at the periphery of a solid circular section in torsion shall be limited to $0.8S_m$. Primary plus secondary and peak shear stresses shall be converted to stress intensities (equal to two times the pure shear stress) and as such shall not exceed the basic stress limits of NB-3222.2 and NB-3222.4.

[98]

NB-3227.3 Progressive Distortion of Nonintegral Connections.

Screwed on caps, screwed in plugs, shear ring closures, and breech lock closures are examples of nonintegral connections which are subject to failure by bell mousing or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore, primary plus secondary stress intensities (NB-3222.2), which result in slippage between the parts of a nonintegral connection in which disengagement could occur as a result of progressive distortion, shall be limited to the value S_y (Section II, Part D, Subpart 1, Table Y-1).

[98]

NB-3227.4 Triaxial Stresses.

The algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) shall not exceed four times the tabulated value of S_m , except for Service Level D.

NB-3227.5 Nozzle Piping Transition.

Within the limits of reinforcement given by NB-3334, whether or not nozzle reinforcement is provided, the P_m classification is applicable to stress intensities resulting from pressure-induced general membrane stresses as well as stresses other than discontinuity stresses due to external loads and moments including those attributable to restrained free end displacements of the attached pipe. Also, within the limits of reinforcement, a P_L classification shall be applied to local primary membrane stress intensities derived from discontinuity effects plus primary bending stress intensities due to combined pressure and external loads and moments, including those attributable to restrained free end displacements of the attached pipe; and a $P_L + P_b + Q$ classification shall apply to primary plus secondary stress intensities resulting from a combination of pressure, temperature, and external loads and moments, including those due to restrained free end displacements of the attached pipe. Beyond the limits of reinforcement, a P_m classification is applicable to stress intensities resulting from pressure-induced general membrane stresses as well as the average stress across the nozzle thickness due to externally applied nozzle axial, shear, and torsional loads other than those attributable to restrained free end displacement of the attached pipe. Also, outside the limits of reinforcement a $P_L + P_b$ classification is applicable to the stress intensities that result from adding those stresses classified as P_m to those due to externally applied bending moments, except those attributable to restrained free end displacement of the pipe. Further, beyond the limits of reinforcement, a $P_L + P_b + Q$ classification is applicable to stress intensities resulting from all pressure, temperature, and external loads and moments, including those attributable to restrained free end displacements of the attached pipe. Beyond the

Page 88

limits of reinforcement, the $3S_m$ limit on the range of primary plus secondary stress intensity may be exceeded as provided in NB-3228.5, except that in the evaluation of NB-3228.5(a) stresses from restrained free end displacements of the attached pipe may also be excluded. The range of membrane plus bending stress intensity attributable solely to the restrained free end displacements of the attached pipe shall be $\leq 3S_m$. The nozzle, outside the reinforcement limit, shall not be thinner than the larger of the pipe thickness or the quantity $t_p(S_{mp}/S_{mn})$, where t_p is the nominal thickness of the mating pipe, S_{mp} is the allowable stress intensity value for the pipe material, and S_{mn} is the allowable stress intensity value for the nozzle material.

NB-3227.6 Applications of Elastic Analysis for Stresses Beyond the Yield Strength.

Certain of the allowable stresses permitted in the design criteria are such that the maximum stress calculated on an elastic basis may exceed the yield strength of the material. The limit on primary plus secondary stress intensity of $3S_m$ (NB-3222.2) has been placed at a level which ensures shakedown to elastic action after a few repetitions of the stress cycle except in regions containing significant local structural discontinuities or local thermal stresses. These last two factors are considered only in the performance of a fatigue evaluation. Therefore:

(a) In evaluating stresses for comparison with the stress limits on other than fatigue allowables, stresses shall be calculated on an elastic basis.

(b) In evaluating stresses for comparison with fatigue allowables, all stresses except those which result from local thermal stresses [NB-3213.13(b)] shall be evaluated on an elastic basis. In evaluating local thermal stresses, the elastic equations shall be used, except that the numerical value substituted for Poisson's ratio shall be determined from the expression:

$$\nu = 0.5 - 0.2 (S_y/S_a), \text{ but not less than } 0.3$$

where

S_a = value obtained from the applicable design fatigue curve (Figs. I-9.0) for the specified number of cycles of the condition being considered

S_y = yield strength of the material at the mean value of the temperature of the cycle

NB-3227.7 Requirements for Specially Designed Welded Seals

(a) Welded seals, such as omega and canopy seals (NB-4360), shall be designed to meet the pressure induced general primary membrane stress intensity limits specified in this Subsection. Note that the general primary membrane stress intensity varies around the toroidal cross section.

(b) All other membrane and bending stress intensities developed in the welded seals may be considered as secondary stress intensities. The range of these stress intensities combined with the general primary membrane stress intensity may exceed the primary plus secondary stress intensity limit of $3S_m$ if they are analyzed in accordance with NB-3228.5 as modified in (1) and (2) below.

(1) In lieu of NB-3228.5(a), the range of the combined primary plus secondary membrane stress intensities shall be $\leq S_m$.

(2) NB-3228.5(d) need not apply.

NB-3228 Applications of Plastic Analysis

The following subparagraphs provide guidance in the application of plastic analysis and some relaxation of the basic stress limits which are allowed if plastic analysis is used.

[98]

NB-3228.1 Limit Analysis.

The limits on General Membrane Stress Intensity (NB-3221.1), Local Membrane Stress Intensity (NB-3221.2), and Primary Membrane Plus Primary Bending Stress Intensity (NB-3221.3) need not be satisfied at a specific location if it can be shown by limit analysis that the specified loadings do not exceed two-thirds of the lower bound collapse load. The yield strength to be used in these calculations is $1.5S_m$. The use of $1.5S_m$ for the yield strength of those materials of Section II, Part D, Subpart 1, Tables 2A and 2B to which Note (2) of the Table is applicable may result in small permanent strains during the first few cycles of loading. If these strains are not acceptable, the yield strength to be used shall be reduced according to the strain limiting factors of Section II, Part D, Subpart 1, Table Y-2. When two-thirds of the lower bound collapse load is used, the effects of plastic strain concentrations in localized areas of the structure such as the points where hinges form must be considered. The effects of these concentrations of strain on the fatigue behavior, ratcheting behavior, or buckling behavior of the structure must be considered in the design. The design shall satisfy the minimum wall thickness requirements.

[98]

NB-3228.2 Experimental Analysis.

The limits of General Primary Membrane Stress Intensity (NB-3221.1), Local Membrane Stress Intensity (NB-3221.2), and Primary Membrane Plus Primary Bending Stress Intensity (NB-3221.3) need not be satisfied at a specific location if it can be shown that the specified loadings do not exceed two-thirds of the test collapse load

Page 89

determined by application of II-1430, in which case the effects of plastic strain concentrations in localized areas of the structure, such as the points where hinges form, must be considered. The effects of these concentrations of strain on the fatigue behavior, ratcheting behavior, or buckling behavior of the structure must be considered in the design. The design shall satisfy the minimum wall thickness requirements.

NB-3228.3 Plastic Analysis.

Plastic analysis is a method of structural analysis by which the structural behavior under given loads is computed by considering the actual material stress-strain relationship and stress redistribution, and it may include either strain hardening or change in geometry, or both.

The limits of General Membrane Stress Intensity (NB-3221.1), Local Membrane Stress Intensity (NB-3221.2), and Primary Membrane Plus Primary Bending Stress Intensity (NB-3221.3) need not be satisfied at a specific location if it

can be shown that the specified loadings do not exceed two-thirds of the plastic analysis collapse load determined by application of II-1430 to a load-deflection or load-strain relationship obtained by plastic analysis. When this rule is used, the effects of plastic strain concentrations in localized areas of the structure, such as the points where hinges form, must be considered. The effects of the concentrations of strain on the fatigue behavior, ratcheting behavior, or buckling behavior of the structure must be considered in the design. The design shall satisfy the minimum wall thickness requirements.

NB-3228.4 Shakedown Analysis.

The limits on Thermal Stress Ratchet in Shell (NB-3222.5) and Progressive Distortion of Non-Integral Connections (NB-3227.3) need not be satisfied at a specific location, if, at the location, the procedures of (a) through (c) below are used.

(a) In evaluating stresses for comparison with the remaining stress limits, the stresses shall be calculated on an elastic basis.

(b) In lieu of satisfying the specific requirements of NB-3221.2, NB-3222.2, NB-3222.5, and NB-3227.3 at a specific location, the structural action shall be calculated on a plastic basis, and the design shall be considered to be acceptable if shakedown occurs (as opposed to continuing deformation). However, this shakedown requirement need not be satisfied for materials having a minimum specified yield strength to specified minimum ultimate strength ratio of less than 0.70 provided the maximum accumulated local strain at any point, as a result of cyclic operation to which plastic analysis is applied, does not exceed 5.0%. In all cases, the deformations which occur shall not exceed specified limits.

**TABLE NB-3228.5(b)-1
VALUES OF m , n , AND $T_{\max}$ FOR VARIOUS
CLASSES OF PERMITTED MATERIALS**

Materials	m	n	$T_{\max}$ /° F
Carbon steel	3.0	0.2	700
Low alloy steel	2.0	0.2	700
Martensitic stainless steel	2.0	0.2	700
Austenitic stainless steel	1.7	0.3	800
Nickel-chromium-iron	1.7	0.3	800
Nickel-copper	1.7	0.3	800

TABLE NB-3228.5(b)-1 VALUES OF m , n , AND $T_{\max}$ FOR VARIOUS CLASSES OF PERMITTED MATERIALS

(c) In evaluating stresses for comparison with fatigue allowables, the numerically maximum principal total strain range shall be multiplied by one-half the modulus of elasticity of the material (Section II, Part D, Subpart 2, Tables TM) at the mean value of the temperature of the cycle.

NB-3228.5 Simplified Elastic-Plastic Analysis.

The $3S_m$ limit on the range of primary plus secondary stress intensity (NB-3222.2) may be exceeded provided that the requirements of (a) through (f) below are met.

(a) The range of primary plus secondary membrane plus bending stress intensity, excluding thermal bending stresses, shall be $\leq 3S_m$.

(b) The value of S_a used for entering the design fatigue curve is multiplied by the factor K_e where:

$$\begin{aligned} K_e &= 1.0, \text{ for } S_n \leq 3S_m \\ &= 1.0 + [(1 - n)/n(m - 1)]S_n/3S_m - 1, \text{ for } 3S_m < S_n < 3mS_m \\ &= 1/n, \text{ for } S_n \geq 3mS_m \\ S_n &= \text{range of primary plus secondary stress intensity, psi} \end{aligned}$$

The values of the material parameters m and n for the various classes of permitted materials are as given in Table NB-3228.5(b)-1.

(c) The rest of the fatigue evaluation stays the same as required in NB-3222.4, except that the procedure of NB-3227.6 need not be used.

(d) The component meets the thermal ratcheting requirement of NB-3222.5.

(e) The temperature does not exceed those listed in Table NB-3228.5(b)-1 for the various classes of materials.

(f) The material shall have a specified minimum yield strength to specified minimum tensile strength ratio of less than 0.80.

Page 90

NB-3228.6 Reversing Dynamic Loading in Piping.

For piping fabricated from material designated P-No. 1 through P-No. 9 in Table 2A, Section II, Part D, if the Design Specifications specify any Service Loading for which Level D limits are designated [NCA-2142.2(b)(4)], the rules contained in NB-3228.6 may be used as an alternative to those contained in Appendix F. For other piping materials, the rules of Appendix F may be used in evaluating these loadings, independently of all other Design and Service Loadings. As an alternative to meeting the requirements of Appendix F, for piping components subjected to reversing type dynamic loading as defined in NB-3213.35, the requirements of (a)(1) and (a)(2) below shall be satisfied. However, when the specified Level D Load combination includes nonreversing dynamic loads (NB-3213.36) alone or coincident with earthquake and other reversing dynamic loads for which the Design Specification requires satisfaction of Level D Service Limits, the requirements of Appendix F must be satisfied for Level D.

(a) Deflections, deformations, and strains, including those caused by incremental ratcheting, must be evaluated on an inelastic basis to assure compliance with these limits.

(1) The effective ratchet strain averaged through the wall thickness of the piping component due to the application of all simultaneously applied loading including pressure, the effects of gravity, thermal expansion ranges, earthquake inertia ranges, anchor motion ranges, (including thermal, earthquake, etc.) and reversing dynamic loading ranges shall not exceed 5%.

(2) The effective local peak cyclic single-amplitude strain ϵ_{ar} in the wall of the piping component due to the application of all simultaneously applied loading ranges considered in (a)(1) above shall not exceed the following.

$$\epsilon_{an} \leq \frac{S_{a10}}{(E\sqrt{N})}$$

where

the *equivalent strain range* is defined as follows.

Step 1: Identify all strain components for each point, i , in time (ϵ_{xp} ϵ_{yp} ϵ_{zp} Γ_{xyp} Γ_{yzp} Γ_{zxp}) for a complete cycle of interest.

Step 2: Select a time point when conditions are at an extreme for the cycle, either maximum or minimum. Refer to this time point as o .

Step 3: Calculate the history of the change in strain components by subtracting the values at the time, o , from the corresponding components at each point in time, i , during the cycle.

$$\delta\epsilon_{xi} = \epsilon_{xi} - \epsilon_{xo}$$

$$\delta\epsilon_{yi} = \epsilon_{yi} - \epsilon_{yo}$$

etc.

Step 4: Calculate the equivalent strain ranges for each point in time as:

$$\delta\epsilon_{equiv.i} = \frac{\sqrt{2}}{3} \left[(\delta\epsilon_{xi} - \delta\epsilon_{yi})^2 + (\delta\epsilon_{yi} - \delta\epsilon_{zi})^2 + (\delta\epsilon_{zi} - \delta\epsilon_{xi})^2 + \frac{3}{2} (\delta\Gamma_{xyi}^2 + \delta\Gamma_{yzi}^2 + \delta\Gamma_{zxi}^2) \right]^{1/2}$$

Step 5: The *equivalent strainrange* is the maximum value of the above calculated equivalent strain ranges, $\delta\epsilon_{equiv.i}$. The *effective cyclic single-amplitude strain* is half the equivalent strain range for one typical cycle of loading. The *equivalent ratchet strain* is the value of the above calculated equivalent strain range over all the cycles of loading.

E = Young's Modulus

N = 10 for earthquake event. For other reversing dynamic loads N is the number of cycles defined in the Design Specification. However, N can never be taken as less than 10.

S_{a10} = The S_a value at 10 cycles from the applicable Design Fatigue Curve in Appendix I

[98]

NB-3229 Design Stress Values

The design stress intensity values S_m are given in Section II, Part D, Subpart 1, Tables 2A and 2B for component materials. Values for intermediate temperatures may be found by interpolation. These form the basis for the various stress limits. Values of yield strength are given in Section II, Part D, Subpart 1, Table Y-1. Values of the coefficient of thermal expansion and modulus of elasticity are in Section II, Part D, Subpart 2, Tables TE and TM. The basis for establishing stress values is given in Appendix III. The design fatigue curves used in conjunction with NB-3222.4 are those of Figs. I-9.0.

[98]

NB-3230 STRESS LIMITS FOR BOLTS

NB-3231 Design Conditions

(a) The number and cross-sectional area of bolts required to resist the Design Pressure shall be determined in accordance

with the procedures of Appendix E, using the larger of the bolt loads, given by the equations of Appendix E, as a Design Mechanical Load. The allowable bolt design stresses shall be the values given in Section II, Part D, Subpart 1, Table 4 for bolting material.

(b) When sealing is effected by a seal weld instead of a gasket, the gasket factor m and the minimum design seating stress y may be taken as zero.

(c) When gaskets are used for preservice testing only, the design is satisfactory if the above requirements are satisfied for $m=y=0$, and the requirements of NB-3232 are satisfied when the appropriate m and y factors are used for the test gasket.

NB-3232 Level A Service Limits

Actual service stresses in bolts, such as those produced by the combination of preload, pressure, and differential thermal expansion, may be higher than the values given in Section II, Part D, Subpart 1, Table 4.

NB-3232.1 Average Stress.

The maximum value of service stress, averaged across the bolt cross section and neglecting stress concentrations, shall not exceed two times the stress values of Section II, Part D, Subpart 1, Table 4.

NB-3232.2 Maximum Stress.

The maximum value of service stress, except as restricted by NB-3232.3(b), at the periphery of the bolt cross section resulting from direct tension plus bending and neglecting stress concentrations shall not exceed three times the stress values of Section II, Part D, Subpart 1, Table 4. Stress intensity, rather than maximum stress, shall be limited to this value when the bolts are tightened by methods other than heaters, stretchers, or other means which minimize residual torsion.

NB-3232.3 Fatigue Analysis of Bolts.

Unless the components on which they are installed meet all the conditions of NB-3222.4(d) and thus require no fatigue analysis, the suitability of bolts for cyclic service shall be determined in accordance with the procedures of (a) through (e) below.

(a) *Bolting Having Less Than 100.0 ksi (689 MPa) Tensile Strength.* Bolts made of material which has specified minimum tensile strength of less than 100.0 ksi (689 MPa) shall be evaluated for cyclic service by the methods of NB-3222.4(e), using the applicable design fatigue curve of Figs. I-9.0 and an appropriate fatigue strength reduction factor [NB-3232.3(c)].

(b) *High Strength Alloy Steel Bolting.* High strength alloy steel bolts and studs may be evaluated for cyclic service by the methods of NB-3222.4(e) using the design fatigue curve of Fig. I-9.4 provided:

(1) the maximum value of the service stress (NB-3232.2) at the periphery of the bolt cross section, resulting from direct tension plus bending and neglecting stress concentration, shall not exceed $2.7S_m$ if the higher of the two fatigue design curves given in Fig. I-9.4 is used. The $2S_m$ limit for direct tension is unchanged.

(2) threads shall be of a Vee-type having a minimum thread root radius no smaller than 0.003 in. (0.076 mm);

(3) fillet radii at the end of the shank shall be such that the ratio of fillet radius to shank diameter is not less than 0.060.

(c) *Fatigue Strength Reduction Factor (NB-3213.17).* Unless it can be shown by analysis or tests that a lower value is appropriate, the fatigue strength reduction factor used in the fatigue evaluation of threaded members shall not be less than 4.0. However, when applying the rules of NB-3232.3(b) for high strength alloy steel bolts, the value used shall not be less than 4.0.

(d) *Effect of Elastic Modulus.* Multiply S_{alt} (as determined in NB-3216.1 or NB-3216.2) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve at this value on the ordinate axis and find the corresponding number of cycles on the

abscissa. If the service cycle being considered is the only one which produces significant fluctuating stresses, this is the allowable number of cycles.

(e) *Cumulative Damage*. The bolts shall be acceptable for the specified cyclic application of loads and thermal stresses provided the cumulative usage factor U , as determined in NB-3222.4(e)(5), does not exceed 1.0.

NB-3233 Level B Service Limits

Level A Service Limits (NB-3232) apply.

NB-3234 Level C Service Limits

The stress limits of NB-3232.1 and NB-3232.2 apply.

NB-3235 Level D Service Limits

If the Design Specifications specify any Service Loadings for which Level D Limits are designated

Page 92

[NCA-2142.4(b)(4)], the rules contained in Appendix F may be used in evaluating these loadings independently of all other Design and Service Loadings.

NB-3236 Design Stress Intensity Values

The design stress intensity values S_m are given in Section II, Part D, Subpart 1, Table 4 for bolting. Values for intermediate temperature may be found by interpolation. The basis for establishing stress intensity values is given in Appendix III.

NB-3300 VESSEL DESIGN

NB-3310 GENERAL REQUIREMENTS

NB-3311 Acceptability

The requirements for acceptability of a vessel design are as follows.

(a) The design shall be such that the requirements of NB-3100 and NB-3200 shall be satisfied.

(b) The rules of this Subarticle shall be met. In cases of conflict between NB-3200 and NB-3300 the requirements of NB-3300 shall govern.

NB-3320 DESIGN CONSIDERATIONS

NB-3321 Design and Service Loadings

The provisions of NB-3110 apply.

NB-3322 Special Considerations

The provisions of NB-3120 apply.

NB-3323 General Design Rules

The provisions of NB-3130 apply except when they conflict with rules of this Subarticle. In case of conflict, this Subarticle governs in the design of vessels.

NB-3324 Tentative Pressure Thickness

The following formulas are given as an aid to the designer for determining a tentative thickness for use in the design. They are not to be construed as formulas for acceptable thicknesses. However, except in local regions (NB-3221.2), the

wall thickness of a vessel shall never be less than that obtained from the formulas in NB-3324.1 and NB-3324.2, in which:

P	= Design Pressure, psi
R	= inside radius of shell or head, in.
R_o	= outside radius of shell or head, in.
S_m	= design stress intensity values (Section II, Part D, Subpart 1, Tables 2A and 2B), psi
t	= thickness of shell or head, in.

NB-3324.1 Cylindrical Shells

$$t = \frac{PR}{S_m - 0.5P} \quad \text{or} \quad t = \frac{PR_o}{S_m + 0.5P}$$

NB-3324.2 Spherical Shells

$$t = \frac{PR}{2S_m - P} \quad \text{or} \quad t = \frac{PR_o}{2S_m}$$

NB-3330 OPENINGS AND REINFORCEMENT

NB-3331 General Requirements for Openings

(a) For vessels or parts thereof which meet the requirements of NB-3222.4(d), analysis showing satisfaction of the requirements of NB-3221.1, NB-3221.2, NB-3221.3, and NB-3222.2 in the immediate vicinity of the openings is not required for pressure loading if the rules of NB-3330 are met.

(b) For vessels or parts thereof that do not meet the requirements of NB-3222.4(d) so that a fatigue analysis is required, the rules contained in NB-3330 ensure satisfaction of the requirements of NB-3221.1, NB-3221.2, and NB-3221.3 in the vicinity of openings, and no specific analysis showing satisfaction of those stress limits is required for pressure loading. The requirements of NB-3222.2 may also be considered to be satisfied if, in the vicinity of the nozzle, the stress intensity resulting from external nozzle loads and thermal effects, including gross but not local structural discontinuities, is shown by analysis to be less than $1.5S_m$. In this case, when evaluating the requirements of NB-3222.4(e), the peak stress intensity resulting from pressure loadings may be obtained by application of the stress index method of NB-3338 or NB-3339.

(c) The provisions of (a) and (b) above are not intended to restrict the design to any specified section thicknesses or other design details, provided the basic stress limits are satisfied. If it is shown by analysis that all the stress requirements have been met, the rules of NB-3330 are waived.

(d) Openings shall be circular, elliptical, or of any other shape which results from the intersection of a circular or elliptical cylinder with a vessel of the shapes permitted by this Subsection. Additional restrictions given in NB-3338.2(d) are applicable if the Stress Index

Page 93

Method is used. If fatigue analysis is not required, the restrictions on hole spacing are applicable unless there will be essentially no pipe reactions.

(e) Openings are not limited as to size except to the extent provided in NB-3338.2(d).

(f) All references to dimensions apply to the finished dimensions excluding material added as corrosion allowance. Rules regarding metal available for reinforcement are given in NB-3335.

(g) Any type of opening permitted in these rules may be located in a welded joint.

NB-3332 Reinforcement Requirements for Openings in Shells and Formed Heads

NB-3332.1 Openings Not Requiring Reinforcement.

The rules for openings not requiring reinforcement are given in (a) through (c) below, where R is the mean radius and t is the nominal thickness of the vessel shell or head at the location of the opening; and *locally stressed area* means any area in the shell where the primary local membrane stress exceeds $1.1S_m$ but excluding those areas where such primary local membrane stress is due to an unreinforced opening.

(a) A single opening has a diameter not exceeding $0.2\sqrt{Rt}$, or if there are two or more openings within any circle of diameter $2.5\sqrt{Rt}$, but the sum of the diameters of such unreinforced openings shall not exceed $0.25\sqrt{Rt}$.

(b) No two unreinforced openings shall have their centers closer to each other, measured on the inside of the vessel wall, than 1.5 times the sum of their diameters.

(c) No unreinforced opening shall have its center closer than $2.5\sqrt{Rt}$ to the edge of a locally stressed area in the shell.

NB-3332.2 Required Area of Reinforcement.

The total cross-sectional area of reinforcement A , required in any given plane for a vessel under internal pressure, shall not be less than:

$$A = dt_r F$$

where

d

= finished diameter of a circular opening or finished dimension (chord length) of an opening on the plane being considered for elliptical and obround openings in corroded condition, in.

F

= a correction factor which compensates for the variation in pressure stresses on different planes with respect to the axis of

a vessel. (A value of 1.00 shall be used for all configurations, except that Fig. NB-3332.2-1 may be used for integrally reinforced openings in cylindrical shells and cones.)

t_r

= the thickness which meets the requirements of NB-3221.1 in the absence of the opening, in.

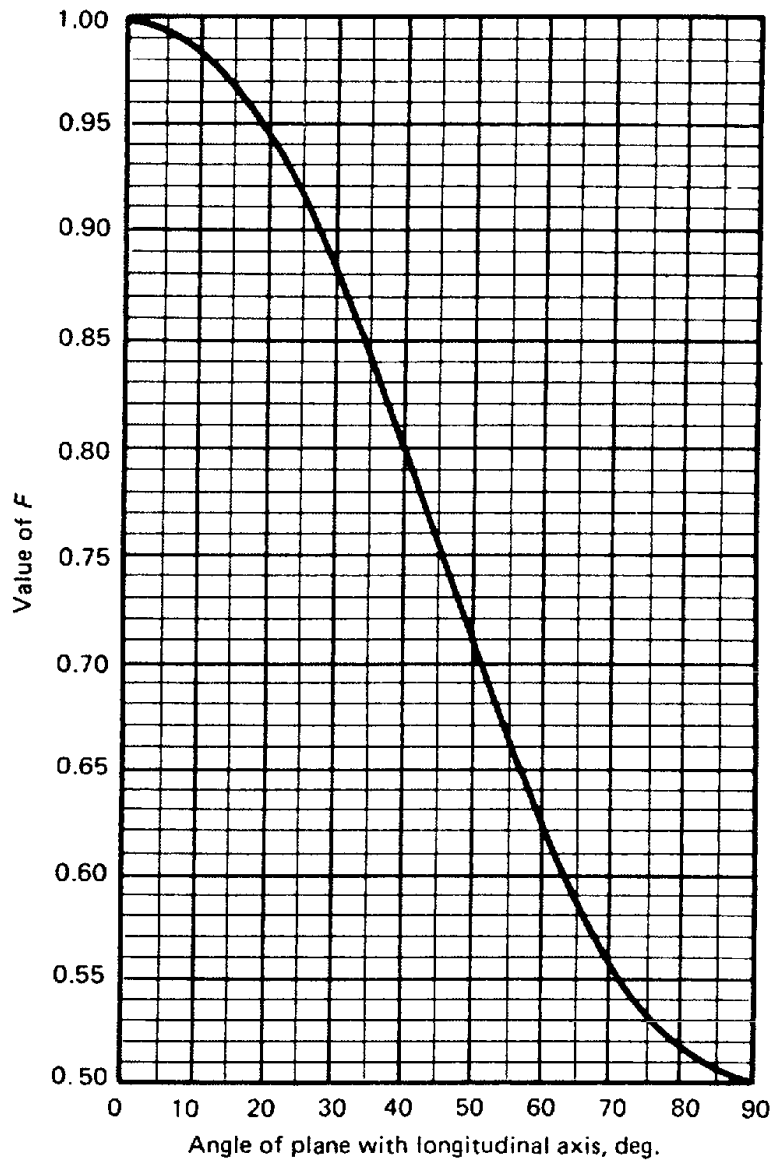


FIG. NB-3332.2-1 CHART FOR DETERMINING
VALUE OF F

FIG. NB-3332.2-1 CHART FOR DETERMINING VALUE OF F

Not less than half the required material shall be on each side of the center line.

NB-3333 Reinforcement Required for Openings in Flat Heads

Flat heads that have an opening with a diameter that does not exceed one-half the head diameter shall have a total cross-sectional area of reinforcement not less than that given by the formula:

Page 94

$$A = 0.5dt_r$$

where d is as defined in NB-3332 and t_r is the thickness, in., which meets the requirements of NB-3221.1 and NB-3221.3 in the absence of the opening.

NB-3334 Limits of Reinforcement

The boundaries of the cross-sectional area in any plane normal to the vessel wall and passing through the center of the opening and within which metal shall be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane and are given in the following subparagraphs.

NB-3334.1 Limit of Reinforcement Along the Vessel Wall.

The limits of reinforcement, measured along the midsurface of the nominal wall thickness, shall meet the following.

(a) One hundred percent of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) the diameter of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus the sum of the thicknesses of the vessel wall and the nozzle wall.

(b) Two-thirds of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) $r + 0.5\sqrt{Rt}$, where R is the mean radius of shell or head, t is the nominal vessel wall thickness, and r is the radius of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus two-thirds the sum of the thicknesses of the vessel wall and the nozzle wall.

NB-3334.2 Limit of Reinforcement Normal to the Vessel Wall.

The limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to the following limits as shown in Fig. NB-3338.2(a)-2.

(a) For Fig. NB-3338.2(a)-2 sketches (a), (b), (d), and (e):

$$\text{Limit} = 0.5\sqrt{r_i^2 - t_n^2} + 0.5r_2$$

where

r_i = inside radius, in.

r_m = mean radius, in.

$$= r_i + 0.5t_n$$

r_2 = transition radius, in., between nozzle and wall

t_n = nominal nozzle thickness, as indicated, in.

For the case of a nozzle with a tapered inside diameter, the limit shall be obtained by using r_i and t_n values at the nominal outside diameters of the vessel wall [Fig. NB-3338.2(a)-2 sketch (e)].

(b) For Fig. NB-3338.2(a)-2 sketches (c) and (f):

$$\text{Limit} = 0.5 \sqrt{r_m t_n}$$

where

r_i	= inside radius, in.
r_m	= $r_i + 0.5t_p$ in.
t_n	= $t_p + 0.667X$
t_p	= nominal thickness of the attached pipe, in.
X	= slope offset distance, in.
θ	= angle between vertical and slope, 45 deg. or less

For the case of a nozzle with a tapered inside diameter, the limit shall be obtained by using r_i and t_n values at the center of gravity of nozzle reinforcement area. These values must be determined by a trial and error procedure [Fig. NB-3338.2(a)-2 sketch (f)].

NB-3335 Metal Available for Reinforcement

Metal may be counted as contributing to the area of reinforcing called for in NB-3332, provided it lies within the limits of reinforcement specified in NB-3334, and shall be limited to material which meets the following requirements:

(a) metal forming a part of the vessel wall which is in excess of that required on the basis of membrane stress intensity (NB-3221.1) and is exclusive of corrosion allowance;

(b) similar excess metal in the nozzle wall, provided the nozzle is integral with the vessel wall or is joined to it by a full penetration weld;

(c) weld metal which is fully continuous with the vessel wall;

(d) the mean coefficient of thermal expansion of metal to be included as reinforcement under (b) and (c) above shall be within 15% of the value of the vessel wall material;

(e) metal not fully continuous with the shell, such as that in nozzles attached by partial penetration welds, shall not be counted as reinforcement;

(f) metal available for reinforcement shall not be considered as applying to more than one opening.

NB-3336 Strength of Reinforcing Material

Material used for reinforcement shall preferably be the same as that of the vessel wall. If the material of

Page 95

the nozzle wall or reinforcement has a lower design stress intensity value S_m than that for the vessel material, the amount of area provided by the nozzle wall or reinforcement in satisfying the requirements of NB-3332 shall be taken as the actual area provided multiplied by the ratio of the nozzle or reinforcement design stress intensity value to the vessel material design stress intensity value. No reduction in the reinforcing required may be taken for the increased strength of reinforcing material and weld metal having higher design stress intensity values than that of the material of the vessel wall. The strength of the material at the point under consideration shall be used in fatigue analyses.

NB-3337 Attachment of Nozzles and Other Connections

NB-3337.1

Nozzles and other Category D connections (NB-3351) shall be attached to the shell or head of the vessel by one of the methods provided in NB-3352.

NB-3337.2 Full Penetration Welded Nozzles.

Full penetration welds, as shown in Figs. NB-4244(a)-1, NB-4244(b)-1, NB-4244(c)-1, and NB-4244(e)-1 may be used (except as otherwise provided in NB-3337.3) for the purpose of achieving continuity of metal and facilitating the required radiographic examination. When all or part of the required reinforcement is attributable to the nozzle, the nozzle shall be attached by full penetration welds through either the vessel or the nozzle thickness, or both.

NB-3337.3 Partial Penetration Welded Nozzles

(a) Partial penetration welds, as shown in Figs. NB-4244(d)-1 and NB-4244(d)-2, are allowed only for nozzles on which there are substantially no piping reactions, such as control rod housings, pressurizer heater wells, and openings for instrumentation. Earthquake loadings need not be considered in determining whether piping reactions are substantial. For such nozzles, all reinforcement shall be integral with the portion of the vessel penetrated. Partial penetration welds shall be of sufficient size to develop the full strength of the nozzles. Nozzles attached by partial penetration welds shall have an interference fit or a maximum diametral clearance between the nozzle and the vessel penetration of:

- (1) 0.010 in. (0.25 mm) for $d \leq 1$ in. (25 mm)
- (2) 0.020 in. (0.51 mm) for 1 in. (25 mm) $< d \leq 4$ in. (102 mm)
- (3) 0.030 in. (0.76 mm) for $d > 4$ in. (102 mm)

where d is the outside diameter of the nozzle, except that the above limits on maximum clearance need not be met for the full length of the opening, provided there is a region at the weld preparation and a region near the end of the opening opposite the weld that does meet the above limits on maximum clearance and the latter region is extensive enough (not necessarily continuous) to provide a positive stop for nozzle deflection.

(b) In satisfying the limit of NB-3222.2, the stress intensities resulting from pressure induced strains (dilation of hole) may be treated as secondary in the penetrating part of partial penetration welded construction, provided the requirements of NB-3352.4(d) and Fig. NB-4244(d)-1 are fulfilled.

NB-3338 Fatigue Evaluation of Stresses in Openings

NB-3338.1 General.

For the purpose of determining peak stresses around the opening, three acceptable methods are listed below.

(a) *Analytical Method.* This method uses suitable analytical techniques such as finite element computer analyses, which provide detailed stress distributions around openings. In addition to peak stresses due to pressure, the effects of other loadings shall be included. The total peak stress at any given point shall be determined by combining stresses due to pressure, thermal, and external loadings in accordance with the rules of NB-3200.

(b) *Experimental Stress Analysis.* This is based on data from experiments (Appendix II).

(c) *Stress Index Method.* This uses various formulas together with available data obtained from an extensive series of tests covering a range of variation of applicable dimensional ratios and configurations (NB-3338.2). This method covers only single, isolated openings. Stress indices may also be determined by theoretical or experimental stress analysis.

NB-3338.2 Stress Index Method

(a) The term *stress index*, as used herein, is defined as the numerical ratio of the stress components σ_r , σ_θ , and σ_z [Fig. NB-3338.2(a)-1] under consideration to the computed membrane hoop stress in the unpenetrated vessel material; however, the material which increases the thickness of a vessel wall locally at the nozzle shall not be included in the calculations of these stress components. When the thickness of the vessel wall is increased over that required to the extent provided hereinafter, the values of r_1 and r_2 in Fig. NB-3338.2(a)-2 shall be referred to the thickened section.

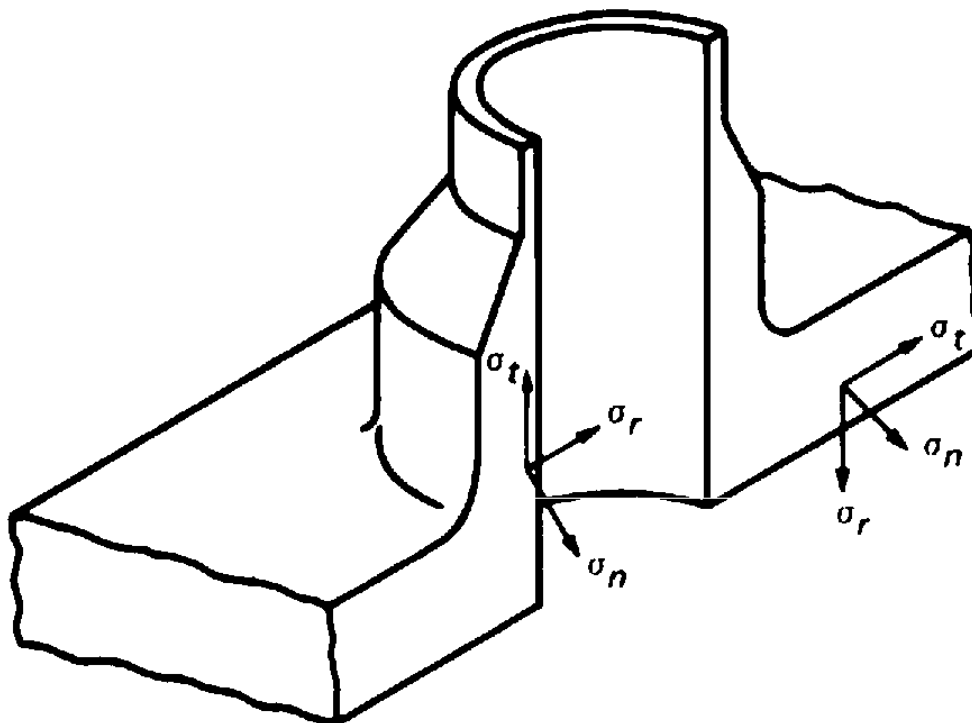


FIG. NB-3338.2(a)-1 DIRECTION OF STRESS COMPONENTS

FIG. NB-3338.2(a)-1 DIRECTION OF STRESS COMPONENTS

(b) The nomenclature used in NB-3338 is defined as follows.

R	= inside radius, in corroded condition, of cylindrical vessel, spherical vessel, or spherical head, in.
S	= stress intensity (combined stress) at the point under consideration, psi
t	= nominal wall thickness, less corrosion allowance, of vessel or head, in.
σ_n	= stress component normal to the plane of the section (ordinarily the circumferential stress around the hole in the

shell), psi

σ_r = stress component normal to the boundary of the section, psi
 σ_t = stress component in the plane of the section under consideration and parallel to the boundary of the section, psi

(c) When the conditions of (d) below are satisfied, the stress indices of Table NB-3338.2(c)-1 may be used for nozzles designed in accordance with the applicable rules of NB-3330. These stress indices deal only with the maximum stresses, at certain general locations, due to internal pressure. In the evaluation of stresses in or adjacent to vessel openings and connections, it is often necessary to consider the effect of stresses due to external loadings or thermal stresses. In such cases, the total stress at a given point may be determined by superposition. In the case of combined stresses due to internal pressure and nozzle loading, the maximum stresses for a given location shall be considered as acting at the same point and added algebraically unless positive evidence is available to the contrary.

(d) The indices of Table NB-3338.2(c)-1 apply when the conditions stipulated in (1) through (7) below exist.

(1) The opening is for a circular nozzle whose axis is normal to the vessel wall. If the axis of the nozzle makes an angle ϕ with the normal to the vessel wall and if $d/D \leq 0.15$, an estimate of the σ_n index on the inside may be obtained from one of the following formulas.

For hillside connections in spheres or cylinders:

$$K_2 = K_1 (1 + 2 \sin^2 \phi)$$

For lateral connections in cylinders:

$$K_2 = K_1 [1 + (\tan \phi)^{4/3}]$$

where

K_1 = the σ_n inside stress index of Table NB-3338.2(c)-1 for a radial connection
 K_2 = the estimated σ_n inside stress index for the nonradial connection

(2) The arc distance measured between the center lines of adjacent nozzles along the inside surface of the shell is not less than three times the sum of their inside radii for openings in a head or along the longitudinal axis of a shell and is not less than two times the sum of their radii for openings along the circumference of a cylindrical shell. When two nozzles in a cylindrical shell are neither in a longitudinal line nor in a circumferential arc, their center line distance along the inside surface of the shell shall be such that $[(L_c/2)^2 + (L_l/3)^2]^{1/2}$ is not less than the sum of their inside radii, where L_c is the component of the center line distance in the circumferential direction and L_l is the component of the center line distance in the longitudinal direction.

(3) The following dimensional ratios are met:

Ratio	Cylinder	Sphere
D/t	10 to 100	10 to 100
d/D	0.5 max.	0.5 max.
$d/\sqrt{Dt}$	...	0.8 max.
$d/\sqrt{Dt} \sqrt{t_2/t}$	1.5 max.	...

where D is the inside shell diameter, t is the shell thickness, and d is the inside nozzle diameter. In the case of cylindrical shells, the total nozzle reinforcement area on the transverse axis of the connections, including any outside of the reinforcement limits, shall not exceed 200% of that required for the longitudinal axis (compared to 50% permitted by Fig. NB-3332.2-1) unless a tapered transition section is incorporated into the

reinforcement and the shell, meeting the requirements of NB-3361.

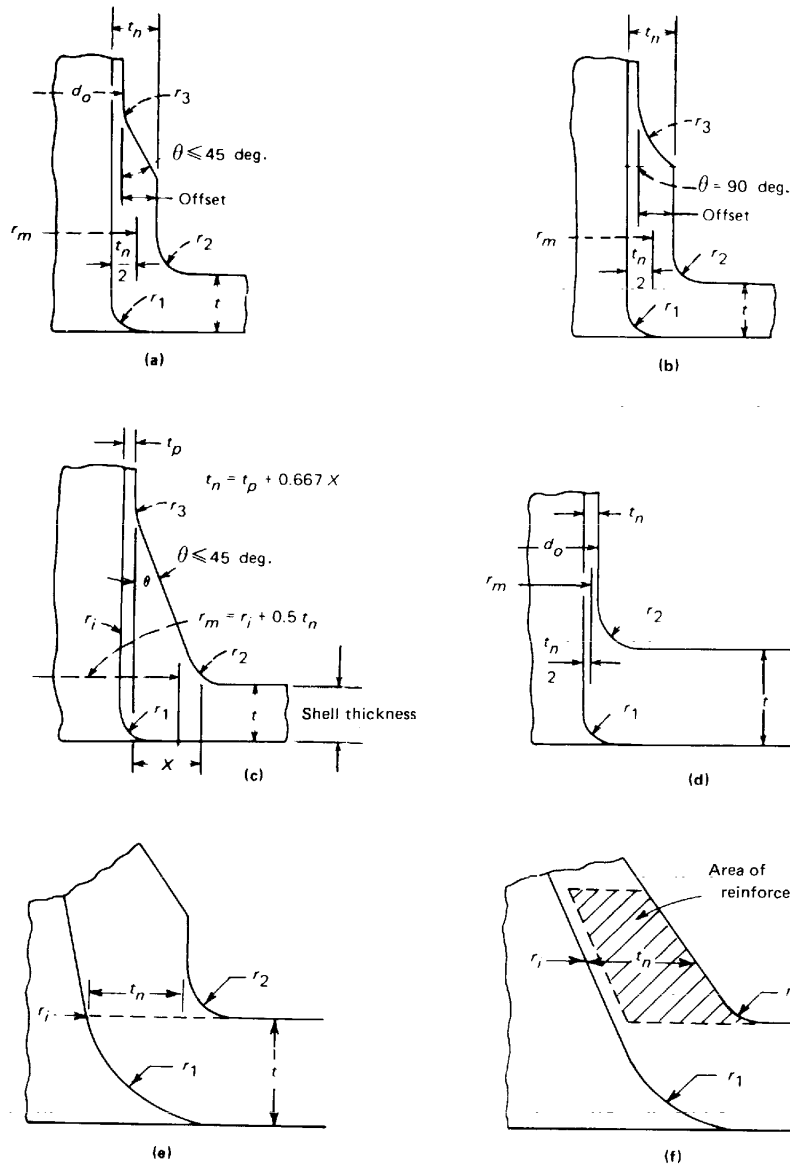


FIG. NB-3338.2(a)-2 NOZZLE DIMENSIONS

FIG. NB-3338.2(a)-2 NOZZLE DIMENSIONS

**TABLE NB-3338.2(c)-1
STRESS INDICES FOR NOZZLES**

Nozzles in Spherical Shells and Formed Heads		
Stress	Inside Corner	Outside Corner
σ_n	2.0	2.0
σ_t	- 0.2	2.0
σ_r	- 2t/R	0
S	2.2	2.0

Nozzles in Cylindrical Shells				
Stress	Longitudinal Plane		Transverse Plane	
	Inside	Outside	Inside	Outside
σ_n	3.1	1.2	1.0	2.1
σ_t	- 0.2	1.0	- 0.2	2.6
σ_r	- t/R	0	- t/R	0
S	3.3	1.2	1.2	2.6

TABLE NB-3338.2(c)-1 STRESS INDICES FOR NOZZLES

(4) In the case of spherical shells and formed heads, at least 40% of the total nozzle reinforcement area shall be located beyond the outside surface of the minimum required vessel wall thickness.

(5) The inside corner radius r_1 [Fig. NB-3338.2(a)-2] is between 10% and 100% of the shell thickness t .

(6) The outer corner radius r_2 [Fig. NB-3338.2(a)-2] is large enough to provide a smooth transition between the nozzles and the shell. In addition, for opening diameters greater than $1\frac{1}{2}$ times the shell thickness in cylindrical shells and 2:1 ellipsoidal heads and greater than three shell thicknesses in spherical shells, the value of r_2 shall be not less than one-half the thickness of the shell or nozzle wall, whichever is greater.

(7) The radius r_3 [Fig. NB-3338.2(a)-2] is not less than the greater of the following:

(a) $0.002\theta d_o$, where d_o is the outside diameter of the nozzle and is as shown in Fig. NB-3338.2(a)-2, and the angle θ is expressed in degrees;

(b) $2(\sin \theta)^3$ times offset for the configuration shown in Fig. NB-3338.2(a)-2 sketches (a) and (b).

NB-3339

Subject to the limitations stipulated in NB-3339.1, the requirements of this paragraph constitute an acceptable alternative to the rules of NB-3332 through NB-3336 and NB-3338.

NB-3339.1 Limitations.

These alternative rules are applicable only to nozzles in vessels within the limitations stipulated in (a) through (f) below.

(a) The nozzle is circular in cross section and its axis is normal to the vessel or head surface.

(b) The nozzle and reinforcing (if required) are welded integrally into the vessel with full penetration welds. Details such as those shown in Figs. NB-4244(a)-1, NB-4244(b)-1, and NB-4244(c)-1 are acceptable. However, fillet welds shall be finished to a radius in accordance with Fig. NB-3339.1(b)-1.

(c) In the case of spherical shells and formed heads, at least 40% of the total nozzle reinforcement area shall be located beyond the outside surface of the minimum required vessel wall thickness.

(d) The spacing between the edge of the opening and the nearest edge of any other opening is not less than the smaller of $1.25(d_1 + d_2)$ or $2.5\sqrt{Rt}$, but in any case not less than $d_1 + d_2$, where d_1 and d_2 are the inside diameters of the openings.

(e) The material used in the nozzle, reinforcing, and vessel adjacent to the nozzle shall have a ratio of UTS/YS of not less than 1.5, where

UTS = specified minimum ultimate tensile strength, ksi

YS = specified minimum yield strength, ksi

(f) The following dimensional limitations are met:

	Nozzles in Cylindrical Vessels	Nozzles in Spherical Vessels or Hemispherical Heads
D/t	10 to 100	10 to 100
d/D	0.5 max.	0.5 max.
$d/\sqrt{Dt}$	...	0.8 max.
$d/\sqrt{Dt_n} \sqrt{t}$	1.5 max.	...

NB-3339.2 Nomenclature.

The nomenclature used in NB-3339 is defined as follows:

A_a	= available reinforcing area, sq in.
A_r	= required minimum reinforcing area, sq in.
D	= inside diameter, in corroded condition, of cylindrical vessel, spherical vessel, or spherical head, in.
d	= inside diameter, in corroded condition, of the nozzle, in.
R	= inside radius, in corroded condition, of cylindrical vessel, spherical vessel, or spherical head, in.
t	= nominal wall thickness, less corrosion allowance, of vessel or head, in.
t_n	= nominal wall thickness, less corrosion allowance, of nozzle, in.

t_r

= wall thickness of vessel or head, computed by the equations given in NB-3324.1 for cylindrical vessels and in NB-3324.2 for spherical vessels or spherical heads, in.

t_m

= wall thickness of nozzle, computed by the equation given in NB-3324.1, in.

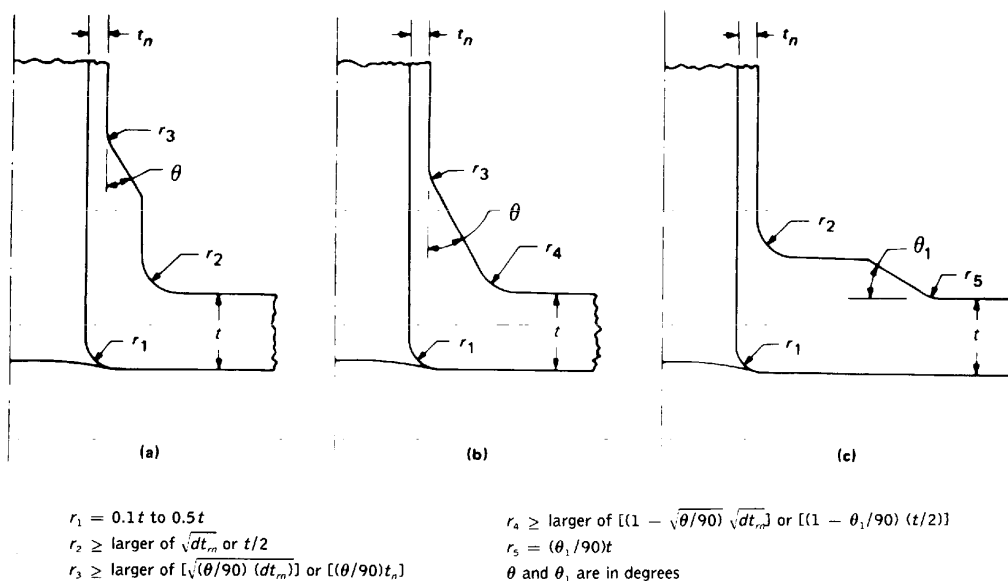


FIG. NB-3339.1(b)-1 EXAMPLES OF ACCEPTABLE TRANSITION DETAILS

FIG. NB-3339.1(b)-1 EXAMPLES OF ACCEPTABLE TRANSITION DETAILS

For the definitions of $r_1, r_2, r_3, r_4, \theta$, and θ_1 see Fig. NB-3339.1(b)-1; for L_c and L_n see Fig. NB-3339.4-1; for S, σ_p, σ_n , and σ_r see NB-3338.2 and Fig. NB-3338.2(a)-1.

NB-3339.3 Required Reinforcement Area.

The required minimum reinforcing area is related to the value of $d/\sqrt{Rt_r}$ as tabulated in Table NB-3339.3-1. The required minimum reinforcing area shall be provided in all planes containing the nozzle axis.

NB-3339.4 Limits of Reinforcing Zone.

Reinforcing metal included in meeting the minimum required reinforcing area specified in Table NB-3339.3-1 must be located within the reinforcing zone boundary shown in Fig. NB-3339.4-1.

NB-3339.5 Strength of Reinforcing Material Requirements.

Material in the nozzle wall used for reinforcing shall preferably be the same as that of the vessel wall. If material with a

lower design stress intensity value S_m is used, the area provided by such material shall be increased in proportion to the inverse ratio of the stress values of the nozzle and the vessel wall material. No reduction in the reinforcing area requirement shall be taken for the increased strength of nozzle material or weld metal which has a higher

design stress intensity value than that of the material of the vessel wall. The strength of the material at the point under consideration shall be used in fatigue analyses. The mean coefficient of thermal expansion of metal to be included as reinforcement shall be within 15% of the value for the metal of the vessel wall.

TABLE NB-3339.3-1 REQUIRED MINIMUM REINFORCING AREA, A_r .

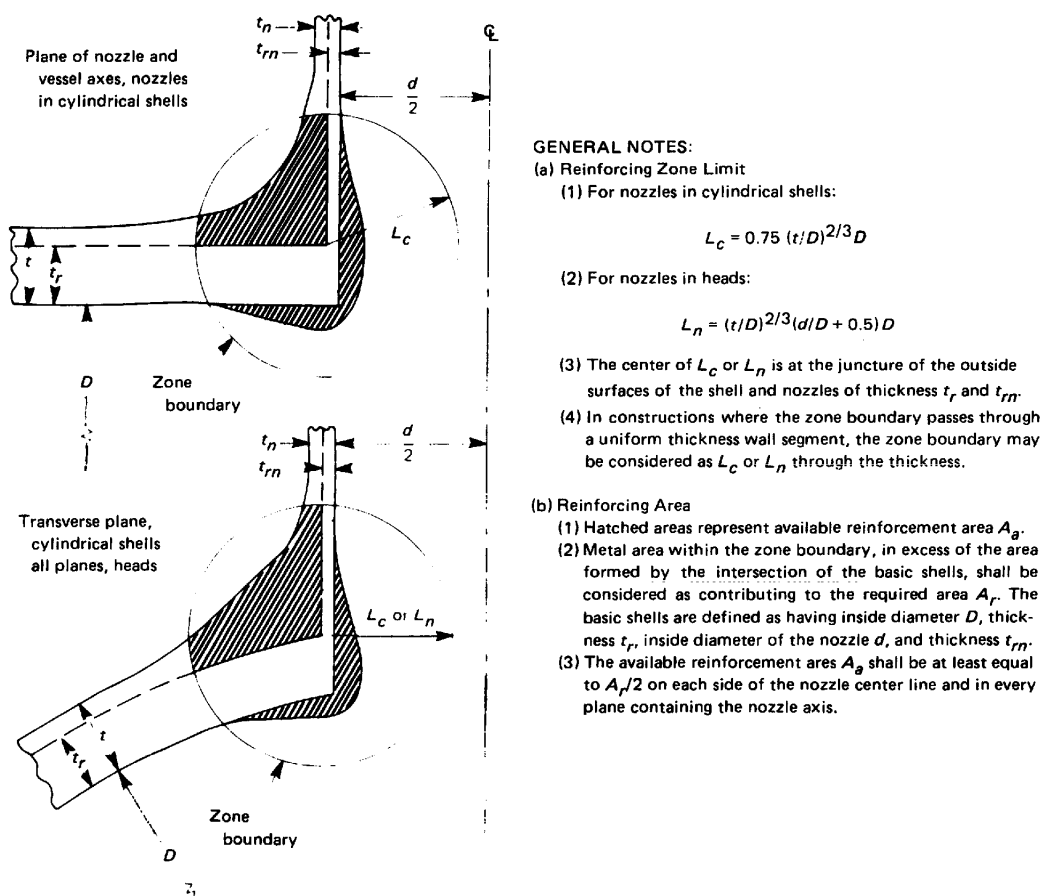


FIG. NB-3339.4-1 LIMITS OF REINFORCING ZONE

FIG. NB-3339.4-1 LIMITS OF REINFORCING ZONE

NB-3339.6 Transition Details.

Examples of acceptable transition tapers and radii are shown in Fig. NB-3339.1(b)-1. Other configurations which meet the reinforcing area requirements of NB-3339.3 and with equivalent or less severe transitions are also acceptable; e.g., larger radius-thickness ratios.

NB-3339.7 Stress Indices

(a) The term *stress index*, as used herein, is defined as the numerical ratio of the stress components σ_r , σ_n , and σ_t , under consideration, to the computed stress σ .

(b) The nomenclature for the stress components is shown in Fig. NB-3338.2(a)-1 and is defined as follows:

P	= service pressure, psi
S	= stress intensity (combined stress) at the point under consideration, psi
σ	= $P(D + t)/4t$ for nozzles in spherical vessels or heads, psi = $P(D + t)/2t$ for nozzles in cylindrical vessels, psi
σ_n	= stress component normal to the plane of the section (ordinarily the circumferential stress around the hole in the shell), psi

Page 101

σ_r	= stress component normal to the boundary of the section, psi
σ_t	= stress component in the plane of the section under consideration and parallel to the boundary of the section, psi

**TABLE NB-3339.7(c)-1
STRESS INDICES FOR INTERNAL
PRESSURE LOADING**

Nozzles in Spherical Shells and Spherical Heads		
Stress	Inside	Outside
σ_n	$2.0 - d/D$	$2.0 - d/D$
σ_t	-0.2	$2.0 - d/D$
σ_r	$-4t/(D + t)$	0
S	larger of: $2.2 - d/D$ or $2.0 + [4t/(D + t)] - d/D$	$2.0 - d/D$

Nozzles in Cylindrical Shells				
Stress	Longitudinal Plane		Transverse Plane	
	Inside	Outside	Inside	Outside
σ_n	3.1	1.2	1.0	2.1
σ_t	-0.2	1.0	-0.2	2.6
σ_r	$-2t/(D + t)$	0	$-2t/(D + t)$	0
S	3.3	1.2	1.2	2.6

TABLE NB-3339.7(c)-1 STRESS INDICES FOR INTERNAL PRESSURE LOADING

(c) When the conditions of NB-3339.1 through NB-3339.6 are satisfied, the stress indices given in Table NB-3339.7(c)-1 may be used. These stress indices deal only with the maximum stresses, at certain general locations, due to internal pressure. In the evaluation of stresses in or adjacent to vessel openings and connections, it is often necessary to consider the effect of stresses due to external loadings or thermal stresses. In such cases, the total stress at a given point may be determined by superposition. In the case of combined stresses due to internal pressure and nozzle loading, the maximum stresses shall be considered as acting at the same point and added algebraically. If the stresses are otherwise determined by more accurate analytical techniques or by the experimental stress analysis procedure of Appendix II, the stresses are also to be added algebraically.

NB-3340 ANALYSIS OF VESSELS

The provisions of NB-3214 apply.

NB-3350 DESIGN OF WELDED CONSTRUCTION

NB-3351 Welded Joint Category

The term *Category* defines the location of a joint in a vessel, but not the type of joint. The categories established are for use in specifying special requirements regarding joint type and degree of examination for certain welded joints. Since these special requirements, which are based on service, material, and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in the categories. The special requirements apply to joints of a given category only when specifically stated. The joints included in each category are designated as joints of Categories A, B, C, and D. Figure NB-3351-1 illustrates typical joint locations included in each category.

NB-3351.1 Category A.

Category A comprises longitudinal welded joints within the main shell, communicating chambers,¹³ transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head, or within the side plates¹⁴ of a flat sided vessel; and circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameters, to nozzles, or to communicating chambers.

NB-3351.2 Category B.

Category B comprises circumferential welded joints within the main shell, communicating chambers, nozzles, or transitions in diameter, including joints between the transition and a cylinder at either the large or small end; and circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers.

NB-3351.3 Category C.

Category C comprises welded joints connecting flanges, Van Stone laps, tubesheets, or flat heads to main shell, to formed heads, to transitions in diameter, to nozzles, or to communicating chambers¹³ any welded joint connecting one side plate¹⁴ to another side plate of a flat sided vessel.

¹³ Communicating chambers are defined as portions of the vessel which intersect the shell or heads of a vessel and form an integral part of the pressure-retaining closure, e.g., sumps.

¹⁴ Side plates of a flat sided vessel are defined as any of the flat plates forming an integral part of the pressure-retaining enclosure.

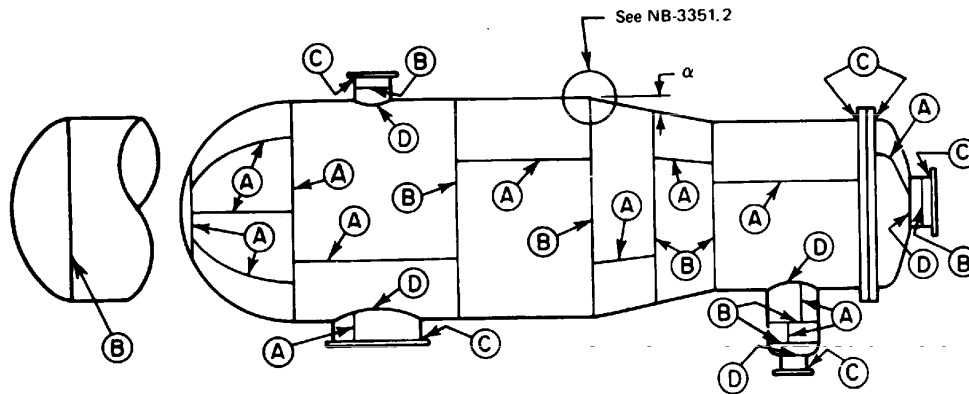


FIG. NB-3351-1 WELDED JOINT LOCATIONS TYPICAL OF CATEGORIES A, B, C, AND D

FIG. NB-3351-1 WELDED JOINT LOCATIONS TYPICAL OF CATEGORIES A, B, C, AND D

NB-3351.4 Category D.

Category D comprises welded joints connecting communicating chambers or nozzles to main shells, to spheres, to transitions in diameter, to heads, or to flat sided vessels, and those joints connecting nozzles to communicating chambers. For nozzles at the small end of a transition in diameter, see Category B.

NB-3352 Permissible Types of Welded Joints

The design of the vessel shall meet the requirements for each category of joint. Butt joints are full penetration joints between plates or other elements that lie approximately in the same plane. Category B angle joints between plates or other elements that have an offset angle α not exceeding 30 deg. are considered as meeting the requirements for butt joints. Figure NB-3352-1 shows typical butt welds for each category joint.

NB-3352.1 Joints of Category A.

All welded joints of Category A as defined in NB-3351 shall meet the fabrication requirements of NB-4241 and shall be capable of being examined in accordance with NB-5210.

NB-3352.2 Joints of Category B.

All welded joints of Category B as defined in NB-3351 shall meet the fabrication requirements of NB-4242 and shall be capable of being examined in accordance with NB-5220. When joints with opposing lips to form an integral backing strip or joints with backing strips not later removed are used, the suitability for cyclic service shall be analyzed by the method of NB-3222.4 using a fatigue strength reduction factor of not less than 2.

NB-3352.3 Joints of Category C.

All welded joints of Category C as defined in NB-3351 shall meet the fabrication requirements of NB-4243 and shall be capable of being examined in accordance with NB-5230. Minimum dimensions of the welds and throat thickness shall be as shown in Fig. NB-4243-1 where:

(a) for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle not greater than 45 deg. measured from the face:

t

t, t_n	= nominal thicknesses of welded parts, in.
t_c	= $0.7t_n$ or $1/4$ in. (6 mm), whichever is less
t_w	= $t_n/2$ or $t/4$, whichever is less

(b) for all other material forms and for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle greater than 45 deg. measured from the face:

t, t_n	= nominal thicknesses of welded parts, in.
t_c	= $0.7t_n$ or $1/4$ in. (6 mm), whichever is less
t_w	= t_n or $t/2$, whichever is less

NB-3352.4 Joints of Category D.

All welded joints of Category D as defined in NB-3351 shall be in accordance with the requirements of one of (a) through (e) below.

(a) *Butt Welded Nozzles*. Nozzles shall meet the fabrication requirements of NB-4244(a) and shall be capable of being examined in accordance with NB-5242. The minimum dimensions and geometrical requirements of Fig. NB-4244(a)-1 shall be met, where

r_1	= $1/4t$ or $3/4$ in. (19 mm), whichever is less
r_2	= $1/4$ in. (6 mm) minimum
t	= nominal thickness of part penetrated, in.

t_n	= nominal thickness of penetrating part, in.
-------	--

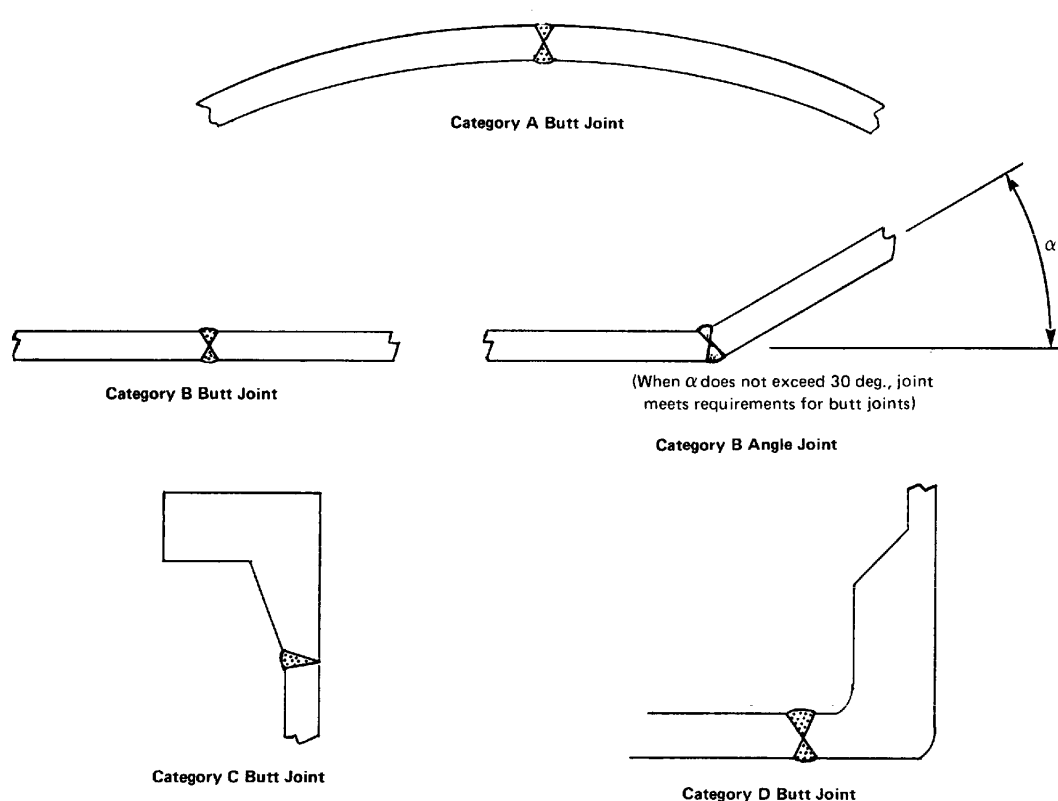


FIG. NB-3352-1 TYPICAL BUTT JOINTS

FIG. NB-3352-1 TYPICAL BUTT JOINTS

(b) *Full Penetration Corner Welded Nozzles.* Nozzles shall meet the fabrication requirements of NB-4244(b) and shall be capable of being examined as required in NB-5243. The minimum dimensions of Fig. NB-4244(b)-1 shall be met, where

r_1	$= \frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2	$= \frac{1}{4}$ in. (6 mm) minimum
t	$=$ nominal thickness of part penetrated, in.
t_c	$= 0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_n	$=$ nominal thickness of penetrating part, in.

(c) *Use of Deposited Weld Metal for Openings and Nozzles*

(1) Nozzles shall meet the fabrication requirements of NB-4244(c) and shall be capable of being examined in accordance with NB-5244.

(2) When the deposited weld metal is used as reinforcement, the coefficients of thermal expansion of the base metal, the weld metal, and the nozzle shall not differ by more than 15% of the lowest coefficient involved.

(3) The minimum dimensions of Fig. NB-4244(c)-1 shall be met, where

r_1	= $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
t	= nominal thickness of part penetrated, in.
t_c	= $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_n	= nominal thickness of penetrating part, in.

(4) The corners of the end of each nozzle neck extending less than $\sqrt{d}t_n$ beyond the inner surface of the part penetrated shall be rounded to a radius of one-half the thickness t_n of the nozzle neck or $\frac{3}{4}$ in. (19 mm), whichever is smaller.

(d) Attachment of Nozzles Using Partial Penetration Welds

(1) Partial penetration welds used to connect nozzles as permitted in NB-3337.3 shall meet the fabrication

Page 104

requirements of NB-4244(d) and shall be capable of being examined in accordance with the requirements of NB-5245.

(2) The minimum dimensions of Figs. NB-4244(d)-1 and NB-4244(d)-2 shall be met, where

d	= outside diameter of nozzle or of the inner cylinder as shown in Fig. NB-4244(d)-2
r_1	= $\frac{1}{4}t_n$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2	= $\frac{1}{16}$ in. (1.6 mm) minimum
r_3	= r_2 or equivalent chamfer minimum
r_4	= $\frac{1}{2}t_n$ or $\frac{3}{4}$ in. (19 mm), whichever is less
t	= nominal thickness of part penetrated, in.
t_c	= $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_n	= nominal thickness of penetrating part or the lesser of t_{n1} or t_{n2} in Fig. NB-4244(d)-2, in.
λ	= $\frac{1}{16}$ in. (1.6 mm) minimum
λ	= t_n maximum, in.

(3) The corners of the end of each nozzle, extending less than $\sqrt{d}t_n$ beyond the inner surface of the part penetrated, shall be rounded to a radius of one-half of the thickness t_n of the penetrating part or $\frac{3}{4}$ in. (19 mm), whichever is smaller.

(4) Weld groove design for partial penetration joints attaching nozzles may require special consideration to achieve the $1.25t_n$ minimum depth of weld and adequate access for welding examination. The welds shown in the sketches of Figs. NB-4244(d)-1 and NB-4244(d)-2 may be on either the inside or the outside of the vessel shell. Weld preparation may be J-groove as shown in the figures or straight bevel.

(5) A fatigue strength reduction factor of not less than four shall be used when fatigue analysis is required.

(e) Oblique Full Penetration Nozzles. Internal or external nozzles shall meet the fabrication requirements of NB-4244 (e) and shall be capable of being examined in accordance with NB-5246. Radiography of the nozzle weld may be waived by NB-5246, provided the requirements of (1) through (6) below are met.

(1) The inside nozzle diameter shall not exceed 6 in.

(2) The angle which the nozzle axis makes with the vessel wall at the point of attachment shall not be smaller than 40 deg.

(3) The opening shall be completely reinforced, with the reinforcement located in the shell or head of the vessel.

(4) The nozzle shall be subjected to essentially no pipe reactions and no thermal stresses greater than in the vessel itself.

(5) The nozzle wall and the weld shall develop the full strength of the nozzle.

(6) The minimum dimensions of Fig. NB-4244(e)-1 shall be met, where

r_1	= $\frac{1}{2}$ or $\frac{3}{4}$ in. (19 mm), whichever is less
t	= nominal thickness of part penetrated, in.
t_c	= $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_n	= nominal thickness of penetrating part, in.

NB-3354 Structural Attachment Welds

Welds for structural attachments shall meet the requirements of NB-4430.

NB-3355 Welding Grooves

The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration, except as otherwise permitted in NB-3352.4.

NB-3357 Thermal Treatment

All vessels and vessel parts shall be given the appropriate postweld heat treatment prescribed in NB-4620.

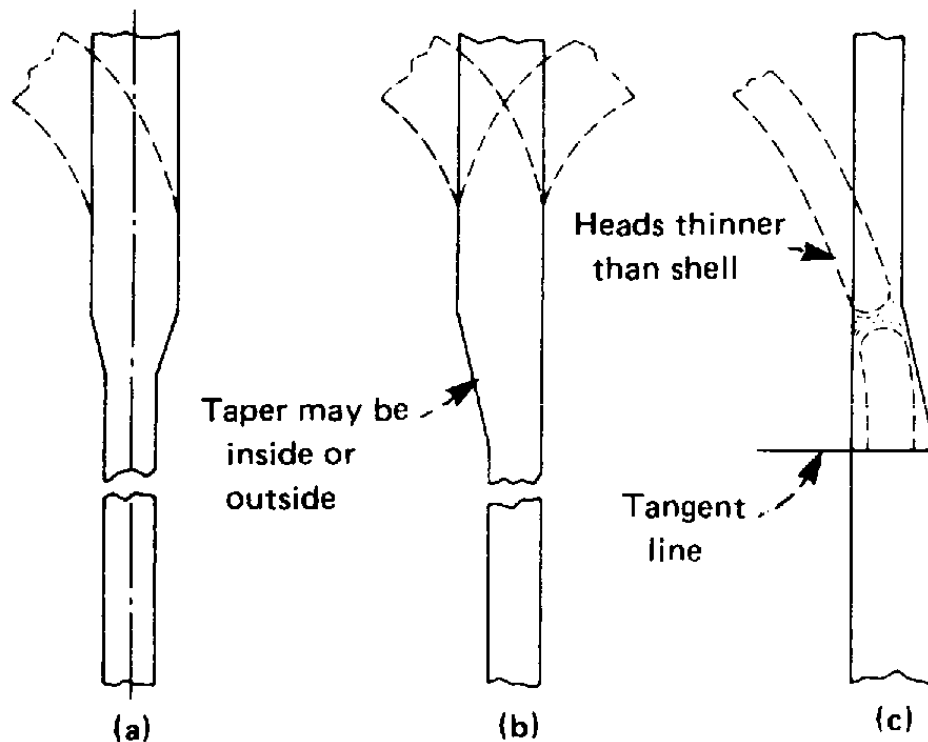
NB-3360 SPECIAL VESSEL REQUIREMENTS

NB-3361 Category A or B Joints Between Sections of Unequal Thickness

In general, a tapered transition section as shown in Fig. NB-3361-1 which is a type of gross structural discontinuity (NB-3213.2) shall be provided at joints of Categories A and B between sections that differ in thickness by more than one-fourth the thickness of the thinner section. The transition section may be formed by any process that will provide a uniform taper. An ellipsoidal or hemispherical head which has a greater thickness than a cylinder of the same inside diameter may be machined to the outside diameter of the cylinder provided the remaining thickness is at least as great as that required for a shell of the same diameter. A uniform taper is not required for flanged hubs. The adequacy of the transition shall be evaluated by stress analysis. Stress intensity limitations are given in NB-3220. The requirements of this paragraph do not apply to flange hubs.

NB-3362 Bolted Flange Connections

It is recommended that the dimensional requirements of bolted flange connections to external piping conform to ANSI B16.5, Steel Pipe Flanges and Flanged Fittings.



GENERAL NOTE:

Length of taper may include the width of the weld.

**FIG. NB-3361-1 CATEGORY A AND B JOINTS
BETWEEN SECTIONS OF UNEQUAL THICKNESS**

FIG. NB-3361-1 CATEGORY A AND B JOINTS BETWEEN SECTIONS OF UNEQUAL THICKNESS

NB-3363 Access Openings

Access openings, where provided, shall consist of handhole or manhole openings having removable covers. These may be located on either the inside or outside of the shell or head openings and may be attached by studs or bolts in combination with gaskets or welded membrane seals or strength welds. Plugs using pipe threads are not permitted.

NB-3364 Attachments

Attachments used to transmit support loads shall meet the requirements of NB-3135.

NB-3365 Supports

All vessels shall be so supported and the supporting members shall be arranged and attached to the vessel wall in such a way as to provide for the maximum imposed loadings. The stresses produced in the vessel by such loadings and by steady state and transient thermal conditions shall be subjected to the stress limits of this Subsection. Additional requirements are given in NCA-3240 and Subsection NF.

NB-3400 PUMP DESIGN

NB-3410 GENERAL REQUIREMENTS FOR CENTRIFUGAL PUMPS

NB-3411 Scope

NB-3411.1 Applicability.

The rules of NB-3400 apply to (a) through (j) below.

(a) pump casings

(b) pump inlets and outlets

(c) pump covers

(d) clamping rings

(e) seal housing and seal glands

(f) related bolting

(g) pump internal heat exchanger piping

(h) pump auxiliary nozzle connections up to the face of the first flange or circumferential joint in welded connections, excluding the connecting weld

(i) piping identified with the pump and external to and forming part of the pressure-retaining boundary and supplied with the pump

(j) mounting feet or pedestal supports when integrally attached to the pump pressure-retaining boundary and supplied with the pump

[98]

NB-3411.2Exemptions.

The rules of NB-3400 do not apply to (a) through (c) below.

(a) pump shafts and impellers; shafts may be designed in accordance with Appendix S

(b) nonstructural internals

(c) seal packages

[98]

NB-3412 Acceptability

[98]

NB-3412.1 Acceptability of Large Pumps.

The requirements for the design acceptability of pumps having an inlet connection greater than 4 in. nominal pipe size (DN 100) diameter are given in (a), (b), and (c) below.

(a) The design shall be such that the requirements of NB-3100 and of NB-3200 or Appendix II (provided the requirements of NB-3414 and the minimum wall thicknesses of NB-3430 are met) are satisfied.

(b) The rules of this Subarticle shall be met. In cases of conflict between NB-3100 and NB-3200 or Appendix II and NB-3400, the requirements of NB-3400 apply.

(c) The requirements for prevention of nonductile fracture as set forth in NB-3211(d) shall be met.

[98]

NB-3412.2 Acceptability of Small Pumps.

The requirements for the design acceptability of pumps having an inlet connection 4 in. nominal pipe size (DN 100) diameter or smaller are given in (a) and (b) below.

Page 106

(a) The design shall be such that the requirements of NB-3100 or Appendix II are satisfied.

(b) The rules of this Subarticle shall be met. In cases of conflict between NB-3100 or Appendix II and NB-3400, the requirements of this Subarticle shall apply.

NB-3414 Design and Service Conditions

The general design considerations, including definitions of NB-3100 plus the requirements of NB-3320, NB-3330, NB-3361, and NB-3362 are applicable to pumps.

NB-3415 Loads From Connected Piping

(a) Loads imposed on pump inlets and outlets by connected piping shall be considered in the pump casing design. The forces and moments produced by the connected piping on each pump inlet and outlet shall be provided by the Owner in the Design Specifications.

(b) Stresses generated in the pump casing by the connected piping shall be combined with the pressure stresses in accordance with the requirements of NB-3200.

NB-3417 Earthquake Loadings

(a) The effects of earthquake shall be considered in the design of pumps, pump supports, and restraints. The stresses resulting from these earthquake effects shall be included with the stresses resulting from pressure or other applied loads.

(b) Where pumps are provided with drivers on extended supporting structures and these structures are essential to maintaining pressure integrity, an analysis shall be performed when required by the Design Specifications.

NB-3418 Corrosion

The requirements of NB-3121 apply.

NB-3419 Cladding

Cladding dimensions used in the design of pumps shall be required as in NB-3122.

NB-3420 DEFINITIONS

NB-3421 Radially Split Casing

A radially split casing shall be interpreted as one in which the primary sealing joint is radially disposed around the shaft.

NB-3422 Axially Split Casing

An axially split casing shall be interpreted as one in which the primary sealing joint is axially disposed with respect to the shaft.

NB-3423 Single and Double Volute Casings

Figures NB-3423-1 and NB-3423-2 show typical single and double volute casings, respectively.

NB-3424 Seal Housing

Seal housing is defined as that portion of the pump cover or casing assembly which contains the seal and forms a part of the primary pressure boundary.

NB-3425 Typical Examples of Pump Types

Figures NB-3441.1-1 through NB-3441.6(a)-1 are typical examples to aid in the determination of pump type and are not to be considered as limiting. Bearing locations and inlet and outlet orientations are optional.

NB-3430 DESIGN REQUIREMENTS FOR CENTRIFUGAL PUMPS

NB-3431 Design of Welding

(a) The design of welded construction shall be in accordance with NB-3350.

(b) Partial penetration welds are permitted for piping connections 2 in. nominal pipe size and less when the requirements of NB-3337.3 and NB-3352.4(d) are met.

NB-3432 Cutwater Tip Stresses

(a) It is recognized that localized high stresses may occur at the cutwater tips of volute casings (Fig. NB-3441.3-2). Adequacy of the design in this area shall be demonstrated either by an investigation through experimental stress analysis in accordance with Appendix II

Page 107

or by detailing satisfactory service performance of other pumps under similar operating conditions.

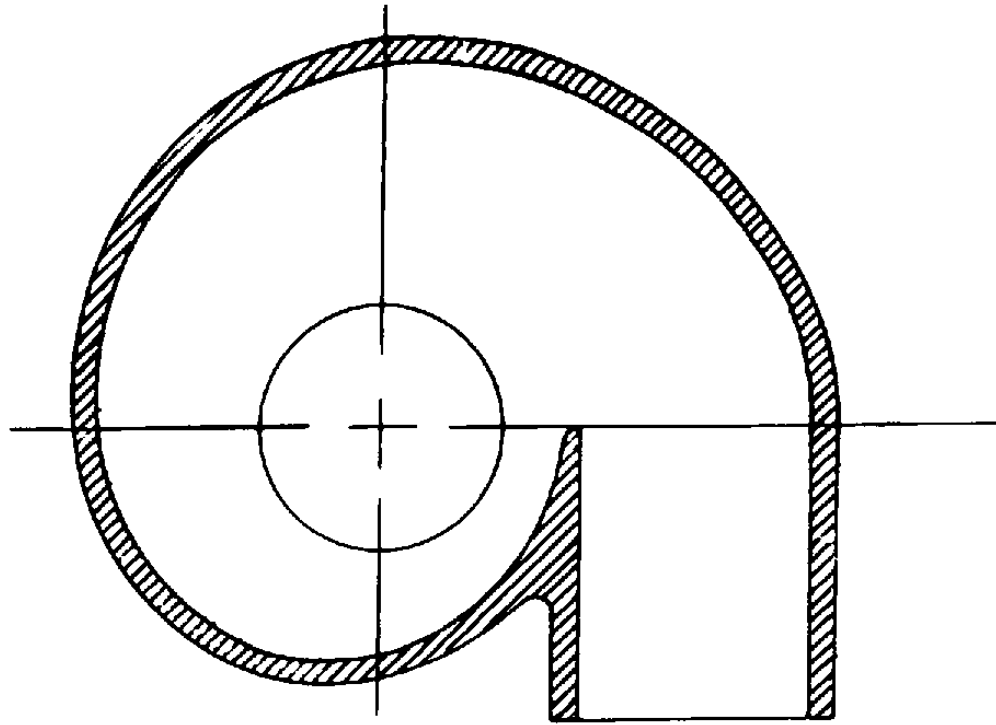
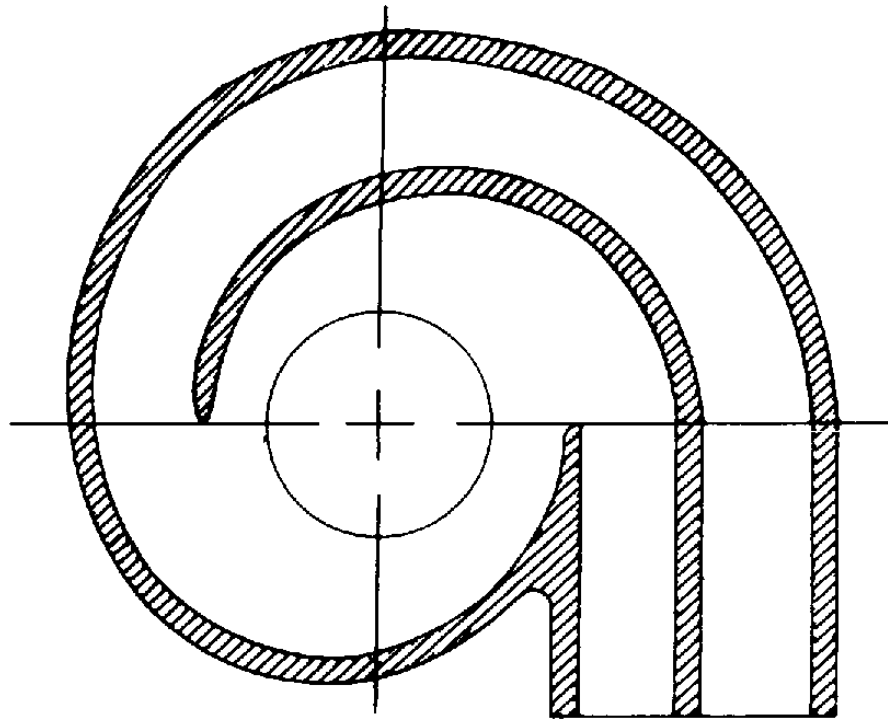


FIG. NB-3423-1
TYPICAL SINGLE VOLUTE CASING

FIG. NB-3423-1 TYPICAL SINGLE VOLUTE CASING



**FIG. NB-3423-2
TYPICAL DOUBLE VOLUTE CASING**

FIG. NB-3423-2 TYPICAL DOUBLE VOLUTE CASING

(b) Where experimental stress analysis is used, stress intensity at this point shall meet the requirements of NB-3222.

NB-3433 Reinforcement of Pump Casing Inlets and Outlets

NB-3433.1 Axially Oriented Inlets and Outlets

(a) An axially oriented pump casing inlet or outlet shall be considered similar to an opening in a vessel and shall be reinforced. It shall be treated as required in NB-3331 through NB-3336.

(b) To avoid stress concentrations, the outside radius r_2 in Fig. NB-3441.3-2 shall not be less than one-half the thickness of the inlets and outlets as reinforced.

NB-3433.2 Radially Oriented Inlets and Outlets.

Reinforcement of radially oriented inlets and outlets in accordance with the rules of NB-3331 through NB-3336 is required.

NB-3433.3 Tangential Inlets and Outlets.

Except as modified in NB-3433.4, any design which has been demonstrated to be satisfactory for the specified Design Loadings may be used.

NB-3433.4 Minimum Inlet and Outlet Wall Thicknesses.

The wall thickness of the inlet or outlet shall not be less than the minimum wall thickness of the casing for a distance l as shown in Fig. NB-3433.4-1. The wall thickness beyond the distance l may be reduced to the minimum wall thickness of the connected piping. The change in wall thickness shall be gradual and have a maximum slope as indicated in Fig. NB-4250-1. The distance l in Fig. NB-3433.4-1 is the limit of reinforcement. The value of l , in., shall be determined from the relationship:

$$l = 0.5 \sqrt{r_i t_m}$$

where

r_i	= inlet or outlet inside radius, in. = $d_i/2$
r_m	= $r_i + 0.5t_m$, in.
t_m	= mean inlet or outlet wall thickness, in., taken between section x-x and a parallel section y-y

NB-3434 Bolting

Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with NB-3230.

NB-3435 Piping

NB-3435.1 Piping Under External Pressure.

Piping located within the pressure-retaining boundary of the pump shall be designed in accordance with NB-3133.

NB-3435.2 Piping Under Internal Pressure.

Piping identified with the pump and external to or forming a part of the pressure-retaining boundary, such as auxiliary water connections, shall be designed in accordance with NB-3600.

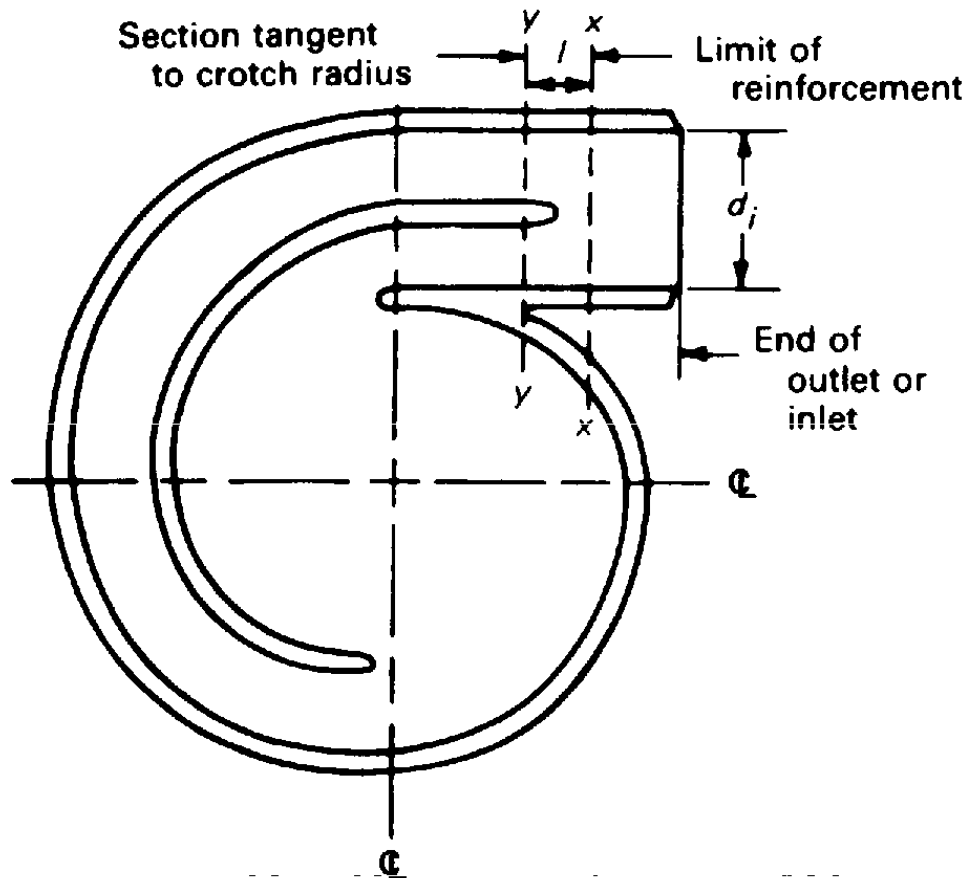


FIG. NB-3433.4-1 MINIMUM TANGENTIAL INLET AND OUTLET WALL THICKNESS

FIG. NB-3433.4-1 MINIMUM TANGENTIAL INLET AND OUTLET WALL THICKNESS

NB-3436 Attachments

(a) External and internal attachments to pumps shall be designed so as not to cause excessive localized bending stresses or harmful thermal gradients in the pump as determined by the rules of NB-3200. Such attachments shall be designed to minimize stress concentrations in applications where the number of stress cycles, due either to pressure or thermal effect, is relatively large for the expected life of the equipment.

(b) Attachments shall meet the requirements of NB-3135.

NB-3437

Pump covers shall be designed in accordance with NB-3200.

NB-3438 Supports

Pump supports shall be designed in accordance with the requirements of Subsection NF unless included under the rules of NB-3411.1(j).

NB-3440 DESIGN OF SPECIFIC PUMP TYPES

NB-3441 Standard Pump Types

NB-3441.1 Design of Type A Pumps.

Type A pumps are those having single volutes and radially split casings with single suction, as illustrated in Figs. NB-3441.1-1 and NB-3441.1-2. Their design shall be in accordance with the requirements of this Subarticle.

NB-3441.2 Design of Type B Pumps.

Type B pumps are those having single volutes and radially split casings with double suction, as illustrated in Fig. NB-3441.2-1. Their design shall be in accordance with the requirements of this Subarticle.

NB-3441.3 Design of Type C Pumps.

Type C pumps are those having double volutes and radially split casings with single suction, as illustrated in Figs. NB-3441.3-1 and NB-3441.3-2. The splitter is considered a structural part of the casing. Casing design shall be in accordance with the requirements of this Subarticle and with those given in (a) through (d) below.

(a) *Casing Wall Thickness.* Except where specifically indicated in these rules, no portion of the casing wall shall be thinner than the value of t determined as follows:

$$t = (0.63 \times P \times A) / S_m$$

where

A	= scroll dimension inside casing as shown in Fig. NB-3441.3-2, in.
P	= Design Pressure, psig
S_m	= allowable stress intensity for casing material at Design Temperature, psi
t	= minimum allowable wall thickness, in.

(b) Splitter Wall Thickness

(1) The splitter shall have a minimum wall thickness of t as determined above for the casing wall and shall extend from point B in Fig. 3441.3-2 through a minimum angle of 135 deg. to point C. Beyond point C, the splitter wall may be reduced in thickness and tapered to blend with the cutwater tip radius.

(2) Cutwater tip and splitter tip radii shall not be less than $0.05t$.

(3) All cutwater and splitter fillets, including the tips, where they meet the casing wall, shall have a minimum radius of $0.10t$ or 0.25 in. (6 mm), whichever is greater.

(c) *Crotch Radius (Fig. NB-3441.3-2).* The crotch radius shall not be less than $0.3t$.

(d) Bottom of Casing

(1) That section of the pump casing within the diameter defined by dimension A in Fig. NB-3441.3-2 on the inlet side of the casing, normally referred to as the bottom of the casing (Fig. NB-3441.3-1), shall have a wall thickness no less than the value of t determined in (a) above.

(2) The casing surface shall be analyzed in accordance with an acceptable procedure, such as that shown for flat heads in A-5000, or by an experimental stress technique, such as described in Appendix II.

(3) The minimum permissible thickness of the bottom of the casing shall be the lesser of the value determined by the analysis in (2) above and the value obtained from the calculation shown in (a) above.

NB-3441.4 Design of Type D Pumps

(a) Type D pumps are those having double volutes and radially split casings with double suction as illustrated in Fig. NB-3441.4(a)-1. The design shall be in accordance with this Subarticle.

(b) The requirements of NB-3441.3(a), (b), and (c), governing casing wall thickness, splitter wall thickness, and crotch radius, apply.

(c) In the casing portion between the cover and the casing wall, a wall thickness in excess of t may be required.

NB-3441.5 Design of Type E Pumps.

Type E pumps are those having volute type radially split casings and multivane diffusers which form structural parts of the casing as illustrated in Fig. NB-3441.5-1. The design shall be in accordance with this Subarticle.

NB-3441.6 Design of Type F Pumps

(a) Type F pumps are those having radially split, axisymmetric casings with either tangential or radial outlets as illustrated in Fig. NB-3441.6(a)-1. The basic configuration of a Type F pump casing is a shell with a dished head attached at one end and a bolting flange at the other. The inlet enters through the dished head, and the outlet may be either tangent to the side or normal to the center line of the casing. Variations of these inlet and outlet locations are permitted.

(b) The design of Type F pumps shall be in accordance with this Subarticle.

NB-3442 Special Pump Types - Type J Pumps

(a) Type J pumps are those that cannot logically be classified with any of the preceding types.

(b) Any design method which has been demonstrated to be satisfactory for the specified Design Conditions may be used.

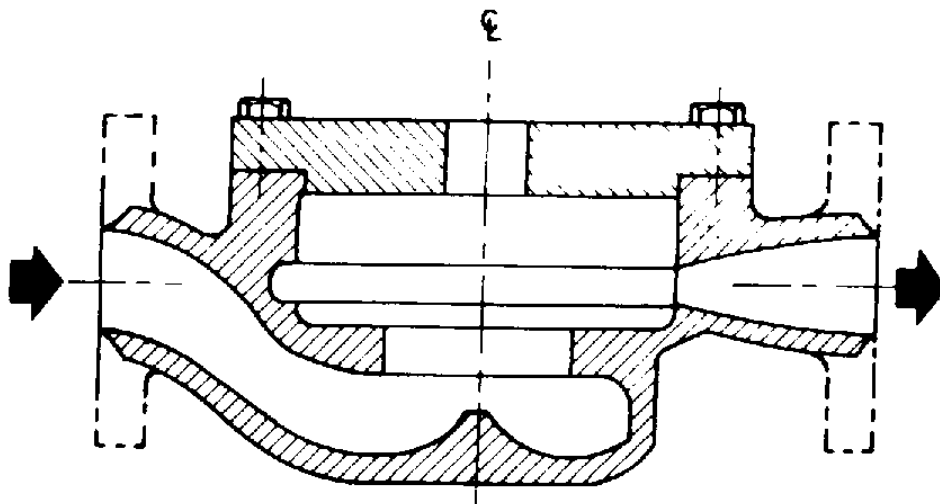


FIG. NB-3441.1-1 TYPE A PUMP

FIG. NB-3441.1-1 TYPE A PUMP

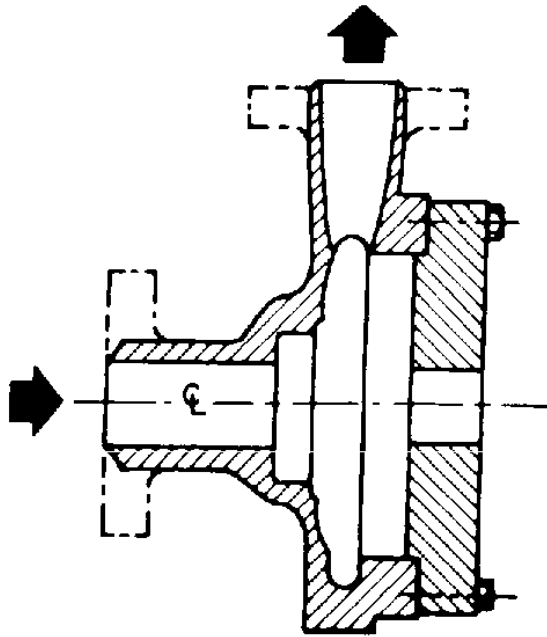


FIG. NB-3441.1-2 TYPE A PUMP

FIG. NB-3441.1-2 TYPE A PUMP

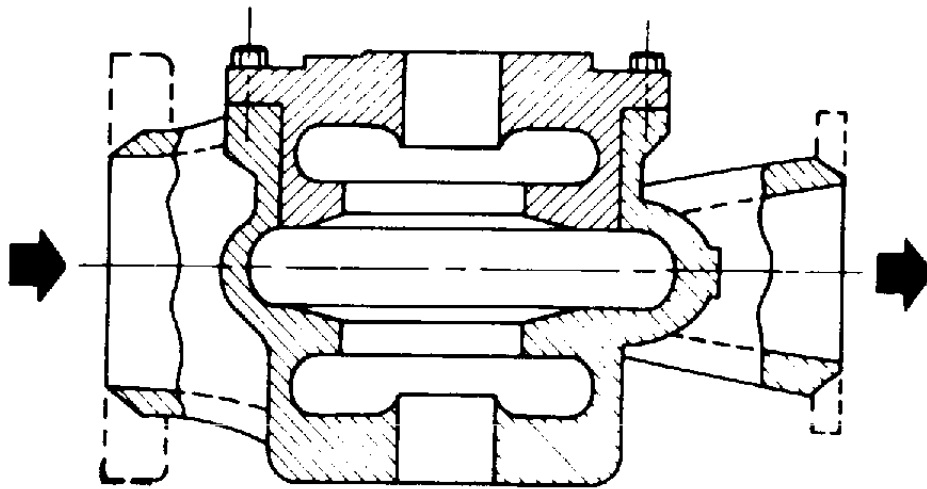


FIG. NB-3441.2-1 TYPE B PUMP

FIG. NB-3441.2-1 TYPE B PUMP

Page 110

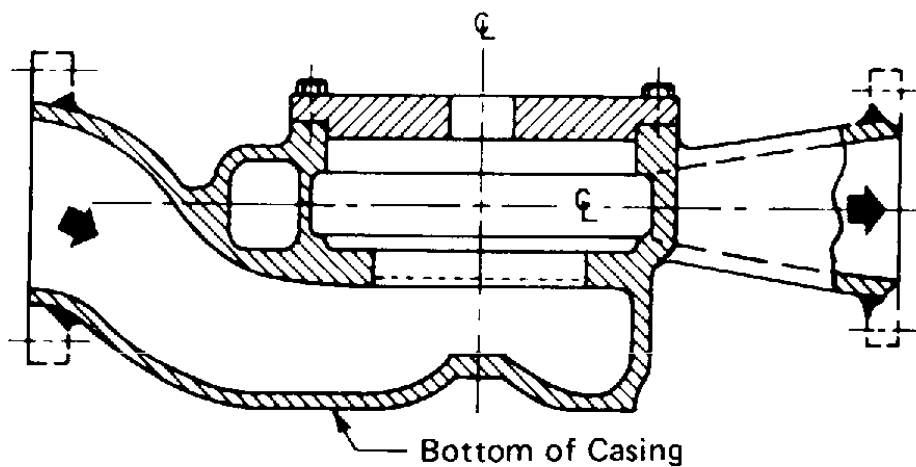


FIG. NB-3441.3-1 TYPE C PUMP

FIG. NB-3441.3-1 TYPE C PUMP

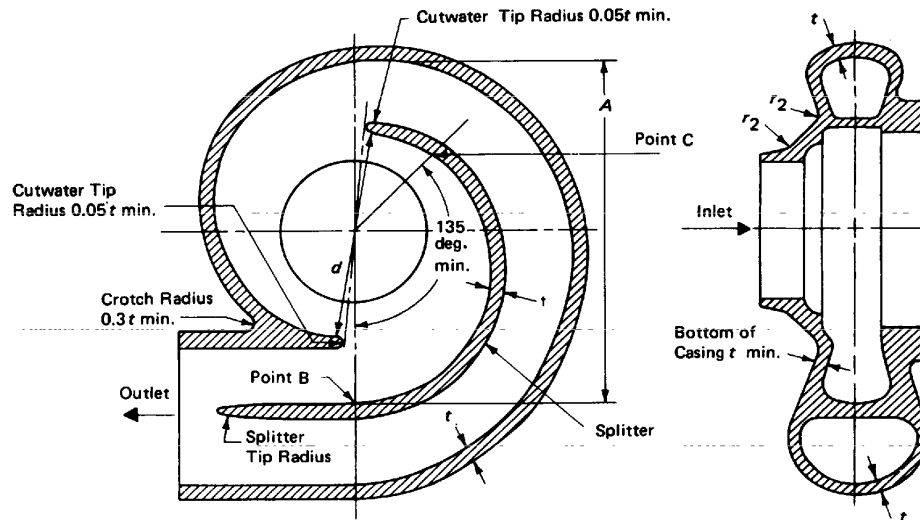


FIG. NB-3441.3-2 TYPE C PUMP

FIG. NB-3441.3-2 TYPE C PUMP

NB-3500 VALVE DESIGN

NB-3510 ACCEPTABILITY¹⁵

¹⁵ These requirements for the acceptability of a valve design are not intended to ensure the functional adequacy of the valve. However, for pressure relief valves the Designer is cautioned that the requirements of NB-7000 relative to set pressure, lift, blowdown, and closure shall be met.

¹⁶

CAUTIONARY NOTE: Certain types of double seated valves have the capability of trapping liquid in the body or bonnet cavity in the closed position. If such a cavity accumulates liquid and is in the closed position at a time when adjacent system piping is increasing in temperature, a substantial and uncontrolled increase in pressure in the body or bonnet cavity may result. Where such a condition is possible, it is the responsibility of the Owner or the Owner's designee to provide, or require to be provided, protection against harmful overpressure in such valves.

¹⁷ The severity and frequency of specified fluid temperature variations may be such that the period of calculated pressure integrity is less than plant design life. In such cases it is the responsibility of the Certificate Holder to state these conditions in the Design Report (NB-3560).

NB-3511 General Requirements^{16 17}

The requirements for design acceptability for valves shall be those given in this Subarticle. In all cases, pressure-temperature rating shall be as given in NB-3530 and, except for NB-3512.2(d) and in local regions (NB-3221.2), the wall thickness of the valve body shall not be less than that given by NB-3541. The requirements for prevention of nonductile fracture as set forth in NB-3211(d) shall be met. The requirements of NCA-3254(a) for specifying the location of valve boundary jurisdiction may be considered to have been met by employing the minimum limits of NB-1131, unless the Design Specification extends the boundary of jurisdiction beyond these minimum limits. The requirements of NCA-3254(b) for specifying the boundary conditions are not applicable to valve end connections.

NB-3512 Acceptability of Large Valves

Valve designs having an inlet piping connection larger than 4 in. nominal pipe size are acceptable when they satisfy

either the standard design rules or one of the alternative design rules.

NB-3512.1 Standard Design Rules.

The design shall be such that requirements of this Subarticle are met. The requirements of NB-3530 through NB-3550 apply to valves of conventional shape having generally cylindrical or spherical bodies with a single neck of a diameter commensurate with that of the main body portion, such as having a neck inside diameter less than twice the main run inside diameter in the neck region.

[98]

NB-3512.2 Alternative Design Rules.

A valve design may not satisfy all of the requirements of NB-3512.1.

Page 111

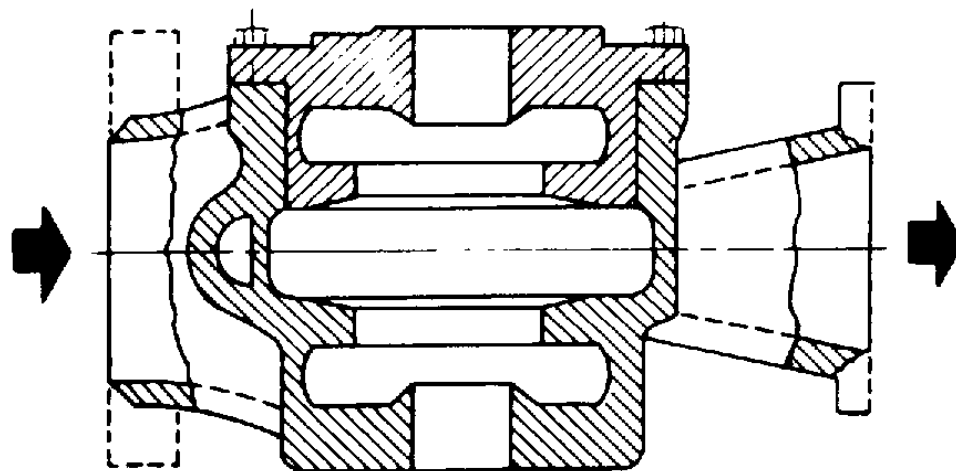


FIG. NB-3441.4(a)-1 TYPE D PUMP

FIG. NB-3441.4(a)-1 TYPE D PUMP

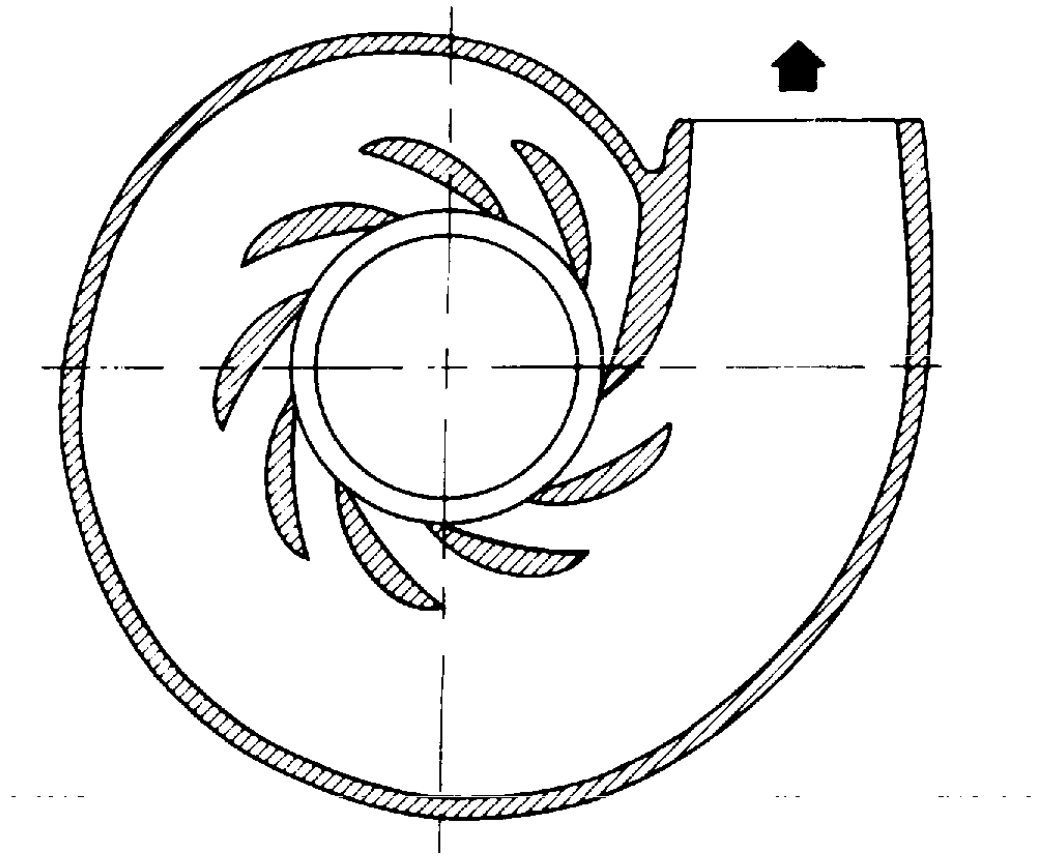


FIG. NB-3441.5-1 TYPE E PUMP

FIG. NB-3441.5-1 TYPE E PUMP

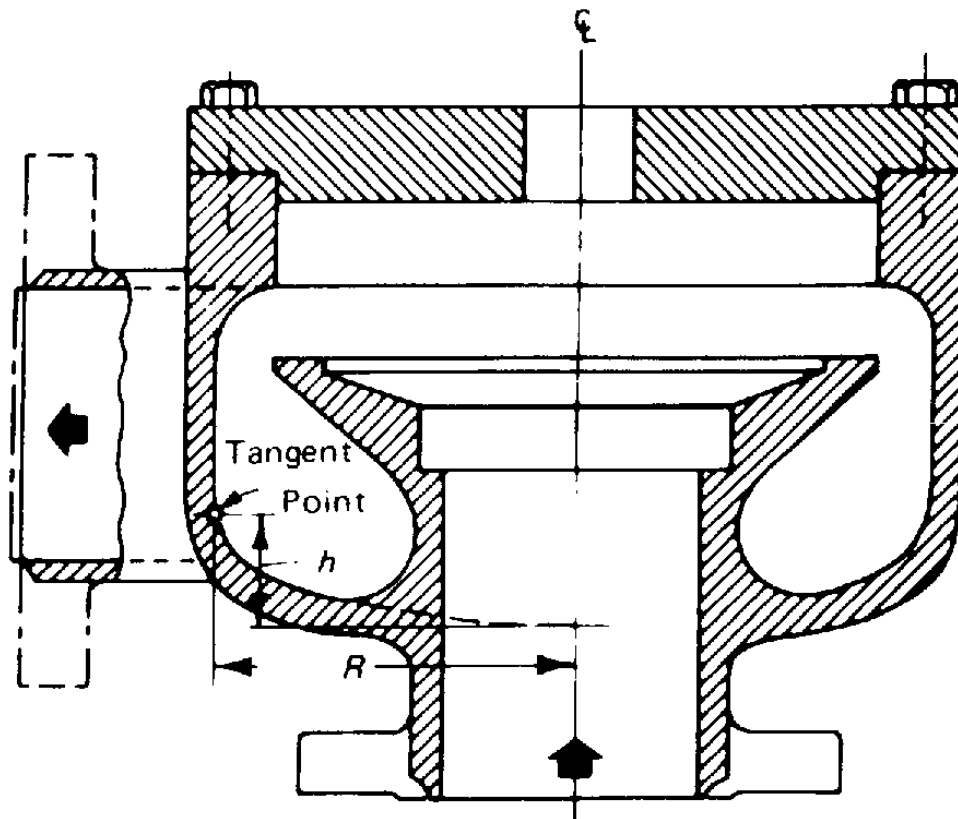


FIG. NB-3441.6(a)-1 TYPE F PUMP

FIG. NB-3441.6(a)-1 TYPE F PUMP

A design may be accepted provided it meets one of the alternatives listed in (a), (b), (c), or (d) below.

(a) When the valve design satisfies the rules of NB-3530 through NB-3546.2 with thermal stresses neglected, the rules of NB-3200 relative to accounting for thermal secondary stresses and fatigue analysis [NB-3222.2, NB-3222.3, and NB-3222.4] shall also be satisfied.

(b) When a valve is exempted from fatigue analysis by the rules of NB-3222.4(d), the design is acceptable, provided that the requirements of (1) or (2) below are met.

(1) The rules of NB-3530 through NB-3546 shall be met. The rules of NB-3200 may be substituted for those of NB-3545.2 for evaluating secondary stresses, and NB-3545.3 need not be considered.

(2) The rules of NB-3530 and NB-3541 shall be met. An experimental stress analysis is performed in accordance with Appendix II, and the rules of NB-3200 with respect to primary and secondary stresses resulting from pressure and mechanical loads shall be met. Unless otherwise specified in the Design Specifications, the pipe reactions shall be taken as those loads which produce a stress [NB-3545.2(b)] of 0.5 times the yield strength of the piping in tension for the direct or axial load and a stress of 1.0 times the yield strength of the piping in bending and torsion. Thermal secondary stresses shall be accounted for by either the rules of NB-3200 or NB-3545.

(c) When a valve design satisfies the rules of NB-3530 and NB-3541, and when an experimental stress analysis has been performed upon a similar valve in accordance with Appendix II, and an acceptable analytic method has been established, the results may be used in conjunction with the requirements of NB-3200 for pressure and mechanical loads to establish design acceptability. Accommodation of thermal secondary stresses and pipe reactions shall be as given in NB-3512.2(b)(2). Requirements for fatigue analysis of either NB-3200 or NB-3550 shall be met.

(d) When permitted by the Design Specification, a weld end valve that does not meet all of the requirements of NB-3540 may be designed so that it meets the requirements of NB-3200 for all pressure-retaining parts and those parts defined by NB-3546.3(a), and shall also meet all of the following requirements.

(1) Pressure, thermal, and mechanical effects, such as those resulting from earthquake, maximum stem force, closure force, assembly forces, and others that may be defined in the Design Specification, shall be included in the design analysis. For Level A Service Limits, the pipe reaction effects are to be determined by considering that the maximum fiber stress in the

Page 112

connected pipe is at one-half of its yield strength in direct tension and at its yield strength in torsion and in bending in the plane of the neck and run, and also in the plane of the run perpendicular to the neck, each considered separately. The individual pipe reaction effects that result in the maximum stress intensity at all points, including all other effects, shall be used for the analysis to satisfy the rules of NB-3200. The valve Design Specification shall provide the loadings and operating requirements to be considered under Level B, C, and D Service Limits [NCA-3252(a)(6)] for which a design analysis is to be included in the Design Report.

(2) In place of using the values of S_m to satisfy the rules of NB-3200, the allowable stress intensity values for ferritic valve body and bonnet materials shall be those allowable stress values given in Section II, Part D, Subpart 1, Table 1A. For materials in Section II, Part D, Subpart 1, Tables 2A and 2B, a reduced allowable stress intensity based on applying a factor of 0.67 to the yield strengths listed in Section II, Part D, Subpart 1, Table Y-1 shall be used.

(3) The adequacy of the stress analysis of the body and bonnet shall be verified by experimental stress analysis conducted in accordance with the requirements of II-1100 through II-1400. Individual tests shall be made to verify the adequacy of the stress analysis of internal pressure effects and pipe reaction effects. Tests shall be made on at least one valve model of a given configuration, but a verified analytical procedure may then be applied to other valves of the same configuration, although they may be of different size or pressure rating. The geometrical differences shall be accounted for in the extrapolation stress analysis. The analytical procedure shall have verified capability of providing this extrapolation.

(4) A Design Report shall be prepared in sufficient detail to show that the valve satisfies all applicable requirements.

(5) Prior to installation, the valve shall be hydro statically tested in accordance with NB-3531.2. For this purpose, the primary pressure rating shall be determined by interpolation in accordance with NB-3543(c).

[98]

NB-3513 Acceptability of Small Valves

Valve designs having an inlet piping connection 4 in. nominal pipe size or less are acceptable when they satisfy either the standard design rules or the alternative design rules.

NB-3513.1 Standard Design Rules.

The design shall be such that the requirements of NB-3530 and NB-3541 shall be met for wall thicknesses corresponding to the applicable pressure-temperature rating. When the Special Class Ratings of ANSI B16.34 apply, the NDE exemptions of NB-2510 shall not be used.

NB-3513.2 Alternative Design Rules.

A valve design shall satisfy the requirements of NB-3512.2.

NB-3515 Acceptability of Metal Bellows and Metal Diaphragm Stem Sealed Valves

Valves using metal bellows or metal diaphragm stem seals shall be constructed in accordance with the rules of this Subarticle, based on the assumption that the bellows or diaphragms do not retain pressure, and Design Pressure is imposed on a required backup stem seal such as packing. The bellows or diaphragms need not be constructed in accordance with the requirements of this Section.

NB-3520 DESIGN CONSIDERATIONS

NB-3521 Design and Service Loadings

The general design considerations of NB-3100 are applicable to valves. In case of conflict between NB-3100 and NB-3500, the requirements of NB-3500 shall apply.

NB-3524 Earthquake

The rules of this Subarticle consider that under earthquake loadings the piping system, not the valve, will be limiting and that the integrity of the valve pressure-retaining body is adequately considered under the piping requirements of NB-3600. Where valves are provided with operators having extended structures and these structures are essential to maintaining pressure integrity, an analysis, when required by the Design Specifications, may be performed based on static forces resulting from equivalent earthquake accelerations acting at the centers of gravity of the extended masses.

NB-3525 Levels A and B Service Limits

The design rules of NB-3512 and NB-3513 apply to loadings for which Level A or B Limits are designated except that when evaluating Level B Limits during operation of relief or safety valves (a) and (b) below shall be met.

(a) The service pressure may exceed the Design Pressures defined by the pressure-temperature ratings of ANSI B16.34 by no more than 10%.

Page 113

(b) The rules of NB-3540 apply using allowable stress intensity values of 110% of those listed in Section II, Part D, Subpart 1, Tables 2A and 2B.

NB-3526 Level C Service Limits

If the Design Specifications specify any loadings for which Level C Limits are designated, the rules used in evaluating these loadings shall be those of NB-3512 and NB-3513, except as modified by the following subparagraphs.

NB-3526.1 Pressure-Temperature Ratings.

The pressure permissible for loadings for which Level C Limits are designated shall not exceed 120% of that permitted for Level A Limits.

NB-3526.2 Pipe Reaction Stress.

Pipe reaction stresses shall be computed in accordance with the equations of NB-3545.2(b)(1), and the allowable value considered individually is $1.8S_m$ for the valve body material at 500°F (260°C). In performing these calculations, the value of S shall be taken as 1.2 times the yield strength at 500°F (260°C) of the material of the connected pipe, or 36.0 ksi when the pipe material is not defined in the Design Specifications.

NB-3526.3 Primary Stress and Secondary Stress.

The equation of NB-3545.2 shall be satisfied using C_p equal to 1.5, P_{ed} computed in accordance with NB-3526.2, and Q_T equal to 0, and the calculated value shall be limited to $2.25S_m$.

NB-3526.4 Secondary and Peak Stresses.

The requirements of NB-3545 and NB-3550 need not be met.

NB-3527 Level D Service Limits

If the Design Specifications specify any loadings for which Level D Limits are designated, the guidelines of Appendix F may be used in evaluating those loadings independently of other loadings.

NB-3530 GENERAL RULES

NB-3531 Pressure-Temperature Ratings and Hydrostatic Tests

NB-3531.1 Pressure-Temperature Ratings.

A valve designed in accordance with NB-3541 may be used in accordance with the pressure-temperature ratings in ANSI B16.34, Tables 2-1.1A to 2-2.7A (Standard Class) for flanged end or welding end (including socket welding end) valves, and ANSI B16.34, Tables 2-1.1B to 2-2.7B (Special Class) for welding end (including socket welding end) valves, provided the Design Pressure and Design Temperature are used. When a single valve has a flanged and a welding end, the flanged end requirements shall be used. The materials¹⁸ listed in ANSI B16.34, Table 1, may be used if listed in Section II, Part D, Subpart 1, Tables 2A and 2B, subject to the temperature limitations therein, and as defined in NCA-1220.

NB-3531.2 Hydrostatic Tests

(a) Valves designed in accordance with NB-3541 shall be subjected to the shell hydrostatic test pressures required by ANSI B16.34 and in accordance with other appropriate rules of NB-6000. Valves with a primary pressure rating less than Class 150 shall be subjected to the required test pressure for Class 150 rated valves.

(b) The shell hydrostatic test shall be made with the valve in the partially open position. Stem leakage during this test is permissible. End closure seals for retaining fluid at test pressure in welding end valves may be positioned in the welding end transitions, as defined in NB-3544.8(b), in reasonable proximity to the end plane of the valve so as to ensure safe application of the test pressure.

(c) After the shell hydrostatic test, a valve closure test shall also be performed with the valve in the fully closed position with a test pressure across the valve disk no less than 110% of the 100°F (38°C) pressure rating. For valves that are designed for Service Conditions that have the pressure differential across the closure member limited to values less than the 100°F (38°C) pressure rating, and have closure members or actuating devices (direct, mechanical, fluid, or electrical), or both, that would be subject to damage at high differential pressures, the test pressure may be reduced to 110% of the maximum specified differential pressure in the closed position. This exception shall be identified in the Design Specification, and this maximum specified differential pressure shall be noted on the valve name plate and N Certificate Holder's Data Report Form. During this test, seat leakage is permitted unless a limiting leakage value is defined by the Design Specifications. The duration of this test shall be 1 min/in. of minimum wall thickness t_m with a minimum duration of 1 min unless otherwise defined in the Design Specifications.

18 Special features such as wear surfaces or seating surfaces may demand special alloys or proprietary treatments. The absence of such materials from Section II, Part D, Subpart 1, Tables 2A and 2B shall not be construed to prohibit their use and such materials do not require approval under Appendix IV (NB-2121).

(d) For valves designed for nonisolation service, whose primary function is to modulate flow, and by

Page 114

their design are prevented from providing full closure, the valve closure test defined in (c) above is not required. This exception shall be identified in the Design Specification and noted on the valve nameplate and the N Certificate Holder's Data Report Form.

(e) Hydrostatic tests for metal bellows or metal diaphragm stem sealed valves shall include hydrostatic testing of the valve body, bonnet, body-to-bonnet joint, and either the bellows or diaphragm or the required backup stem seal.

(f) The inlet (primary pressure-containing) portion of pressure relief valves shall be hydrostatically tested at a pressure at least 1.5 times the set pressure marked on the valve. For closed system application, the outlet portion of the pressure relief valves shall be hydrostatically tested to 1.5 times the design secondary pressure (NB-7111).

NB-3531.3 Allowance for Variation From Design Loadings.

Under the conditions of relief or safety valve operation for valves designed in accordance with NB-3541, the service pressure may exceed the Design Pressure as defined by the pressure-temperature ratings of ANSI B16.34 by no more than 10%.

NB-3532 Design Stress Intensity Values

Design stress intensity values to be used in the design of valves are given in Section II, Part D, Subpart 1, Tables 2A and 2B.¹⁸

NB-3533 Marking

Each valve shall be marked as required by ANSI B16.34 and NCA-8220.

NB-3534 Nomenclature

A_f	= effective fluid pressure area based on fully corroded interior contour for calculating crotch primary membrane stress [NB-3545.1(a)], sq in.
A_m	= metal area based on fully corroded interior contour effective in resisting fluid force acting on A_f [NB-3545.1(a)], sq in.
C_a	= stress index for oblique bonnets [NB-3545.2(a)]
C_b	= stress index for body bending secondary stress resulting from moment in connected pipe [NB-3545.2(b)]
C_p	= stress index for body primary plus secondary stress, inside surface, resulting from internal pressure [NB-3545.2(a)]
C_1	= discontinuity temperature gradient index, °F/in. ²
C_2	= stress index for thermal secondary membrane stress resulting from structural discontinuity
C_3	= stress index for maximum secondary membrane plus bending stress resulting from structural discontinuity
C_4	= maximum magnitude of the difference in average wall temperatures for wall thicknesses T_{el} and t_e (resulting from a step change in fluid temperature ΔT_f) divided by ΔT_f
C_5	= stress index for thermal fatigue stress component resulting from through-wall temperature gradient caused by step change in fluid temperature (NB-3550)
C_6	= $E\alpha$ =product of Young's modulus and the coefficient of linear thermal expansion at 500°F, psi/°F (NB-3550)
C_7	= stress index for thermal stress resulting from through-wall temperature gradient associated with 100°F/hr fluid temperature change rate, psi/in.
d	= inside diameter used as a basis for crotch reinforcement [NB-3545.1(a)], in.
d_e	= inside diameter of the larger end of the valve body [NB-3545.2(b)(3)], in.

d_m	= inside diameter used as basis for determining body minimum wall thickness (NB-3541), in.
F_b	= bending modulus of standard connected pipe, in. ³
G_b	= valve body section bending modulus at crotch region [NB-3545.2(b)], in. ³
I	= moment of inertia, in. ⁴ , used in calculating G_b [NB-3545.2(b)(5)]
I_t	= fatigue usage factor for step changes in fluid temperature
K_e	= strain distribution factor used in elastic-plastic fatigue calculation (NB-3550)
$L_A L_N$	= effective distances used to determine $A_f A_m$ [NB-3545.1(a)(3)]
m, n	= material parameters for determining K_e (NB-3554)
N_a	= permissible number of complete startup/shutdown cycles at 100°F/hr fluid temperature change rate (NB-3545.3)
N_i	= permissible number of step changes in fluid temperature from Figs. I-9.0
N_{ri}	= required number of fluid step temperature changes ΔT_{fi} (NB-3553)
P_{eb}	= secondary stress due to pipe reaction [NB-3545.2(b)], psi

Page 115

P_m	= general primary membrane stress intensity at crotch region, calculated according to NB-3545.1(a), psi
p_d	= Design Pressure, psi
p_r	= Pressure Rating Class Index, psi
p_s	= standard calculation pressure from NB-3545.1, psi
p_1, p_2	= rated pressures from tables of ANSI B16.34 corresponding to Pressure Rating Class Indices p_{r1} and p_{r2} , psi
Q_p	= sum of primary plus secondary stresses at crotch resulting from internal pressure [NB-3545.2(a)], psi
Q_{T1}	= maximum thermal stress component caused by through-wall temperature gradient associated with 100°F/hr fluid temperature change rate [NB-3545.2(c)], psi
Q_{T3}	= maximum thermal secondary membrane plus bending stress resulting from structural discontinuity and 100°F/hr fluid temperature change rate, psi
r	= mean radius of body wall at crotch region [Fig. NB-3545.2(c)-1], in.
r_i	= inside radius of body at crotch region for calculating Q_p [NB-3545.2(a)], in.

r_2	= fillet radius of external surface at crotch [NB-3545.1 (a)], in.
S	= assumed maximum stress in connected pipe for calculating the secondary stress due to pipe reaction [NB-3545.2(b)], psi
S_i	= fatigue stress intensity range at crotch region resulting from step change in fluid temperature ΔT_{fi} and pressure ΔP_{fi} (NB-3550), psi
S_m	= design stress intensity (NB-3532), psi
S_n	= sum of primary plus secondary stress intensities at crotch region resulting from 100°F/hr temperature change rate (NB-3545.2), psi
$S_{n(max)}$	= maximum range of sum of primary plus secondary stress, psi
S_{p1}	= fatigue stress intensity at inside surface in crotch region resulting from 100°F/hr fluid temperature change rate (NB-3545.3), psi
S_{p2}	= fatigue stress intensity at outside surface in crotch region resulting from 100°F/hr fluid temperature change rate (NB-3545.3), psi
T_b	= thickness of valve wall adjacent to crotch region for calculating L_A and L_N [Fig. NB-3545.1(a)-1], in.
T_e	= maximum effective metal thickness in crotch region for calculating thermal stresses [Fig. NB-3545.2(c)-1], in.
T_r	= thickness of body (run) wall adjacent to crotch for calculating L_A and L_N [Fig. NB-3545.1(a)-1], in.
t_e	= minimum body wall thickness adjacent to crotch for calculating thermal stresses [Fig. NB-3545.2(c)-1], in.
t_m	= minimum body wall thickness as determined by NB-3541, in.
t_1, t_2	= minimum wall thicknesses from ANSI B16.34 corresponding to Listed Pressure Rating Class Indices p_{r1} and p_{r2} and inside diameter d_m , in.
ΔP_{fi}	= full range of pressure fluctuation associated with ΔT_{fi} , psi
ΔP_i	= specified range of pressure fluctuation associated with ΔT_i , psi
ΔT_{fi}	= a specified step change in fluid temperature, °F, where $i = 1, 2, 3, \dots, n$, used to determine the fatigue acceptability of a valve body (NB-3554)
ΔT_i	= specified range of fluid temperature, °F, where $i = 1, 2, 3, \dots, n$, used to evaluate normal valve usage (NB-3553)
ΔT	= maximum magnitude of the difference in average wall temperatures for walls of thicknesses t_e and T_e , resulting from 100°F/hr fluid temperature change rate, °F

NB-3540 DESIGN OF PRESSURE-RETAINING PARTS

NB-3541 General Requirements for Body Wall Thickness

The minimum wall thickness of a valve body is to be determined by the rules of NB-3542 or NB-3543.

19A listed pressure rated value is one listed in the tables of ANSI B16.34. A nonlisted pressure rated valve is one whose Design Pressure and Temperature do not specifically appear in those table (NB-3543).

NB-3542 Minimum Wall Thickness of Listed Pressure Rated Valves¹⁹

The wall thickness requirements for listed pressure rated valves apply also to integral body venturi valves. For a valve designed to a listed pressure rating of ANSI B16.34, the minimum thickness of its body wall, including the neck, is to be determined from ANSI B16.34, except that the inside diameter d_m shall be the larger of the basic valve body inside diameters in the region near the welding ends. Highly localized variations of inside diameter associated with weld preparation

Page 116

[NB-3544.8(a) and (b)] need not be considered for establishing minimum wall thickness t_m . In all such cases, however, the requirements of NB-3545.2(b)(6) shall be satisfied.

NB-3543 Minimum Wall Thickness of Valves of Nonlisted Pressure Rating¹⁹

To design a valve for Design Pressure and Design Temperature corresponding to other than one of the pressure ratings listed in the tables of ANSI B16.34, the procedure is the same as that of NB-3542 except that interpolation is required as follows.

(a) Based on the Design Temperature, linear interpolation between the tabulated temperature intervals shall be used to determine the listed pressure rating p_1 , next below, and p_2 , next above, the Design Pressure p_d corresponding to listed Pressure Rating Class Indices,²⁰ p_{r1} and p_{r2} respectively.

(b) Determine the minimum wall thickness t_m corresponding to Design Loadings by:

$$t_m = t_1 + \left(\frac{p_d - p_1}{p_2 - p_1} \right) \times (t_2 - t_1)$$

(c) Determine the interpolated Pressure Rating Class Index p_r , corresponding to Design Loadings, by:

$$p_r = p_{r_1} + \left(\frac{p_d - p_1}{p_2 - p_1} \right) \times (p_{r_2} - p_{r_1})$$

NB-3544 Body Shape Rules

The rules of this paragraph constitute minimum requirements intended to limit the fatigue strength reduction factor, associated with local structural discontinuities in critical regions, to 2.0 or less. When smaller values of the fatigue strength reduction factor can be justified, it is permissible to use them.

20For all listed pressure ratings except Class 150, the Pressure Rating Class Index is the same as the pressure rating class designation. For Class 150 use 115 psi for the Pressure Rating Class Index.

NB-3544.1 Fillets for External and Internal Intersections and Surfaces

(a) Intersections of the surfaces of the pressure retaining boundary at the neck to body junction shall be provided with fillets of radius $r_2 \geq 0.3t_m$. Figure NB-3544.1(a)-1 illustrates such fillets.

(b) Corner radii on internal surfaces with $r_4 < r_2$ are permissible.

(c) Sharp fillets shall be avoided. When sharp discontinuities are convenient for ring grooves and similar configuration details, they shall be isolated from the major body primary and secondary stresses or modified as illustrated by Fig. NB-3544.1(c)-1.

NB-3544.2 Penetrations of Pressure-Retaining Boundary.

Penetrations of the pressure-retaining boundary, other than the neck intersection, such as holes required for check valve shafts and drain or sensing lines, shall be located to minimize the compounding of normal body stresses.

NB-3544.3 Attachments.

Attachments, such as lugs and similar protuberances, on the pressure-retaining boundary shall be tapered to minimize discontinuity stresses (Fig. NB-3544.3-1). Reentrant angles shall be avoided. Attachments shall meet the requirements of NB-3135.

NB-3544.4 Body Internal Contours.

Body internal contours in sections normal to the run or neck center lines shall be generally smooth in curvature, or so proportioned that the removal of unavoidable discontinuities, such as the valve seat, will leave generally smooth curvature.

NB-3544.5 Out-of-Roundness.

Out-of-roundness in excess of 5% for sections of essentially uniform thickness shall be such that:

$$\frac{b}{t_b} + \frac{3}{4} \left(\frac{3b^2 - 2ab - a^2}{t_b^2} \right) + 1 \leq 1.5 \left(\frac{S_m}{p_s} \right)$$

where

$2a$	= minor inside diameter, in.
$2b$	= major inside diameter, in.
t_b	= thickness, in.

The ovality criterion can be satisfied by increasing the thickness locally, provided that the thickness variation is smoothly distributed. Out-of-roundness in excess of this limitation must be compensated for by providing reinforcement.

NB-3544.6 Doubly Curved Sections.

Sections curved longitudinally with radius r_{Long} as well as laterally with radius r_{Lat} must be such that:

Page 117

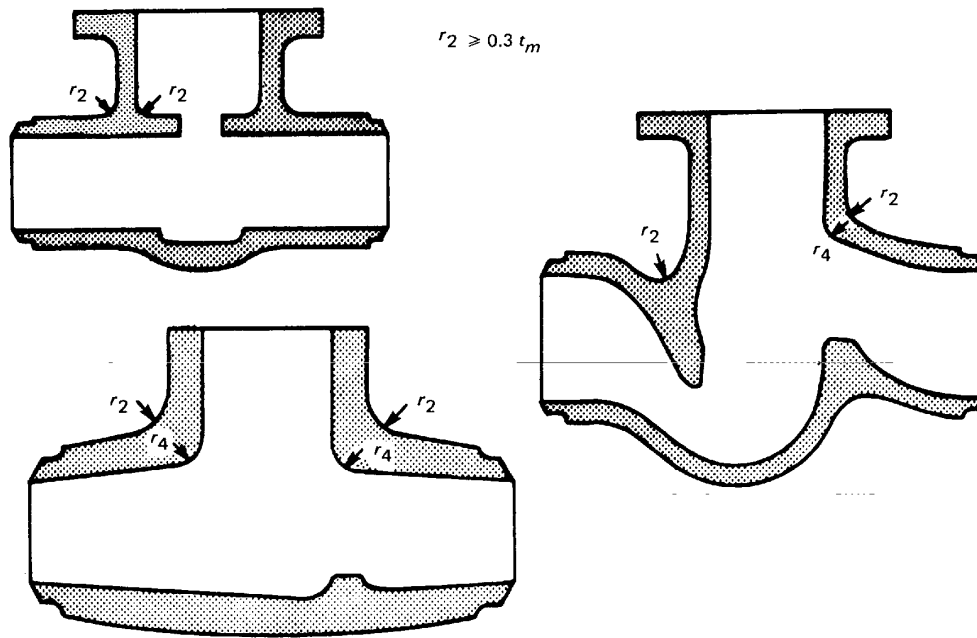


FIG. NB-3544.1(a)-1 FILLETS AND CORNERS

FIG. NB-3544.1(a)-1 FILLETS AND CORNERS

$$r_3 \geq \begin{cases} 0.05 t_m \\ 0.1 h \end{cases} \text{ whichever is greater}$$

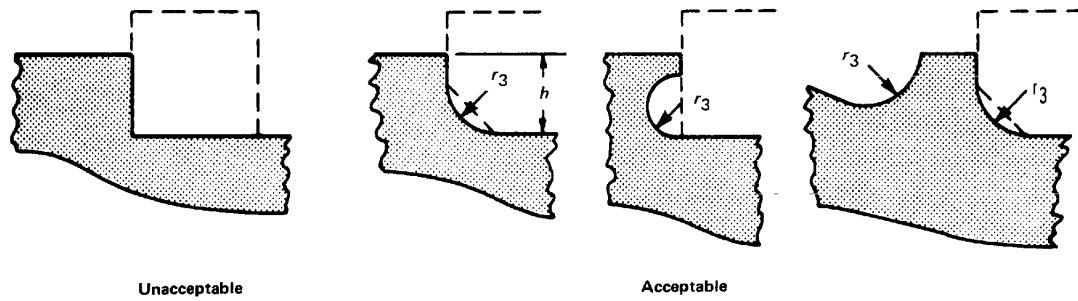


FIG. NB-3544.1(c)-1 RING GROOVES

FIG. NB-3544.1(c)-1 RING GROOVES

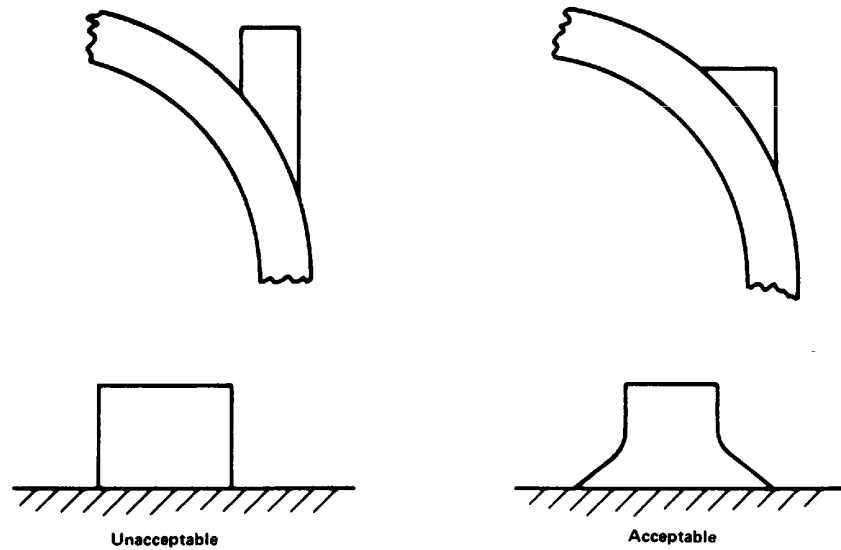


FIG. NB-3544.3-1 LUGS AND PROTUBERANCES

FIG. NB-3544.3-1 LUGS AND PROTUBERANCES

$$\frac{1}{r_{\text{Long}}} + \frac{1}{r_{\text{Lat}}} \geq \frac{4}{3d_m}$$

where d_m is the diameter used to establish the local wall thickness by NB-3541.

NB-3544.7 Flat Sections.

Flat sections shall be sufficiently limited in extent so that arcuate sections having the same radius-thickness ratio as required by NB-3542 may be inscribed (Fig. NB-3544.7-1). The inscribed section may be less thick than the minimum thickness required by NB-3542, provided that its radius is proportionally smaller than the value used to determine the minimum required thickness. The method of NB-3544.6 above may be used to show additive support, but the denominator of the right side term must be reduced in the ratio of the thickness of the inscribed arcuate section to the minimum required thickness (NB-3542). If adequacy cannot be shown by the above rules, it is necessary to determine the stresses in the flat region experimentally to demonstrate adequacy for pressure induced stresses only, with internal pressure equal to the standard calculation pressure p_s .

NB-3544.8 Body End Dimensions

(a) Valve body contours at valve weld ends shall be in accordance with Fig. NB-4250-1, and, unless otherwise stated in the Design Specifications, with ANSI B16.34.

(b) Valve body transitions leading to valve weld ends shall be in accordance with ANSI B16.34.

(c) Flanged ends shall be in accordance with ANSI B16.34.

(d) Alignment tolerances given in Fig. NB-4233(a)-1 shall apply to all auxiliary piping, such as drain lines, which begin or terminate at the valve.

(e) For socket welding ends, valves of nominal size 2 in. (DN 50) and smaller for which the body cavity consists of cylindrically bored sections shall meet all of the following:

- (1) d_m shall be the port drill diameter;
- (2) the requirements of NB-3542 shall be satisfied; and
- (3) socket welding end valves of nominal size greater than 2 in. (DN 50) shall not be used.

NB-3544.9 Openings for Auxiliary Connections.

Openings for auxiliary connections, such as for drains, bypasses, and vents, shall meet the requirements of ANSI B16.34 and the applicable reinforcement requirements of NB-3330.

NB-3545 Body Primary and Secondary Stress Limits

The limits of primary and secondary stresses are established in the following subparagraphs.

NB-3545.1 Primary Membrane Stress Due to Internal Pressure.

For valves meeting all requirements of this Subarticle, the most highly stressed portion of the body under internal pressure is at the neck to flow passage junction and is characterized by circumferential tension normal to the plane of center lines, with the maximum value at the inside surface. The rules of this paragraph are intended to control the general primary membrane stress in this crotch region. The Standard Calculation Pressure p_s to be used for satisfying the requirements of NB-3545 is found either directly or by interpolation from the tables in ANSI B16.34 as the pressure at 500°F (260°C) for the given Pressure Rating Class Index p_r .

(a) In the crotch region, the maximum primary membrane stress is to be determined by the pressure area method in accordance with the rules of (1) through (6) below using Fig. NB-3545.1(a)-1.

(1) From an accurately drawn layout of the valve body, depicting the finished section of the crotch region in the mutual plane of the bonnet and flow passage center lines, determine the fluid area A_f and metal area A_m . A_f and A_m are to be based on the internal surface after complete loss of metal assigned to corrosion allowance.

(2) Calculate the crotch general primary membrane stress intensity:

$$P_m = \left(\frac{A_f}{A_m} + 0.5 \right) p_s$$

The allowable value of this stress intensity is S_m for the valve body material at 500°F (260°C) as given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(3) The distances L_A and L_N which provide bounds on the fluid and metal areas are determined as follows. Use the larger value of:

Page 120

Page 122

Pages 121-121

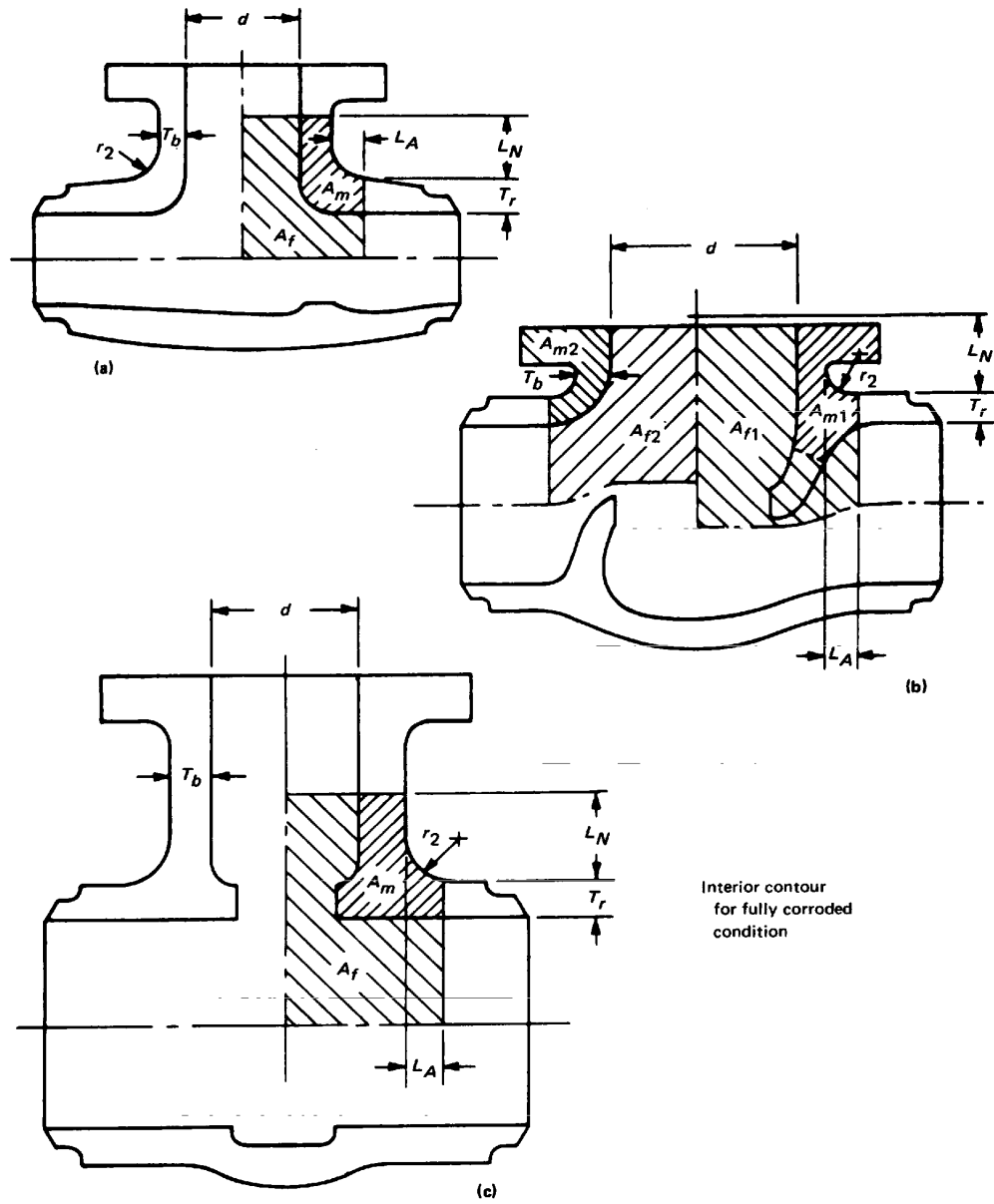


FIG. NB-3545.1(a)-1 PRESSURE AREA METHOD

FIG. NB-3545.1(a)-1 PRESSURE AREA METHOD

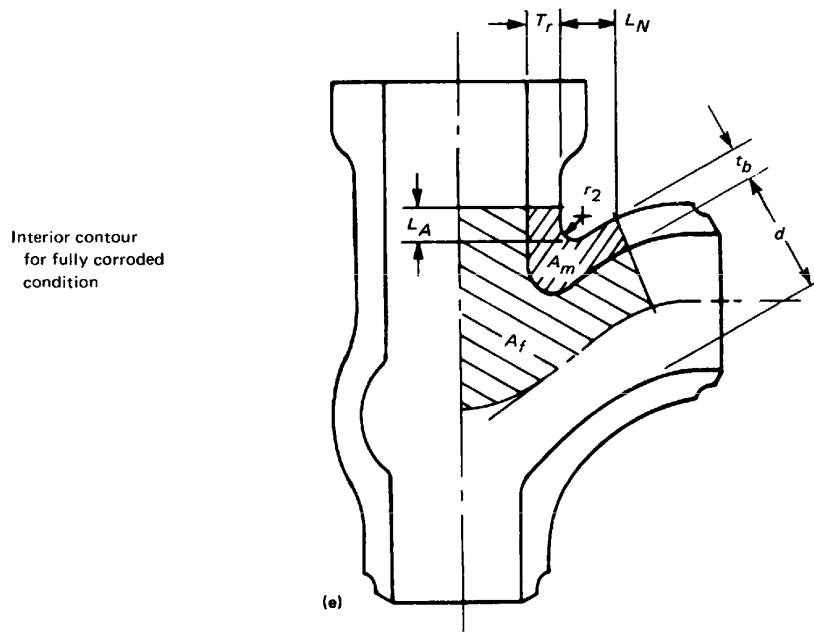
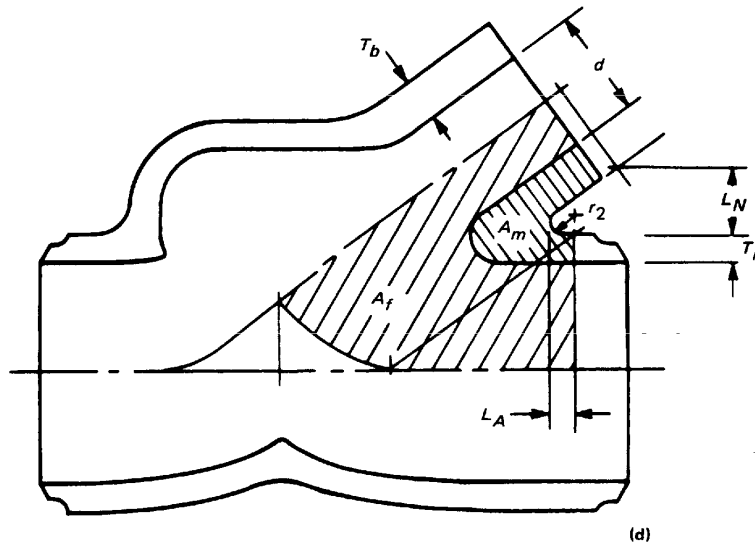


FIG. NB-3545.1(a)-1 PRESSURE AREA METHOD (CONT'D)

FIG.NB-3545.1(a)-1 PRESSURE AREA METHOD (CONT'D)

$$L_A = 0.5d - T_b$$

OR

$$L_A = T_r$$

and use

$$L_N = 0.5r_2 + 0.354 \sqrt{T_b(d + T_b)}$$

where the dimensions are as shown in Fig. NB-3545.1(a)-1.

In establishing appropriate values for the above parameters, some judgment may be required if the valve body is irregular as it is for globe valves and others with nonsymmetric shapes. In such cases, the internal boundaries of A_f shall be the lines that trace the greatest width of internal wetted surfaces perpendicular to the plane of the stem and pipe ends [Fig. NB-3545.1(a)-1 sketches (b), (d), and (e)].

(4) If the calculated boundaries for A_f and A_m as defined by L_A and L_N fall beyond the valve body [Fig. NB-3545.1(a)-1 sketch (b)], the body surface becomes the proper boundary for establishing A_f and A_m . No credit is to be taken for any area of connected piping which may be included within the limits of L_A and L_N . If the flange is included with A_m , the area of one bolt hole is to be subtracted for determining the net value of A_m .

(5) Except as modified below, web or fin-like extensions of the valve body are to be credited to A_m only to an effective length from the wall equal to the average thickness of the credited portion. The remaining web area is to be added to A_f [Fig. NB-3545.1(a)-1 sketch (b)]. However, to the extent that additional area will pass the following test, it may also be included in A_m . A line perpendicular to the plane of the stem and pipe ends from any points in A_m does not break out of the wetted surface but passes through a continuum of metal until it breaks through the outer surface of the body.

(6) In most cases, it is expected that the portions defined by A_m in the several illustrations of Fig. NB-3545.1(a)-1 will be most highly stressed. However, in the case of highly irregular valve bodies, it is recommended that all sections of the crotch be checked to ensure that the largest value of P_m has been established considering both open and fully closed conditions.

(b) In regions other than the crotch, while the value of P_m calculated by NB-3545.1(a) will be the highest value of body general primary membrane stress for all normal valve types with typical wall proportioning, the designer is cautioned to review unusual body configurations for possible higher stress regions. Suspected regions are to be checked by the pressure area method applied to the particular local body contours. The allowable value of this stress intensity is S_m for the valve body material at 500°F (260°C) as given in Section II, Part D, Subpart 1, Tables 2A and 2B.

NB-3545.2 Secondary Stresses.

In addition to satisfying the criteria of NB-3541 through NB-3545.1, a valve body shall also satisfy the criterion that the range of primary plus secondary stresses S_n due to internal pressure, pipe reaction, and thermal effects shall not exceed $3 S_m$ for the body material at 500°F (260°C), where Q_p , P_{eb} , and Q_{T3} are determined by the rules of this paragraph. That is:

$$S_n = Q_p + P_{eb} + 2 Q_{T_3} \leq 3 S_m$$

(a)(1) The body primary plus secondary stress Q_p due to internal pressure is to be determined by:

$$Q_p = C_p \left(\frac{r_i}{t_e} + 0.5 \right) p_s$$

where the primary plus secondary pressure stress index C_p is equal to 3 and

p_s	= Standard Calculation Pressure defined by NB-3545.1, psi
r_i	= radius of a circle which circumscribes the inside wall contour in the crotch region, in.
t_e	= an effective wall thickness at that location, in. (typically $t_e = T_r$) [Fig. NB-3545.1(a)-1]

In choosing an appropriate value for t_e , credit may be taken for general reinforcement material at the critical section but not for local fillets. Protuberances or ribs are not to be considered in determining r_i and t_e . Guidance is provided by Fig. NB-3545.2(a)-1 in which the illustrations correspond to the critical sections of the valve bodies of Fig. NB-3545.1(a)-1. The parameters r_i and t_e are intended to be representative of a tee, reinforced or unreinforced, with the general configuration of the valve body for which minor shape details associated with the valve function are ignored.

(2) For valve bodies with bonnet center lines other than perpendicular to the flow passage, the body stress Q_p due to internal pressure defined above must be multiplied by the factor C_a :

Page 123

Page 124

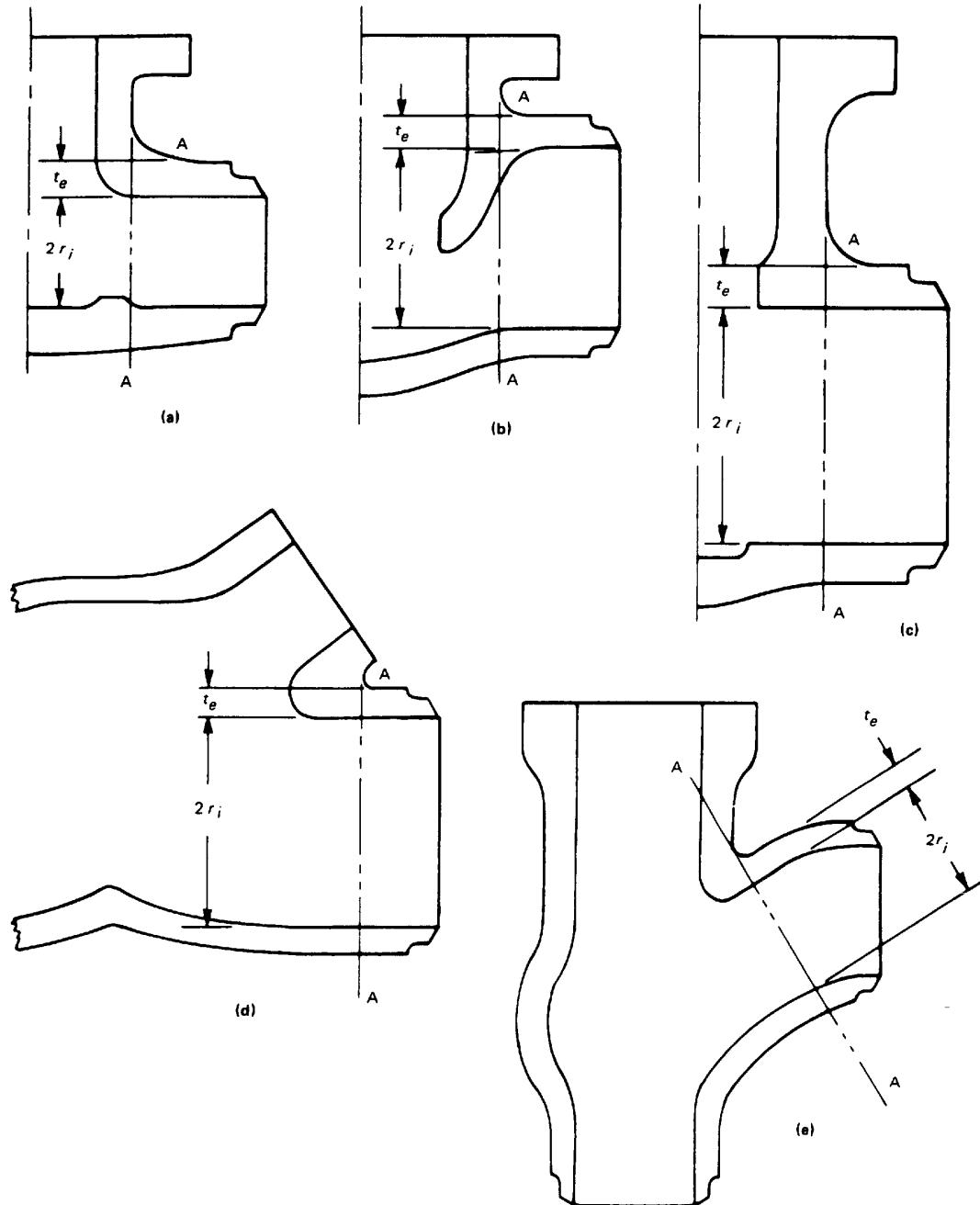


FIG. NB-3545.2(a)-1 CRITICAL SECTIONS OF VALVE BODIES

FIG. NB-3545.2(a)-1 CRITICAL SECTIONS OF VALVE BODIES

$$C_a = 0.2 + \frac{0.8}{\sin \alpha}$$

where

α = acute angle between the bonnet and flow passage center lines, deg.

(b) The secondary stress due to pipe reaction shall meet the criteria of (1) through (6) below to ensure the adequacy of the valve body for safely transmitting forces and moments imposed by the connected piping system.

(1) Based on the critical section A-A at the crotch, as illustrated by Fig. NB-3545.2(a)-1, calculate the value of P_{eb} where

(Bending load effect)

$$P_{eb} = \frac{C_b F_b S}{G_b}$$

The allowable value of P_{eb} is $1.5S_m$ for the valve body material at 500°F (260°C). Determination of S , F_b , C_b , and G_b required to calculate P_{eb} is to be in accordance with the requirements of (2) through (5) below.

(2) When the valve designer knows the material of the connected pipe, S may be calculated as the yield strength for the pipe material at 500°F (260°C). When the designer does not know the piping material or is designing a valve independently of a particular application, the value of S shall be taken as 30.0 ksi (207 MPa).

(3) Calculate F_b where

$$F_b = \frac{0.393 d_e^3 p_s}{20,000 - p_s}$$

but not less than:

(a) the section modulus of Schedule 40 pipe with the next larger inside diameter than d_e for $d_e < 10.02$ in.

(b) $0.295 d_e^2$ for $d_e > 10.02$ in. where d_e equals the inside diameter of the larger end of the valve body.

(4) Calculate the factor C_b :

$$C_b = 0.335 \left(\frac{r}{t_e} \right)^{2/3}$$

When the results are less than 1.0, use $C_b = 1.0$.

(5) The factor G_b is the section modulus $I/(r_i + t_e)$, in.³, for bending at the plane through A-A about the axis perpendicular to the mutual plane of bonnet and body center lines, such as that axis which produces maximum bending stress at the corner of the crotch. The fiber stress at the outside surface is to be considered as governing in calculating G_b .

(6) When valves are to be applied in a venturi arrangement such that the connected pipe may be larger than that corresponding to the nominal size of the valve, it is necessary to base P_{eb} on the actual larger connected pipe. Such cases must be treated individually to ensure compliance with the secondary and fatigue stress criteria of this Subarticle.

When the venturi arrangement is not fabricated by the N Certificate Holder, the Design Specifications shall include sufficient information to permit the N Certificate Holder to make this check.

(c) Thermal secondary stresses in the valve crotch region, resulting from through-wall temperature gradient and thickness variation (average temperature difference), are to be calculated on the basis of a continuous ramp change in fluid temperature at 100°F/hr (56°C/hr) using the model of Fig. NB-3545.2(c)-1 sketch (a). Figure NB-3545.2(c)-1 sketch (b) illustrates how r , T_{e1} , T_{e2} and t_e are to be determined for the typically irregular crotch shape of valves. The thermal secondary stress components are to be determined in accordance with the following:

(1) Stress component Q_{T1} which is the result of a through-wall temperature gradient is defined as:

$$Q_{T1} = C_7 (T_{e1})^2$$

where

$$\begin{array}{ll} C_7 & = 110 \text{ psi/in.}^2 \text{ for ferritic steels, or} \\ C_7 & = 380 \text{ psi/in.}^2 \text{ for austenitic steels} \end{array}$$

T_{e1} is illustrated in Fig. NB-3545.2(c)-1.

(2) Stress component Q_{T3} which is the membrane plus bending stress as a result of wall thickness variation is defined as:

$$Q_{T3} = C_6 C_3 \Delta T'$$

where C_3 is found from Fig. NB-3545.2(c)-4 and

$$\Delta T' = C_1 (T_{e1}^2 - t_e^2)$$

where

$$C_1 = \begin{cases} .53 \text{ } ^\circ\text{F/in.}^2 & \text{for ferritic steels, or} \\ 1.4 \text{ } ^\circ\text{F/in.}^2 & \text{for austenitic steels} \end{cases}$$

t_e is illustrated in Fig. NB-3545.2(c)-1.

NB-3545.3 Fatigue Requirements.

The fatigue analysis requirements are satisfied provided the rules of this subparagraph and the rules of NB-3550 are met.

Page 125

Page 126

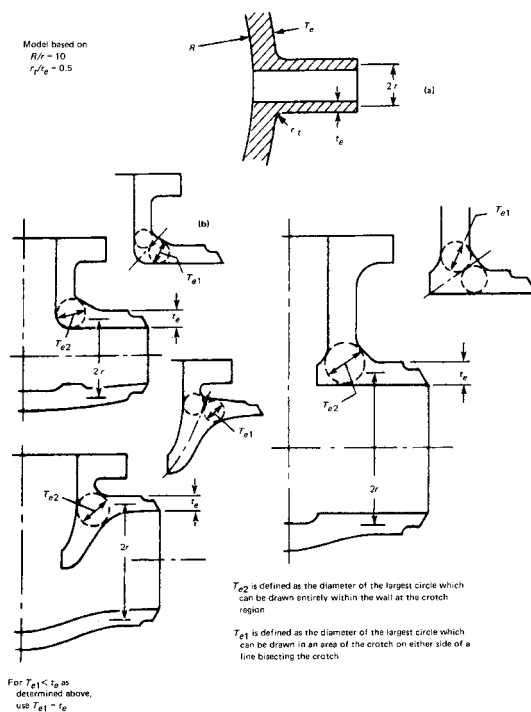


FIG. NB-3545.2(c)-1 MODEL FOR DETERMINING SECONDARY STRESS IN VALVE CROUCH REGION

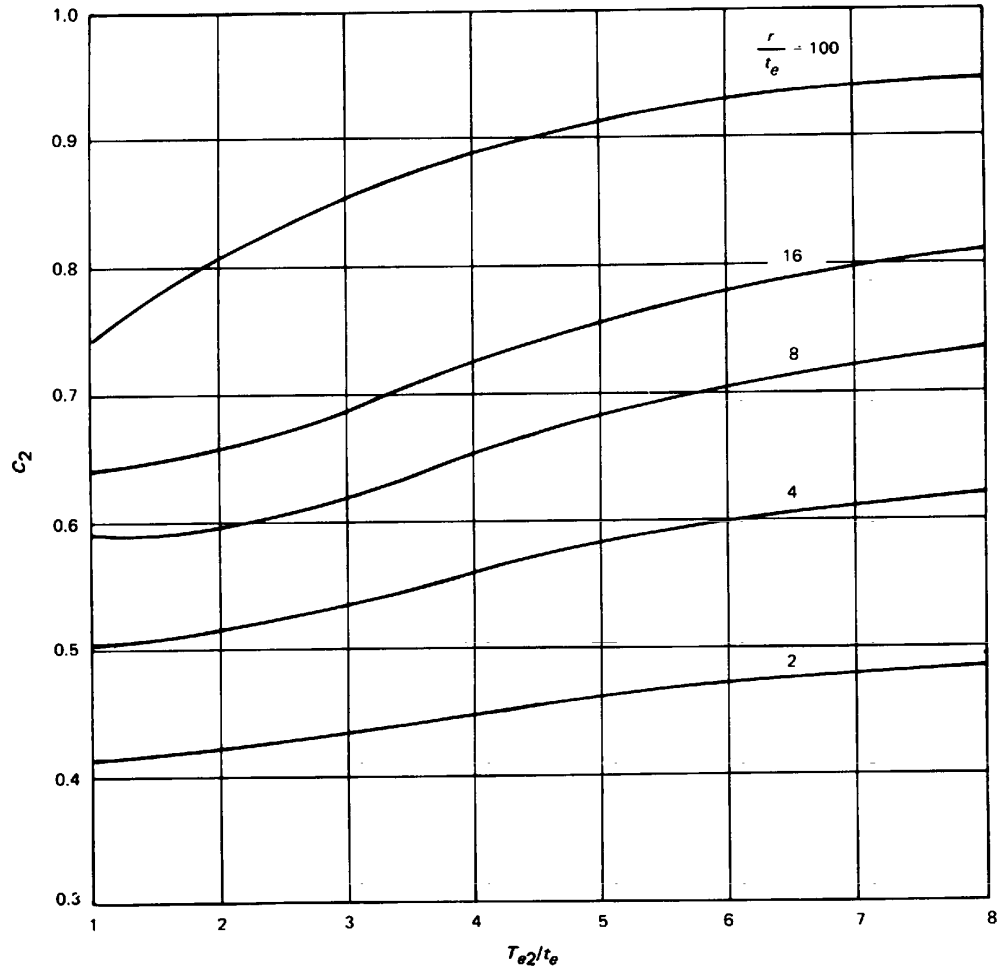


FIG. NB-3545.2(c)-3 THERMAL STRESS INDEX VERSUS THICKNESS CONTINUITY RUN OR BRANCH

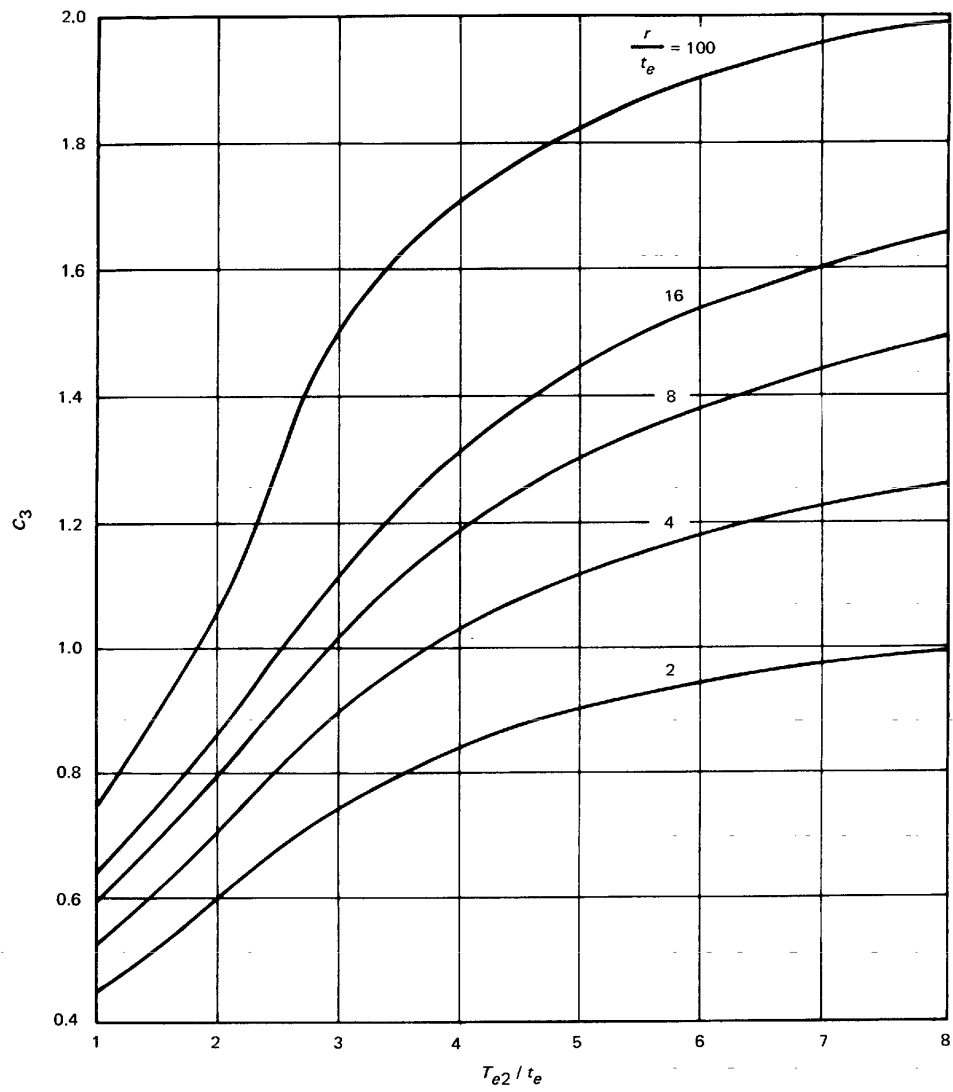


FIG. NB-3545.2(c)-4 SECONDARY STRESS INDEX VERSUS THICKNESS DISCONTINUITY RUN OR BRANCH

FIG. NB-3545.2(c)-4 SECONDARY STRESS INDEX VERSUS THICKNESS DISCONTINUITY RUN OR BRANCH

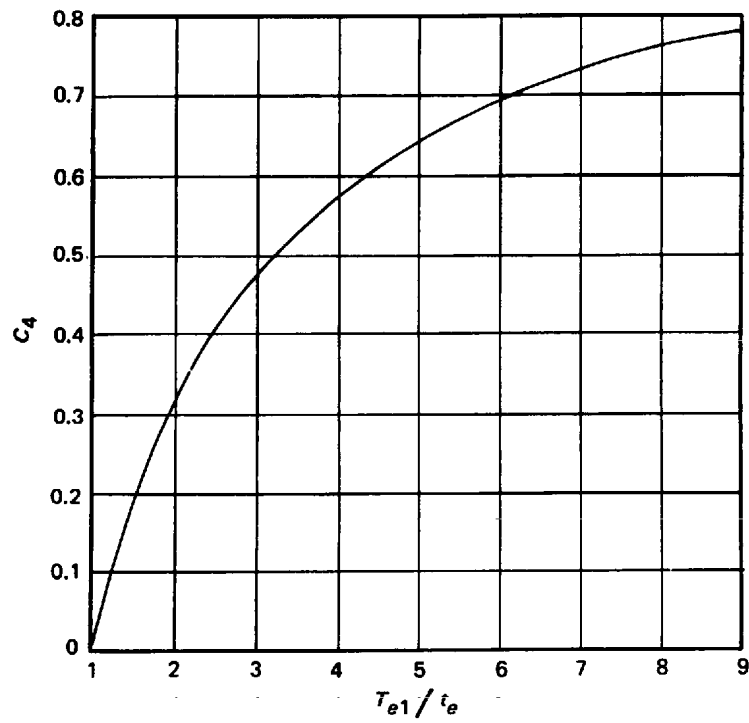


FIG. NB-3545.2(c)-5 C_4 VERSUS T_{e1}/t_e

FIG. NB-3545.2(c)-5 C_4 VERSUS T_{E1}/t_e

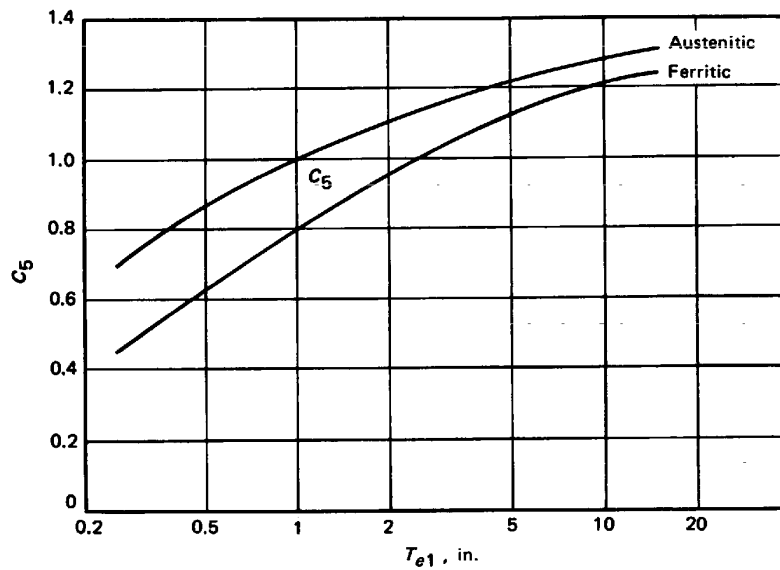


FIG. NB-3545.2(c)-6 STRESS INDEX FOR THERMAL FATIGUE

FIG. NB-3545.2(c)-6 STRESS INDEX FOR THERMAL FATIGUE

The calculated allowable number of cycles is $N_a \geq 2000$ cycles, where N_a is determined from Figs. I-9.0 by entering the appropriate curve with S_a with S_a defined as the larger value of S_{p1} and S_{p2} defined as follows:

$$S_{p1} = \frac{2}{3} Q_p + \frac{P_{eb}}{2} + Q_{T3} + 1.3 Q_{T1}$$

$$S_{p_2} = 0.4Q_p + \frac{K}{2} (P_{eb} + 2Q_{T_3})$$

The values of S_{p_1} and S_{p_2} are based on the values for Q_p , P_{eb} , Q_{T_1} , and Q_{T_3} found in accordance with the rules of NB-3545.2. K is the fatigue strength reduction factor associated with the external fillet at the crotch and is to be considered as 2.0 unless the designer can justify use of a smaller value.

NB-3546 Design Requirements for Valve Parts Other Than Bodies

NB-3546.1 Body-to-Bonnet Joints

(a) Bolted body-to-bonnet joints shall be designed in accordance with the pressure design rules of XI-3000, including the use of the appropriate allowable stress given in Section II, Part D, Subpart 1, Tables 1A and 1B, or by the procedures of NB-3200, except fatigue analysis of bolts is not required.

(b) Body-to-bonnet joints other than bolted connections including joints of special or patented types for which specific standards do not exist may be used provided that the N Certificate Holder shall use methods of design and construction that will be as safe as otherwise required by the rules of this Subarticle for the following design conditions:

(1) Design Pressure equal to Standard Calculation Pressure p_s (NB-3545.1);

(2) calculation temperature of 500°F (260°C);

(3) thermal stresses based on most severe conditions resulting from continuous fluid temperature ramp increase or decrease at 100°F/hr (56°C/hr);

(4) fatigue life at least 2000 cycles of startup/shutdown based on the above conditions with simultaneous increase or decrease of pressure and temperature.

NB-3546.2 Valve Disk.

The valve disk shall be considered a part of the pressure-retaining boundary. The primary membrane stress intensity shall not exceed S_m , and the primary bending stress intensity shall not exceed $1.5S_m$.

NB-3546.3 Other Valve Parts

(a) Valve stems, stem retaining structures, and other significantly stressed valve parts whose failure can lead to gross violation of the pressure-retaining boundary shall be designed so that their primary stresses, based on pressure equal to the 100°F (38°C) pressure rating and conservatively estimated or calculated additional loadings, where applicable, do not exceed S_m as tabulated in Section II, Part D, Subpart 1, Tables 2A and 2B, or for materials not listed in these Tables, do not exceed two-thirds of the minimum specified yield strength or one-fourth of the minimum specified tensile strength, whichever is lower.

(b) Bypass piping shall be designed in accordance with the requirements of NB-3600. Unless otherwise stated in the

valve Design Specifications, bypass piping design shall be the responsibility of the piping system designer.

(c) Valve designs, requiring solenoid plunger core tubes or electromagnetic position indicator core tubes, may substitute the rules of NB-3641.1 for the requirements of NB-3541, NB-3542, or NB-3543 for minimum wall thickness of the extension, provided that detailed calculations are prepared in accordance with NB-3200 at the 100°F (38°C) valve pressure rating conditions, and covering all discontinuities in the core tube, including the cap end and attachment end, and all welds, including any dissimilar metal welds. These calculations shall be included in the Design Report (NB-3560). The calculations shall include the design loadings given in NB-3546.1(b)(1) through NB-3546.1(b)(4) along with any additional requirements given in the Design Specifications.

NB-3546.4 Fatigue Evaluation.

When the Design Specifications include such service loadings that the valve is not exempted from fatigue analysis by the rules of NB-3222.4(d), it is recommended that consideration be given to the cyclic stress duty of the portions considered by NB-3546.

NB-3550 CYCLIC LOADING REQUIREMENTS

NB-3551 Verification of Adequacy for Cyclic Conditions

The adequacy of a valve for cyclic loading shall be verified in accordance with this Subsubarticle. Nonintegral seat rings attached to the valve body by partial penetration or fillet welds (NB-4433) are exempt from the fatigue analysis requirements of NB-3123.2, provided

Page 130

the seat rings are shouldered against the valve body; see Fig. NB-3544.1(c)-1.

NB-3552 Excluded Cycles

In satisfying the cyclic loading requirements, the following variations need not be considered:

- (a) pressure variations less than $p_d/3$ for carbon and low alloy steels and less than $p_d/2$ for austenitic stainless steels;
- (b) temperature variations less than 30°F (17°C);
- (c) accident or maloperation cycles expected to occur less than five times (total) during the expected valve life;
- (d) startup, shutdown cycles with temperature change rates of 100°F/hr (56°C/hr) or less, not in excess of 2000.

NB-3553 Fatigue Usage

The application of a valve conforming to NB-3512.1 is acceptable for cyclic loading conditions provided its fatigue usage I_f is not greater than 1.0 as evaluated in (a), (b), and (c) below.

(a) Consider fluid temperature changes not excluded by NB-3552 to occur instantaneously. Provided that these changes occur in one direction and recovery is at temperature change rates not in excess of 100°F/hr (56°C/hr), the fatigue usage factor may be found by:

$$I_i = \sum \frac{N_{ri}}{N_i}$$

where N_{ri} is the required or estimated number of fluid temperature step changes ΔT_{fi} and N_i is found from Figs. I-9.1 and I-9.2.

(b) If both heating and cooling effects are expected at change rates exceeding 100°F/hr (56°C/hr), the number of cycles are to be associated by temperature ranges ΔT_i . For example, assuming the following variations are specified:

20 variations $\Delta T_1 = 250$ heating

10 variations $\Delta T_2 = 150$ cooling

100 variations $\Delta T_3 = 100$ cooling

lump the ranges of variation so as to produce the greatest effects as follows:

10 cycles ΔT_{f1} = 250 + 150 = 400

10 cycles ΔT_{f2} = 250 + 100 = 350

90 cycles ΔT_{f3} = 100

(c) Pressure fluctuations not excluded by NB-3552 are to be included in the cyclic load calculations. The full range of pressure fluctuation from the normal condition to the condition under consideration shall be represented by Δp_i in NB-3554.

NB-3554 Cyclic Stress Calculations

A valve conforming to NB-3512.1 shall be qualified by the procedure of (a) through (d) below.

(a) The following criterion shall be met by the greatest temperature range:

$$Q_p [\Delta p_{f(\max)} / p_s] + C_6 C_2 C_4 \Delta T_{f(\max)} < 3 S_m$$

where $\Delta T_{f(\max)}$ is the largest lumped temperature range obtained using the methods of NB-3553(b), and $\Delta p_{f(\max)}$ is the largest range of pressure fluctuation associated with $\Delta T_{f(\max)}$.

(b) Calculate:

$$S_{n(\max)} = Q_p [\Delta p_{f(\max)} / p_s] + C_6 C_3 C_4 \Delta T_{f(\max)}$$

Provided that $S_{n(\max)} \leq 3S_m$, calculate the fatigue stresses for each cyclic loading condition as follows:

$$S_i = \sqrt[4]{3} Q_p (\Delta p_{fi} / p_s) + C_6 (C_3 C_4 + C_5) \Delta T_{fi}$$

Determine the allowable number of cycles N_i for each loading condition by entering Figs. I-9.1 and I-9.2 with $S_i/2$, and determine the fatigue usage by NB-3553(a).

(c) If $S_{n(\max)}$ is greater than $3S_m$ but less than $3mS_m$, the value of $S_i/2$ to be used for entering the design fatigue curve is to be found by multiplying S_i by K_e , where:

$$K_e = 1.0 + \frac{(1 - n)}{n(m - 1)} \left(\frac{S_n}{3S_m} - 1 \right)$$

and where the values of the material parameters m and n are as given in Table NB-3228.5(b)-1.

(d) If $S_{n(\max)}$ is greater than $3mS_m$, use $K_e = 1/n$.

NB-3560 DESIGN REPORTS

NB-3561 General Requirements

The certified Design Reports listed in this paragraph meet the requirements of NCA-3550 for the Design Report.

Page 131

NB-3562 Design Report for Valves Larger Than 4 in. Nominal Pipe Size (DN 100)

A Design Report shall be prepared in sufficient detail to show that the valve satisfies the requirements of NB-3512. For a valve designed in accordance with NB-3512.1, the Design Report shall show that the applicable requirements of NB-3530, NB-3541 through NB-3546.2, and NB-3550 have been met. It is not necessary to write a special Design Report based on specified Design Pressure and Design Temperature when they are within the pressure-temperature rating and when supplementary information or calculations are also provided, as necessary, to complete the report for a specific application, such as the thermal cyclic duty evaluation of NB-3550. A report submitted demonstrating a design for loadings more severe than the specified loadings is also acceptable.

NB-3563 Design Report Requirements for 4 in. and Smaller Nominal Pipe Size ($\leq$ DN 100) Valves

For valves whose inlet piping connection is nominally 4 in. (DN 100) or smaller, the Design Report shall include details to show that the requirements of NB-3513 have been met.

NB-3590 PRESSURE RELIEF VALVE DESIGN

NB-3591 Acceptability

NB-3591.1 General.

The rules of this Subsubarticle constitute the requirements for the design acceptability of spring-loaded pressure relief valves. The design rules for pilot operated and power actuated pressure relief valves are covered by NB-3500. The rules of this Subsubarticle cover the pressure-retaining integrity of the valve inlet and outlet connections, nozzle, disk, body structure, bonnet (yoke), and body-to-bonnet (yoke) bolting. The rules of this Subsubarticle also cover other items such as the spring, spindle (stem), spring washers, and set pressure adjusting screw. The rules of this Subsubarticle do not apply to guides, control ring, bearings, set screws, and other nonpressure-retaining items. Figures NB-3591.1-1 and NB-3591.1-2 are illustrations of typical pressure relief valves.

NB-3591.2 Definitions.

The definitions for pressure relief valve terms used in this Subsubarticle are given in ANSI B95.1, Terminology for Pressure Relief Devices, and also in NB-7000. Pressure relief valves characteristically have multipressure zones within the valve, that is, a primary pressure zone and a secondary pressure zone as illustrated by Figs. NB-3591.1-1 and NB-3591.1-2.

NB-3591.3 Acceptability of Small Liquid Relief Valves.

Liquid pressure relief valves meeting the requirements of NB-7000 and having an inlet piping connection 2 in. nominal pipe size (DN 50) and under shall comply with the minimum wall thickness requirements of NB-3542 or NB-3543 for the applicable pressure zone. Flange end ratings of NB-3531.1 shall be used regardless of end connection. The applicable design requirements of this Subsubarticle covering the nozzle, disk, and bonnet shall apply. The analyses of NB-3544, NB-3545, and NB-3550 do not apply.

NB-3591.4 Acceptability of Safety and Safety Relief Valves.

The design shall be such that the requirements of this Subsubarticle are met.

NB-3592 Design Considerations

NB-3592.1 Design Conditions.

The general design requirements of NB-3100 are applicable, with consideration for the design conditions of the primary and secondary pressure zones. The design pressure of the Design Specification shall be used for the applicable zones.

In case of conflict between NB-3100 and NB-3590, the requirements of NB-3590 shall apply. Mechanical loads for both the closed and the open (full discharge) positions shall be considered in conjunction with the service conditions. In addition, the requirements of NB-7000 shall be met.

NB-3592.2 Stress Limits for Specified Service Loadings

(a) Stress limits for Level A and B Service Loadings shall be as follows:

- (1) the primary membrane stress intensity shall not exceed S_m ;
- (2) the primary membrane stress intensity plus primary bending stress intensity shall not exceed $1.5S_m$;
- (3) substantiation by analysis of localized stresses associated with contact loading of bearing or seating surfaces is not required;
- (4) the values of S_m shall be in accordance with Section II, Part D, Subpart 1, Tables 2A, 2B, and 4.

(b) Stress limits for Level C Service Loadings shall be as follows:

- (1) the primary membrane stress intensity shall not exceed $1.5S_m$;

Page 132

Page 133

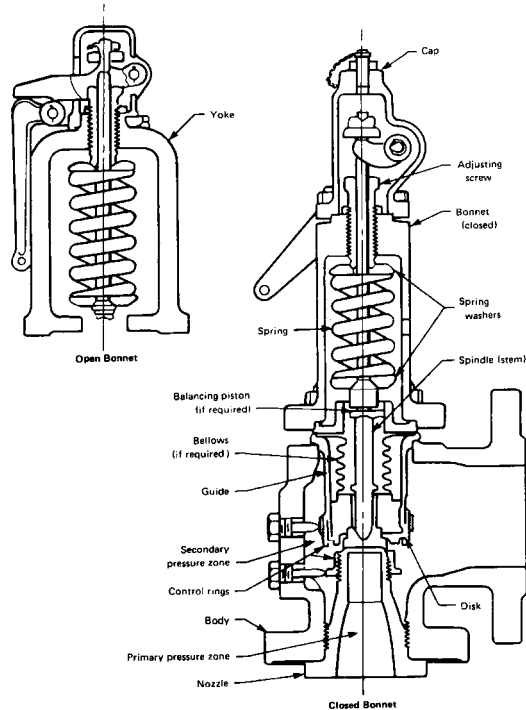


FIG. NB-3591.1-1 TYPICAL PRESSURE RELIEF DEVICES

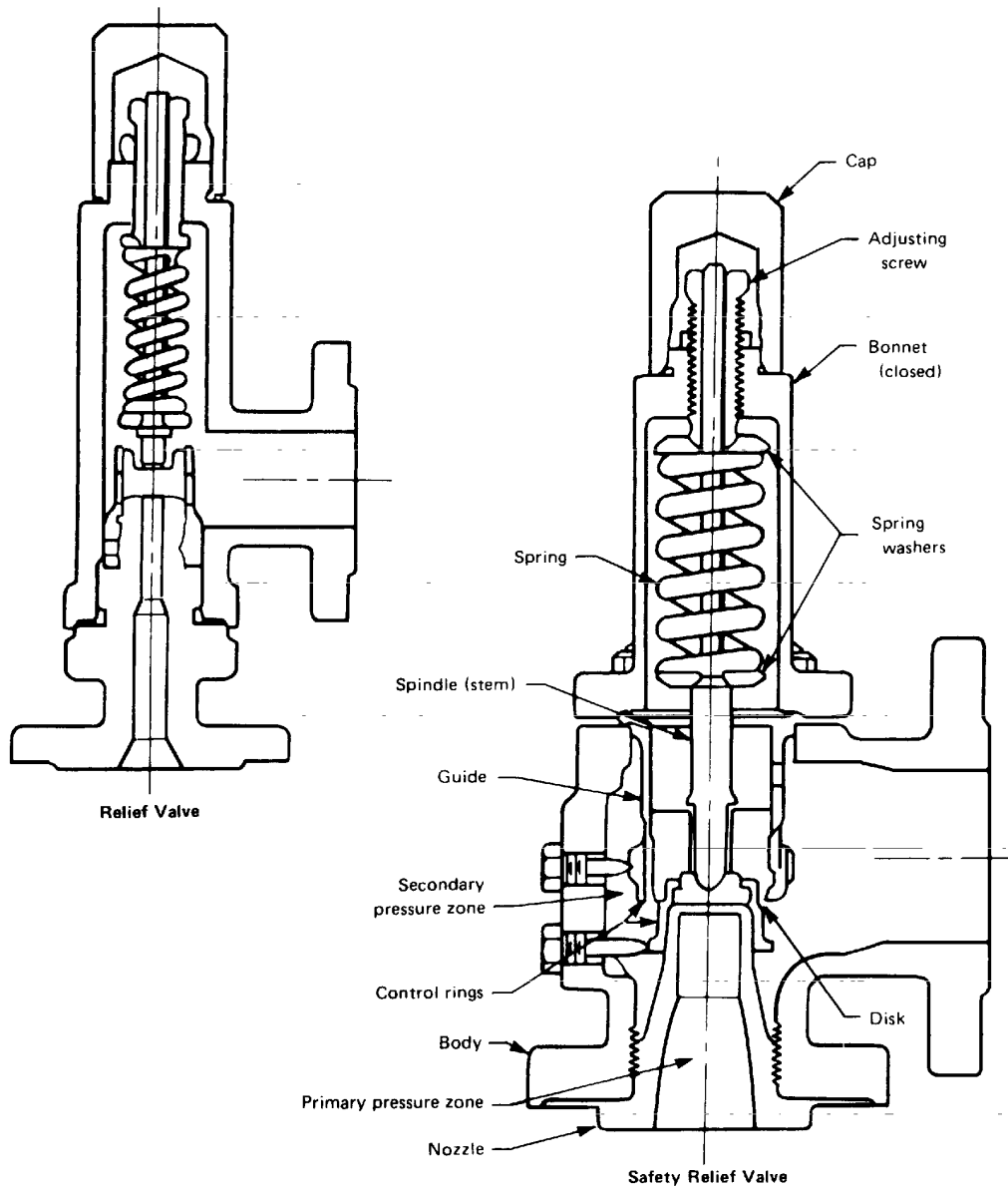


FIG. NB-3591.1-2 TYPICAL PRESSURE RELIEF AND SAFETY RELIEF DEVICES

FIG. NB-3591.1-2 TYPICAL PRESSURE AND SAFETY RELIEF DEVICES

- (2) the primary membrane stress intensity plus primary bending stress intensity shall not exceed $1.8S_m$ (NB-3526.2);
- (3) the rules of NB-3526.3 must be satisfied.
- (c) Stress limits for Level D Service Loadings shall be as follows:
 - (1) the guidelines of Appendix F may be used in evaluating these conditions.
 - (d) These requirements for the acceptability of valve design are not intended to ensure the functional adequacy of the valve. However, the Designer is cautioned that the requirements of NB-7000 relative to set pressure, lift, blowdown, and closure shall be met.

NB-3592.3 Earthquake.

The rules of this Subsubarticle consider that under earthquake loadings the piping system or vessel nozzle, rather than the valve body, will be limiting. Pressure relief valves have extended structures and these structures are essential to maintaining pressure integrity. An analysis, when required by the Design Specification, shall be performed based on static forces resulting from equivalent earthquake acceleration acting at the centers of gravity of the extended masses. Classical bending and direct stress equations, where free body diagrams determine a simple stress distribution that is in equilibrium with the applied loads, may be used.

NB-3593 Special Design Rules

NB-3593.1 Hydrostatic Test.

Hydrostatic testing shall be performed in accordance with NB-3531.2(f).

NB-3593.2 Marking.

In addition to the marking required by NCA-8220 and NB-7000, the secondary Design Pressure shall be marked on the valve or valve nameplate.

NB-3594 Design of Pressure Relief Valve Parts

NB-3594.1 Body.

The valve body shall be analyzed with consideration for the specific configuration of the body and the applicable pressure zone and loadings. The design shall take into consideration the adequacy of the inlet flange connection, the outer flange connection, and the body structural configuration. In valve designs where the outlet flange is an extension of the bonnet, the bonnet design shall conform to all rules of body design. The body shall be designed in accordance with the rules of NB-3540 through NB-3550. The design adequacy of the inlet and outlet flanges shall be determined using the rules of NB-3658. Flanges shall conform to the applicable pressure-temperature ratings of NB-3531.1 and shall meet the interface dimensions of ANSI B16.5.

NB-3594.2 Bonnet (Yoke).

The bonnet (yoke) may be analyzed using classic bending and direct stress formulae, with appropriate free body diagrams. The general primary membrane stress intensity and the general primary membrane plus primary bending stress intensity shall be determined and shall not exceed the stress limits of NB-3592.2.

NB-3594.3 Nozzle.

The nozzle shall be analyzed in accordance with the applicable rules of NB-3540 and NB-3550, with a basic analytical model configuration as shown in Fig. NB-3594.3-1. The sections of the nozzle where dimensions are limited by the flow capacity and the operational control requirements may be considered as simple cylindrical sections. The minimum wall thickness of these sections shall be determined in accordance with NB-3324.1. These requirements are not applicable to the transition region to the seat contacting area of the nozzle, defined by L in Fig. NB-3594.3-1, provided dimension L is less than the nominal wall thickness t_1 .

NB-3594.4 Body-to-Bonnet Joint.

The body-to-bonnet joint shall be analyzed in accordance with NB-3546.1.

NB-3594.5 Disk.

The valve disk shall satisfy the requirements of NB-3546.2.

NB-3594.6 Spring Washer.

The average shear stress shall not exceed $0.6S_m$. The primary bending stress intensity shall not exceed the stress limits of NB-3592.2.

NB-3594.7 Spindle (Stem).

The general primary membrane stress intensity shall not exceed the stress limits of NB-3592.2.

NB-3594.8 Adjusting Screw.

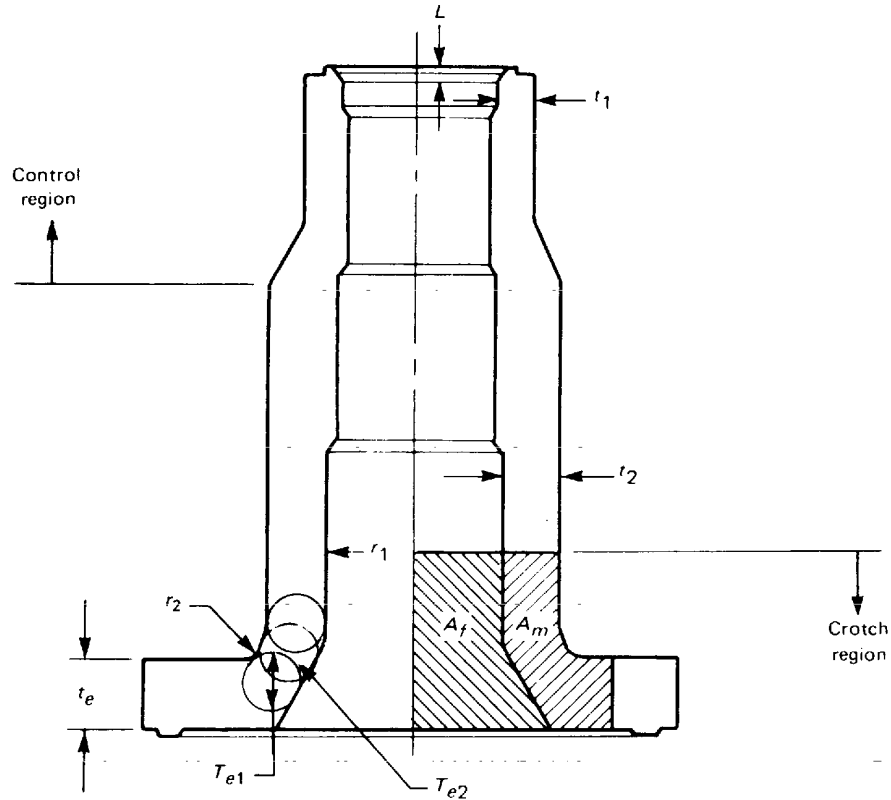
The adjusting screw shall be analyzed for thread shear stress in accordance with the method of ANSI B1.1 and this stress shall not exceed $0.6S_m$. The general primary membrane stress intensity of the adjusting screw shall not exceed the stress limits of NB-3592.2, based on the root diameter of the thread.

NB-3594.9 Spring.

The valve spring shall be designed so that the full lift spring compression shall be no greater than 80% of the nominal solid deflection. The permanent set of the spring (defined as the difference between the free height and height measured a minimum of 10 min after the spring has been compressed solid three additional times after presetting at

Page 135

room temperature) shall not exceed 0.5% of the free height.



- t_1, t_2 = nozzle wall thickness, in.
 t_e = minimum body wall thickness adjacent to crotch, in.
 T_{e1} = maximum effective thickness in crotch region, in.
 T_{e2} = effective crotch wall thickness, in.
 r_1 = inside radius at crotch region, in.
 r_2 = outside fillet radius at crotch
 L = length of seat transition region, in.
 A_f = fluid area, in.²
 A_m = metal area, in.²

FIG. NB-3594.3-1 VALVE NOZZLE

98

[98]

FIG. NB-3594.3-1 VALVE NOZZLE

NB-3595 Design Report

NB-3595.1 General Requirements.

A Design Report shall be prepared in sufficient detail to show that the valve satisfies the rules of this Subsubarticle and NCA-3550.

NB-3600 PIPING DESIGN

NB-3610 GENERAL REQUIREMENTS

NB-3611 Acceptability

The requirements for acceptability of a piping system are given in the following subparagraphs.

NB-3611.1 Stress Limits.

The design shall be such that the stresses will not exceed the limits described in NB-3630 except as provided in NB-3611.2.

Page 136

NB-3611.2 Acceptability When Stresses Exceed Stress Limits.

When the stresses as determined by the methods given in NB-3630 exceed the limits thereof, the design can be accepted, provided it meets the requirements of NB-3200. The rules of NB-3630 meet all the requirements of NB-3200.

NB-3611.3 Conformance to NB-3600.

In cases of conflict between NB-3100 and NB-3600, the requirements of NB-3600 shall apply.

NB-3611.4 Dimensional Standards.

For the applicable year of issue of all dimensional standards referred to in NB-3600, see Table NB-3132-1.

NB-3611.5 Prevention of Nonductile Fracture.

The requirements for prevention of nonductile fracture as set forth in NB-3211(d) shall be met.

NB-3612 Pressure-Temperature Ratings

NB-3612.1 Standard Piping Products

(a) When standard piping products are used, the pressure ratings given as functions of temperature in the appropriate standards listed in Table NB-3132-1 shall not be exceeded. In addition, the requirements of NB-3625 shall be met. When established pressure ratings of standard products do not extend to the upper temperature limits for the material, the ratings between those established and the upper temperature limit may be determined in accordance with NB-3649.

(b) When the adequacy of the pressure design of a standard product is established by burst tests as permitted in NB-3649 (ANSI B16.9, Section 8), the manufacturer of the product shall maintain a record of burst tests conducted to ensure adequacy of product and shall so certify. Such records shall be available to the purchaser.

NB-3612.2 Piping Products Without Specific Ratings.

If piping products are used for which methods of construction are not covered by this Subsection, the manufacturer of the product shall use methods of construction that will be as safe as otherwise provided by the rules of this Subsection. When products are used for which pressure-temperature ratings have not been established by the standards listed in Table NB-3132-1, the products shall be designed and tested in accordance with NB-3640. The manufacturer's recommended pressure-temperature ratings shall not be exceeded.

NB-3612.4 Considerations for Local Conditions and Transients

(a) When piping systems operating at different pressures are connected by a valve or valves, the valve or valves shall be designed for the higher pressure system requirements of pressure and temperature. The lower pressure system shall be designed in accordance with (1), (2), or (3) below.

(1) The requirements of the pressure system shall be met.

(2) Pressure relief devices or safety valves shall be included to protect the lower pressure system in accordance with

NB-7311.

(3) Ensure compliance with all the conditions of (a) through (e) below.

(a) Redundant check or remote actuated valves shall be used in series at the interconnection, or a check in series with a remote actuated valve.

(b) When mechanical or electrical controls are provided, redundant and diverse controls shall be installed which will prevent the interconnecting valves from opening when the pressure in the high pressure system exceeds the Design Pressure of the lower pressure system.

(c) Means shall be provided such that operability of all components, controls, and interlocks can be verified by test.

(d) Means shall be provided to ensure that the leakage rate of the interconnecting valves does not exceed the relieving capacity of the relief devices on the lower pressure system.

(e) Adequate consideration shall be given to the control of fluid pressure caused by heating of the fluid trapped between two valves.

The low pressure system relieving capacity may be determined in accordance with NB-7311, on the basis of interconnecting valve being closed but leaking at a specified rate, when (3)(a) to (3)(e) above are met. The pressure relief devices or safety valves shall adjoin or be as close as possible to the interconnecting valve and shall relieve preferably to a system where the relieved effluent may be contained. The design of the overpressure protection system shall be based on pressure transients that are specified in the Design Specification, and all other applicable requirements of NB-7000 shall be met.

(b) When pressure-reducing valves are used and one or more pressure relief devices or safety valves are provided, bypass valves may be provided around the pressure-reducing valves. The combined relieving capacity of the pressure relief devices, safety valves, and relief piping shall be such that the lower pressure system service pressure will not exceed the lower

Page 137

pressure system Design Pressure by more than 10% if the pressure-reducing valve fails in the open position and the bypass valve is open at the same time. If the pressure-reducing valve and its bypass valve are mechanically or electrically interlocked so that only one may be open at any time the high pressure system is at a pressure higher than the Design Pressure of the low pressure system, then the relieving capacity of the pressure relief devices, safety valves, and relief piping shall be at least equal to the maximum capacity of the larger of the two valves. The interlocks shall be redundant and diverse.

(c) Exhaust and pump suction lines for any service and pressure shall have relief valves of a suitable size unless the lines and attached equipment are designed for the maximum pressure and temperature to which they may be accidentally or otherwise subjected.

(d) The effluent from relief devices may be discharged outside the containment only if provisions are made for the disposal of the effluent.

(e) Drip lines from steam headers, mains, separators, or other equipment operating at different pressures shall not discharge through the same trap. Where several traps discharge into a single header that is or may be under pressure, a stop valve and a check valve shall be provided in the discharge line from each trap. The Design Pressure of trap discharge piping shall not be less than the maximum discharge pressure to which it may be subjected. Trap discharge piping shall be designed for the same pressure as the trap inlet piping unless the discharge piping is vented to a system operated under lower pressure and has no intervening stop valves.

(f) Blowdown, dump, and drain piping from water spaces of a steam generation system shall be designed for saturated steam at the pressures and temperatures given below.

Vessel	Design	Design
Pressure,	Pressure,	Temperature,
psi	psi	°F

		410
601 to 900	400	450
901 to 1500	600	490
1501 and above	900	535

These requirements for blowdown, dump, and drain piping apply to the entire system beyond the blowdown valves to the blowdown tank or other points where the pressure is reduced to approximately atmospheric and cannot be increased by closing a valve. When pressures can be increased because of calculated pressure drop or otherwise, this shall be taken into account in the design. Such piping shall be designed for the maximum pressure to which it may be subjected.

(g) Pump discharge piping shall be designed for the maximum pressure exerted by the pump at any load and for the highest corresponding temperature actually existing.

(h) Where a fluid passes through heat exchangers in series, the design temperature of the piping in each section of the system shall conform to the most severe temperature condition expected to be produced by heat exchangers in that section.

NB-3613 Allowances

NB-3613.1 Corrosion or Erosion.

When corrosion or erosion is expected, the wall thickness of the piping shall be increased over that required by other design requirements. This allowance shall be consistent with the specified design life of the piping.

NB-3613.2 Threading and Grooving.

The calculated minimum thickness of piping that is to be threaded or grooved shall be increased by an allowance equal to the depth of the cut.

NB-3613.3 Mechanical Strength.

When necessary to prevent damage, collapse, or buckling of pipe due to superimposed loads from supports or other causes, the wall thickness of the pipe shall be increased, or, if this is impractical or would cause excessive local stresses, the superimposed loads or other causes shall be reduced or eliminated by other design methods.

NB-3620 DESIGN CONSIDERATIONS

NB-3621 Design and Service Loadings

The provisions of NB-3110 apply.

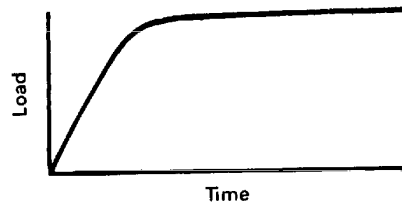
NB-3622 Dynamic Effects

NB-3622.1 Impact.

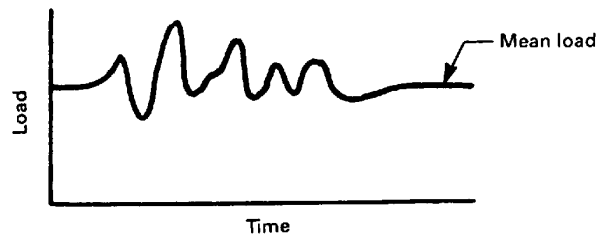
Impact forces caused by either external or internal loads shall be considered in the piping design.

NB-3622.2 Reversing Dynamic Loads.

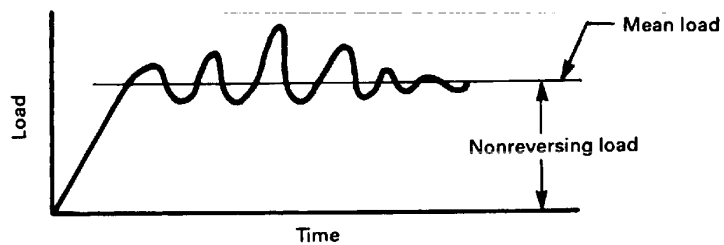
Reversing dynamic loads (Fig. NB-3622-1) are those loads which cycle about a mean value and include building filtered loads, earthquake, and the reflected waves in a piping system due to flow transients resulting from sudden opening or closure of valves. A reversing dynamic load shall be treated as a nonreversing dynamic load in applying the rules of NB-3600 when either of the following conditions exist:



**(a) Nonreversing Dynamic Load
(Relief/Safety Valve Open End Discharge)**



**(b) Reversing Dynamic Load
(Earthquake Load Cycling About Normal Operating Condition)**



**(c) Nonreversing Followed By Reversing
(Initial Water Slug Followed By Reflected Pressure Pulses)**

FIG. NB-3622-1 EXAMPLES OF REVERSING AND NONREVERSING DYNAMIC LOADS

FIG. NB-3622-1 EXAMPLES OF REVERSING AND NONREVERSING DYNAMIC LOADS

(a) The frequency ratio of the dynamic dominant load driving frequency to the lowest piping system natural frequency

is less than 0.5.

(b) The number of reversing dynamic load cycles, exclusive of earthquake, exceeds 20.

NB-3622.3 Vibration.

Piping shall be arranged and supported so that vibration will be minimized. The designer shall be responsible, by design and by observation under startup or initial service conditions, for ensuring that vibration of piping systems is within acceptable levels.

NB-3622.4 Nonreversing Dynamic Loads.

Nonreversing dynamic loads (Fig. NB-3622-1) are those loads which do not cycle about a mean value and include the initial thrust force due to sudden opening or closure of valves and waterhammer resulting from entrapped water in two-phase flow systems.

NB-3623 Weight Effects

Piping systems shall be supported to provide for the effects of live and dead weights, as defined in the following subparagraphs, and they shall be arranged or properly restrained to prevent undue strains on equipment.

NB-3623.1 Live Weight.

The live weight shall consist of the weight of the fluid being handled or of the fluid used for testing or cleaning, whichever is greater.

NB-3623.2 Dead Weight.

The dead weight shall consist of the weight of the piping, insulation, and other loads permanently imposed upon the piping.

NB-3624 Thermal Expansion and Contraction Loads

NB-3624.1 Loadings, Displacements, and Restraints.

The design of piping systems shall take into account the forces and moments resulting from thermal expansion and contraction, equipment displacements and rotations, and the restraining effects of hangers, supports, and other localized loadings.

NB-3624.2 Analysis of Thermal Expansion and Contraction Effects.

The analysis of the effects of thermal expansion and contraction is covered in NB-3672.

NB-3624.3 Provision for Rapid Temperature Fluctuation Effects.

The Designer shall provide for unusual thermal expansion and contraction loads caused by rapid temperature fluctuations.

NB-3625 Stress Analysis

A stress analysis shall be prepared in sufficient detail to show that each of the stress limitations of NB-3640 and NB-3650 is satisfied when the piping is subjected to the loadings required to be considered by this Subarticle.

[98]

NB-3630 PIPING DESIGN AND ANALYSIS CRITERIA

(a) The design and analysis of piping when subjected to the individual or combined effects of the loadings defined in NB-3100 and NB-3620 may be performed in accordance with this Subarticle. Design for pressure loading shall be performed in accordance with the rules of NB-3640. Standard piping products that meet the requirements of ANSI B16.9 or NB-3649

satisfy the requirements of NB-3640, and only the analysis required by NB-3650 need be performed.

(b) Within a given piping system, the stress and fatigue analysis shall be performed in accordance with one of the methods given in NB-3650, NB-3200, or Appendix II. Stress indices are given in NB-3680 for standard piping products, for some fabricated joints, and for some fabricated piping products. Some piping products designed for pressure by applying the rules of NB-3649 may not be listed in NB-3680. For such products, the designer shall determine the stress indices as required in NB-3650.

(c) When a design does not satisfy the requirements of NB-3640 and NB-3650, the more detailed alternative analysis given in NB-3200 or the experimental stress analysis of Appendix II may be used to obtain stress values for comparison with the criteria of NB-3200.

(d) The requirements of this Subarticle shall apply to all Class 1 piping except as exempted under (1) or (2) below.

(1) Piping of 1 in. nominal pipe size or less which has been classified as Class 1 in the Design Specification may be designed in accordance with the design requirements of Subsection NC.

(2) Class 1 piping may be analyzed in accordance with the Class 2 analysis of piping systems in Subsection NC, using the allowable Class 2 stresses and stress limits, provided the specified service loads for which Level A and B Service Limits are designated meet all of the requirements stipulated in (a) through (e) below.

Page 140

(a) *Atmospheric to Service Pressure Cycle.* The specified number of times (including startup and shutdown) that the pressure will be cycled from atmospheric pressure to service pressure and back to atmospheric pressure during normal service does not exceed the number of cycles on the applicable fatigue curve of Figs. I-9.0 corresponding to an S_a value of three times the S_m value for the material at service temperature.

(b) *Normal Service Pressure Fluctuation.* The specified full range of pressure fluctuations during normal service does not exceed the quantity $\frac{1}{3} \times \text{Design Pressure} \times (S_a/S_m)$, where S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant pressure fluctuations and S_m is the allowable stress intensity for the material at service temperature. If the total specified number of significant pressure fluctuations exceeds the maximum number of cycles defined on the applicable design fatigue curve, the S_a value corresponding to the maximum number of cycles defined on the curve may be used. Significant pressure fluctuations are those for which the total excursion exceeds the quantity: $\text{Design Pressure} \times \frac{1}{3} \times (S/S_m)$, where S is defined as follows:

(1) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(2) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(c) *Temperature Difference - Startup and Shutdown.* The temperature difference, °F, between any two adjacent points²¹ of the component during normal service does not exceed $S_a/2E\alpha$, where S_a is the value obtained from the applicable design fatigue curves for the specified number of startup-shutdown cycles, α is the value of the instantaneous coefficient of thermal expansion and E is the modulus of elasticity at the mean value of the temperatures at the two points as given by Section II, Part D, Subpart 2, Tables TE and TM.

²¹Adjacent points are defined as points which are spaced less than the distance $2\sqrt{Rt}$ from each other, where R and t are the mean radius and thickness, respectively, of the vessel, nozzle, flange, or other component in which the points are located.

²⁶Normal service is defined as service, other than startup and shutdown, resulting in specified Service Loadings for which Level A Limits, Level B Limits, or Testing Limits are designated.

(d) *Temperature Difference - Normal Service.*⁹ The temperature difference, °F, between any two adjacent points²¹ does not change²² during normal service by more than the quantity $S_a/2E\alpha$, where S_a is the value obtained from the applicable design fatigue curve of Figs. I-9.0 for the total specified number of significant temperature difference fluctuations. A temperature difference fluctuation shall be considered to be significant if its total algebraic range exceeds the quantity $S/2E\alpha$, where S is defined as follows:

(1) If the total specified number of service cycles is 10⁶ cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10⁶ cycles.

(2) If the total specified number of service cycles exceeds 10⁶ cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(e) *Temperature Difference - Dissimilar Materials.* For components fabricated from materials of differing moduli of elasticity or coefficients of thermal expansion, the total algebraic range of temperature fluctuation, °F, experienced by the component during normal service does not exceed the magnitude $S/2(E_1\alpha_1 - E_2\alpha_2)$, where S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature fluctuations, E_1 and E_2 are the moduli of elasticity, and α_1 and α_2 are the values of the instantaneous coefficients of thermal expansion (Section II, Part D, Subpart 2, Tables TE and TM) at the mean temperature value involved for the two materials of construction. A temperature fluctuation shall be considered to be significant if its total excursion exceeds the quantity $S/2(E_1\alpha_1 - E_2\alpha_2)$, where S is defined as follows.

(1) If the total specified number of service cycles is 10⁶ cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10⁶ cycles.

(2) If the total specified number of service cycles exceeds 10⁶ cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve. If the two materials used have different applicable design fatigue curves, the lower value of S_a shall be used in applying the rules of this paragraph.

[98]

22 The algebraic range of the difference shall be used.

NB-3640 PRESSURE DESIGN

NB-3641 Straight Pipe

[98]

NB-3641.1 Straight Pipe Under Internal Pressure.

The minimum thickness of a pipe wall required for

Page 141

Design Pressure shall be determined from one of the following equations:

$$t_m = \frac{PD_o}{2(S_m + Py)} + A \quad (1)$$

$$t_m = \frac{Pd + 2A(S_m + Py)}{2(S_m + Py - P)} \quad (2)$$

(1 - 2)

(1 - 2)

where

A

= an additional thickness to provide for material removed in threading, corrosion or erosion allowance, and material required for structural strength of the pipe during erection, as appropriate, in.

D_o

= outside diameter of the pipe, in. (For design calculations, the specified outside diameter of pipe disregarding outside tolerances shall be used to obtain the value of t_m .)

d

= inside diameter, in.

P

= internal Design Pressure, psi

S_m

= maximum allowable stress intensity for the material at the Design Temperature taken from Section II, Part D, Subpart 1, Tables 2A and 2B, psi

t_m

= the minimum required wall thickness, in. [Eq. (2) is valid only if $d = D_o - 2t_m$. If pipe is ordered by its nominal wall thickness, the manufacturer's tolerance on wall thickness must be taken into account.]

y

= 0.4

The allowable working pressure of pipe may be determined from the following equation:

$$P_a = \frac{2S_m t}{D_o - 2yt} \quad (3)$$

(3)

where

P_a

= the calculated maximum allowable internal pressure for a straight pipe which shall at least equal the Design Pressure, psi. It may be used for piping products with pressure ratings equal to that of straight pipe (see ANSI B16.9). For standard flanged joints, the rated pressure shall be used instead of P_a . For other piping products where the pressure rating may be less than that of the pipe [for example, flanged joints designed to Appendix XI and reinforced branch connections (NB-3643), where part of the required reinforcement is in the run pipe], the Design Pressure of those products shall be used instead of P_a .

P_a may be rounded out to the next higher unit of 10.

t

= the specified or actual wall thickness minus, as appropriate, material removed in threading, corrosion or erosion allowance, material manufacturing tolerances, bending allowance (NB-3642.1), or material to be removed by counterboring, in.

[98]

**TABLE NB-3642.1(b)-1
BEND RADIUS VERSUS THICKNESS**

Radius of Bends	Minimum Thickness Recommended Prior to Bending [Note (1)]
6 pipe diameters or greater	$1.06t_m$
5 pipe diameters	$1.08t_m$
4 pipe diameters	$1.16t_m$
3 pipe diameters	$1.25t_m$

NOTE:

(1) t_m is determined by Eq. (1) or (2) of NB-3641.1.

TABLE NB-3642.1(b)-1 BEND RADIUS VERSUS THICKNESS

NB-3641.2 Straight Pipe Under External Pressure.

The rules of NB-3133 shall be used.

NB-3642 Curved Segments of Pipe

NB-3642.1 Pipe Bends.

The wall thickness for pipe bends shall be determined in the same manner as determined for straight pipe in accordance with NB-3641, subject to the limitations given in (a), (b), and (c) below.

- (a) The wall thickness after bending shall not be less than the minimum wall thickness required for straight pipe.
- (b) The information in Table NB-3642.1(b)-1 is given to guide the designer when ordering pipe.
- (c) For the effects of ovality on stress levels, see NB-3680.

NB-3642.2 Elbows.

Elbows, manufactured in accordance with the standards listed in Table NB-3132-1 as limited by NB-3612.1, shall be considered as meeting the requirements of NB-3640, except that the minimum thickness in the crotch region of short radius welding elbows in accordance with ANSI B16.28 shall be 20% greater than the minimum thickness required for the straight pipe by Eq. (1) (NB-3641.1). The crotch region is defined as that portion of the elbow between $\phi = 210$ deg. and 330 deg., where ϕ is defined in Fig. NB-3685.2-1.

Page 142

NB-3643 Intersections

NB-3643.1 General Requirements

- (a) The rules contained in this paragraph meet the requirements of NB-3640 in the vicinity of branch connections.
- (b) Openings shall be circular, elliptical, or of any other shape that results from the intersection of a circular or elliptical cylinder with a cylindrical shape. Additional restrictions affecting stress indices are given in NB-3680.
- (c) Openings are not limited in size except to the extent provided for in connection with the stress indices listed in NB-3680.
- (d) All references to dimensions apply to the finished dimensions, excluding material added for corrosion allowance.
- (e) Any type of opening permitted in these rules may be located in a welded joint.
- (f) Where intersecting pipes are joined by welding a branch to a run pipe as shown in Fig. NB-3643.3(a)-2, the angle α between axes of the intersecting pipes shall not be less than 60 deg. or more than 120 deg. For angles outside this range, use fittings as specified in NB-3643.2(a) or (b).

NB-3643.2 Branch Connections.

Branch connections in piping may be made by using one of the products or methods set forth in (a) through (c) below.

- (a) Flanged, butt welding, or socket welding fittings meeting the applicable ANSI standards listed in Table NB-3132-1, subject to the limitations or requirements of this Subsection, are acceptable. Fittings that comply with the test requirements of ANSI B16.9 or of NB-3649 are not required to meet requirements for reinforcement given in NB-3643.3.
- (b) Welded outlet fittings, cast or forged branches, pipe adapters, couplings, or similar products with butt welding, socket welding, or flanged ends are acceptable for attachment to the run pipe when limited to types that have integral reinforcement and are attached to the main run by welding [Figs. NB-4244(a)-1 and NB-4244(b)-1].
- (c) An extruded outlet at right angles to the run pipe is acceptable.

NB-3643.3 Reinforcement for Openings

(a) Nomenclature

(1) The following terms are as shown in Fig. NB-3643.3(a)-1.

d_o	= outside diameter of the branch pipe, in.
R_m	= mean radius of the run pipe, in.
r_i	= inside radius of branch pipe, in.
r_m	= mean radius of the branch pipe, in.
	= $r_i + 0.5T_b$
r'_m	= mean radius of the branch pipe, in.

	$= r_i + 0.5T_b$
r_n	= nominal radius [sketch (c) only], in.
	$= r_i + 0.5T_b + 0.5y \cos \theta$
r_2	= transition radius between branch or extruded lip and run pipe, in.
T_b	= nominal thickness of the reinforced branch, not including corrosion allowance or mill tolerance, in.
T_b	= nominal thickness of the branch pipe, not including corrosion allowance or mill tolerance, in.
T_o	= corroded finished thickness or extruded outlet measured at a height of r_2 above the outside surface of the run pipe, in.
T_r	= nominal thickness of the run pipe, not including corrosion allowance or mill tolerance, in.
y	= slope offset distance, in.
θ	= angle between vertical and slope, deg.

(2) The following terms are as shown on Fig. NB-3643.3(a)-2.

A_1	= metal area available for reinforcement, sq in.
A_2	= metal area available for reinforcement, sq in.
A_3	= metal area available for reinforcement, sq in.
d	= diameter in the given plane of the finished opening in its corroded condition, in.
L_A	= half-width of reinforcement zone measured along the midsurface of the run pipe, in.
L'_A	= half-width of zone in which two-thirds of compensation must be placed, in.
L_N	= limit of reinforcement measured normal to run pipe wall, in.
r	= radius of the finished opening in the corroded condition, in.
T_r	= nominal thickness of the run pipe, not including corrosion allowance or mill tolerance, in.
t_b	= minimum required thickness of the branch pipe, not including corrosion allowance, according to NB-3641.1, in.
	$= t_m - A$
t_r	= minimum required thickness of the run pipe, not including corrosion allowance, according to NB-3641.1, in.
	$= t_m - A$
α	= angle between axes of branch and run (90 deg. $\geq \alpha \geq$ 60 deg.), deg.

(3) The following terms are as shown in Fig. NB-3643.3(a)-3.

D

D_o

= outside diameter of the run pipe, in.

T_o

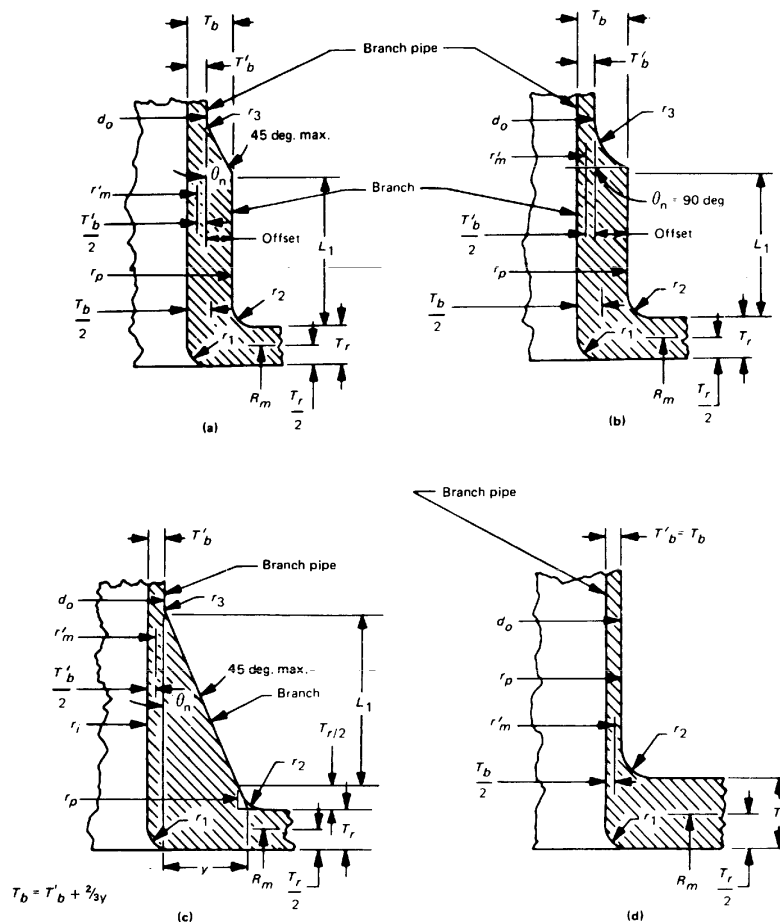
= finished thickness of the extruded outlet in the corroded condition measured at a height equal to r_2 above the outside surface of the main run, in.

T_r

= minimum thickness of the run pipe after extrusion of the opening, not including corrosion allowance or mill tolerance, in. Allowance shall be made for thinning of the run pipe wall by the extrusion of the opening, if it occurs.

h

= height of the extruded lip, equal to or greater than r_2 , in.



GENERAL NOTE:

If L_1 equals or exceeds $0.5 \sqrt{r_i T_b}$, then r'_m can be taken as the radius to the center of T_b .

FIG. NB-3643.3(a)-1 BRANCH CONNECTION NOMENCLATURE

FIG. NB-3643.3(a)-1 BRANCH CONNECTION NOMENCLATURE

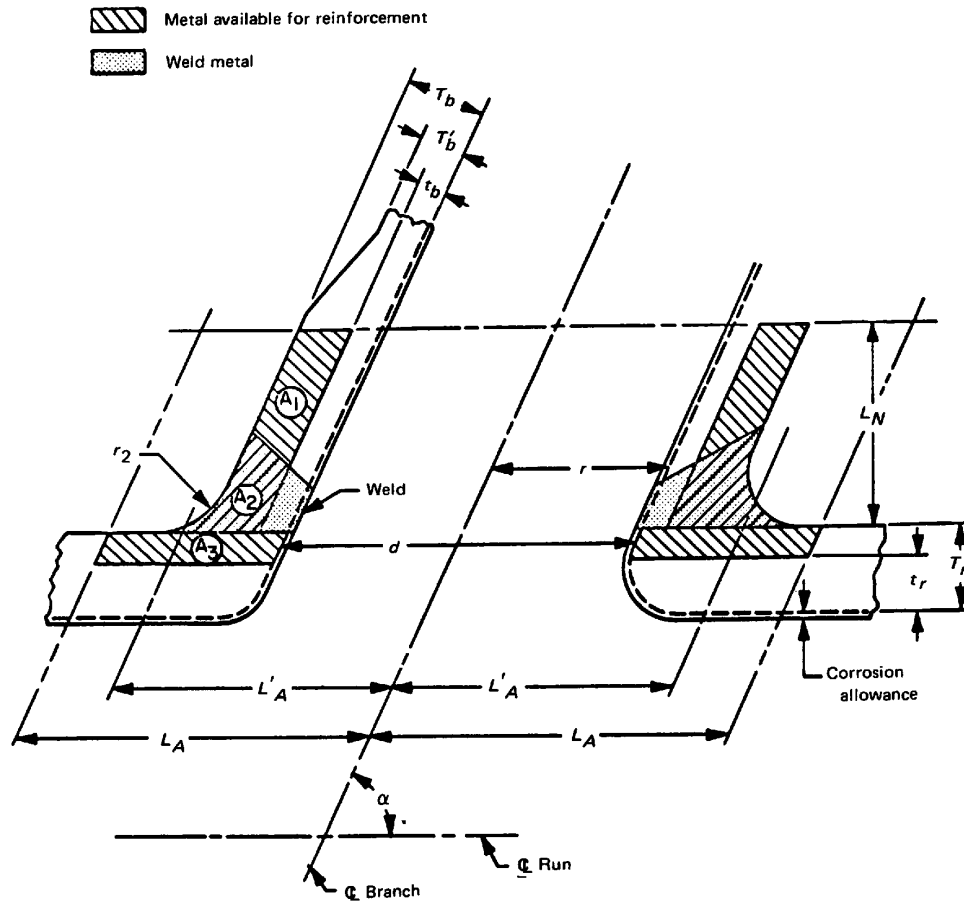


FIG. NB-3643.3(a)-2 TYPICAL REINFORCEMENT OF OPENINGS

FIG. NB-3643.3(a)-2 TYPICAL REINFORCEMENT OF OPENINGS

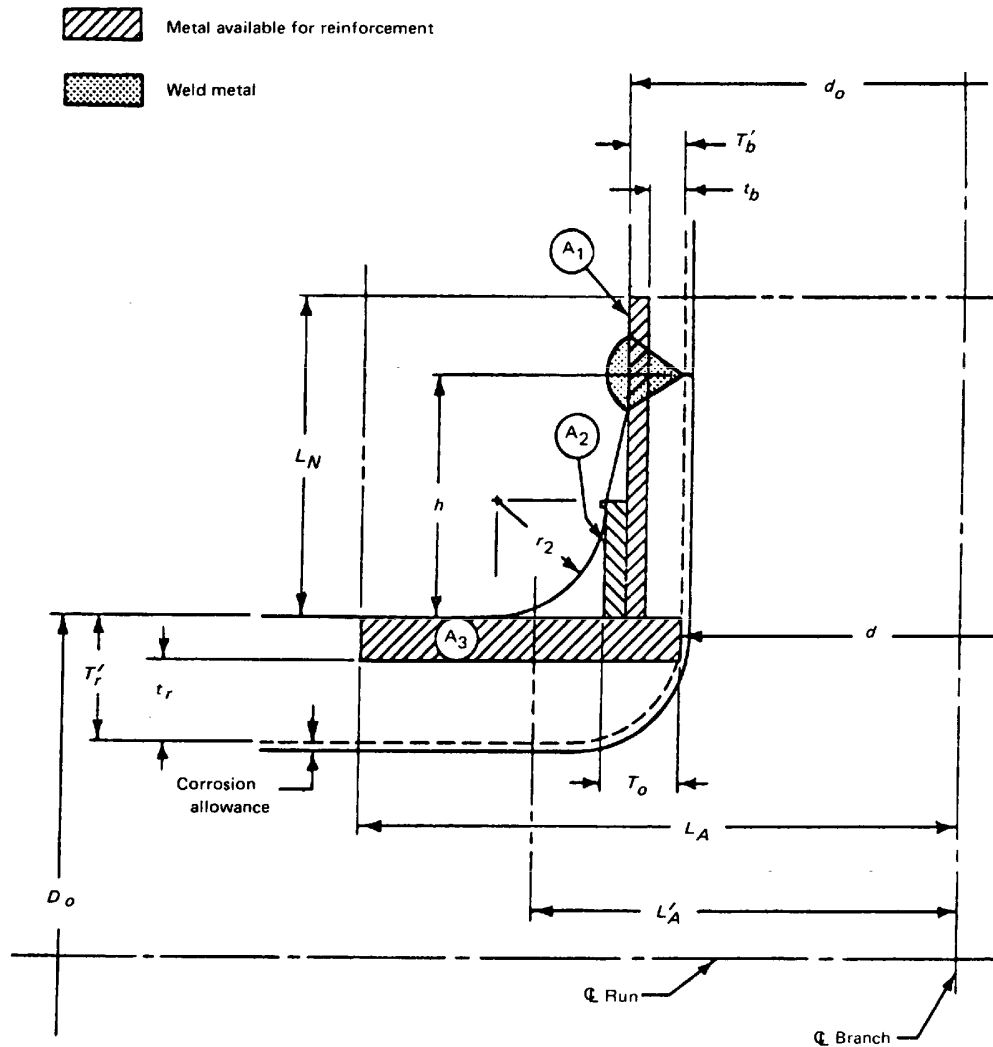
(b) Requirements

(1) Reinforcement shall be provided in amount and distribution so that the requirements for the area of reinforcement are satisfied for all planes through the center of the opening and normal to the surface of the run pipe, except that openings need not be provided with reinforcement if all of the requirements of (a), (b), and (c) below are met.

(a) A single opening has a diameter not exceeding $0.2\sqrt{R_m - T_r}$ or, if there are two or more openings within any circle of diameter, $2.5\sqrt{R_m - T_r}$ but the sum of the diameters of such unreinforced openings shall not exceed $0.25\sqrt{R_m - T_r}$.

(b) No two unreinforced openings shall have their centers closer to each other, measured on the inside wall of the run pipe, than the sum of their diameters.

(c) No unreinforced opening shall have its center closer than $2.5\sqrt{R_m - T_r}$ to the edge of any other locally stressed area.



GENERAL NOTE:
The areas A_1 , A_2 , and A_3 , shown are only one-half of those defined in NB-3643.3(f)(3).

FIG. NB-3643.3(a)-3 TYPICAL REINFORCED EXTRUDED OUTLET

FIG. NB-3643.3(a)-3 TYPICAL REINFORCED EXTRUDED OUTLET

(2) The total cross-sectional area of reinforcement A required in any given plane for a pipe under internal pressure shall not be less than:

$$A = dt_r(2 - \sin \alpha)$$

(3) The required reinforcing material shall be uniformly distributed around the periphery of the branch except that, in the case of branches not at right angles, the designer may elect to provide additional reinforcement in the area of the crotch.

(c) *Limits of Reinforcement.* The boundaries of the cross-sectional area in any plane passing through the axis of the opening within which metal may be located to have value as reinforcement are designated as the limits of reinforcement for that plane, and they are given in (1) and (2) below.

(1) The limits of reinforcement, measured along the midsurface of the nominal wall thickness of the run pipe, L_A , shall be at a distance on each side of the axis of the opening that is equal to the greater of (a) or (b) below:

(a) the diameter of the finished opening in the corroded condition; or

(b) the radius of the finished opening in the corroded condition r , plus the nominal thickness of the run pipe T_r , plus the nominal thickness of the branch wall T_b

(c) In addition, two-thirds of the required reinforcement shall be provided within the greater of the limit given in (b) above and the limit L'_A which is the greater of either

$$r + 0.5 \sqrt{R_m - T_r}$$

or

$$r + T_b/\sin \alpha + T_r$$

(2) The limits of reinforcement measured normal to the wall of the run pipe L_N shall conform to the contour of the surface of the branch at a distance from each surface equal to the limits given in (a) and (b) below and as shown in Fig. NB-3643.3(a)-1.

(a) For nozzle types of Fig. NB-3643.3(a)-1 sketches (a), (b), and (d):

$$L_N = 0.5 \sqrt{r_m - T_b} + 0.5r_2$$

(b) For Fig. NB-3643.3(a)-1 sketch (c):

$$L_N = 0.5 \sqrt{r_n - T_b}$$

(d) *Metal Available for Reinforcement*

(1) Metal may be counted as contributing to the area of reinforcement called for in NB-3643.3(b) if it lies within the area of reinforcement specified in NB-3643.3 (c), and it shall be limited to material that meets the requirements of (a), (b), and (c) below:

(a) metal forming a part of the run wall that is in excess of that required on the basis of NB-3641.1 and is exclusive of corrosion allowance shown in Fig. NB-3643.3(a)-2;

(b) similar excess metal in the branch wall, if the branch is integral with the run wall or is joined to it by a full penetration weld, as denoted by A_1 in Fig. NB-3643.3(a)-2;

(c) weld metal that is fully continuous with the wall of the run pipe, as denoted by area A_2 in Fig. NB-3643.3(a)-2.

(2) The mean coefficient of thermal expansion of the metal to be included as reinforcement under (1)(b) and (1)(c) above shall be within 15% of the value for the metal in the wall of the run pipe.

(3) Metal available for reinforcement shall not be considered as applying to more than one opening.

(4) Metal not fully continuous with the run pipe, as that in branches attached by partial penetration welds, shall not be counted as reinforcement.

(e) *Strength of Metal.* Material used for reinforcement shall preferably be the same as that of the wall of the run pipe. If material with a lower design stress intensity S_m is used, the area provided by such material shall not be counted at full value but shall be multiplied by the ratio (less than unity) of the design stress intensity values S of the reinforcement

material and of the run pipe material before being counted as reinforcement. No reduction in the ^mreinforcement requirement may be taken for the increased strength of either the branch material or weld metal having a higher design stress intensity value than that of the material of the run pipe wall. The strength of the material at the point under consideration shall be used in the fatigue analysis.

(f) *Requirements for Extruded Outlets.* Extruded outlets shall meet all of the requirements of NB-3643.3(a) and NB-3643.3(b), and these rules apply only where the axis of the outlet intersects and is perpendicular to the axis of the run pipe.

(1) *Geometric Requirements*

(a) An extruded outlet is one in which the extruded lip at the outlet has a height h above the surface of the run pipe that is equal to or greater than

Page 147

the transition radius between the extruded lip and the run pipe r_2 .

(b) The minimum value of the transition radius r_2 shall not be less than $0.05d_o$, except that on branch pipe sizes larger than 30 in. (750 mm) the transition radius need not exceed 1.5 in. (38 mm). The maximum value of the transition radius r_2 shall be limited as follows: for branch pipes nominally 8 in. (DN 200) and larger, the dimension of the transition radius shall not exceed $0.10d_o + 0.50$ in. (13 mm); for branch pipe sizes nominally less than 8 in. (DN 200), r_2 shall not be greater than 1.25 in. (31 mm).

(c) When the external contour contains more than one radius, the radius of any arc sector of approximately 45 deg. shall meet the requirements given in (b) above.

(d) Machining shall not be employed to meet the requirements of (b) and (c) above.

(2) *Limits of Reinforcement*

(a) The height of the reinforcement zone shall be limited as shown in Fig. NB-3643.3(a)-3:

$$L_N = 0.5 \sqrt{d_o T_o}$$

(b) The half width of the reinforcement zone shall be limited as shown in Fig. NB-3643.3(a)-3:

$$L_A = d$$

(3) *Metal Available for Reinforcement.* The reinforcement area shall be the sum of areas $A_1 + A_2 + A_3$ defined in (a), (b), and (c) below and shown in Fig. NB-3643.3(a)-3. Metal counted as reinforcement shall not be applied to more than one opening.

(a) Area A_1 is the area lying within the reinforcement zone that results from any excess thickness available in the wall of the branch pipe:

$$A_1 = 2L_N(T_b - t_b)$$

(b) Area A_2 is the area lying within the reinforcement zone that results from excess thickness available in the lip of the extruded outlet:

$$A_2 = 2r_2(T_o - T_b)$$

(c) Area A_3 is the area lying within the reinforcement zone that results from any excess thickness in the run pipe wall:

$$A_3 = d(T_r - t_r)$$

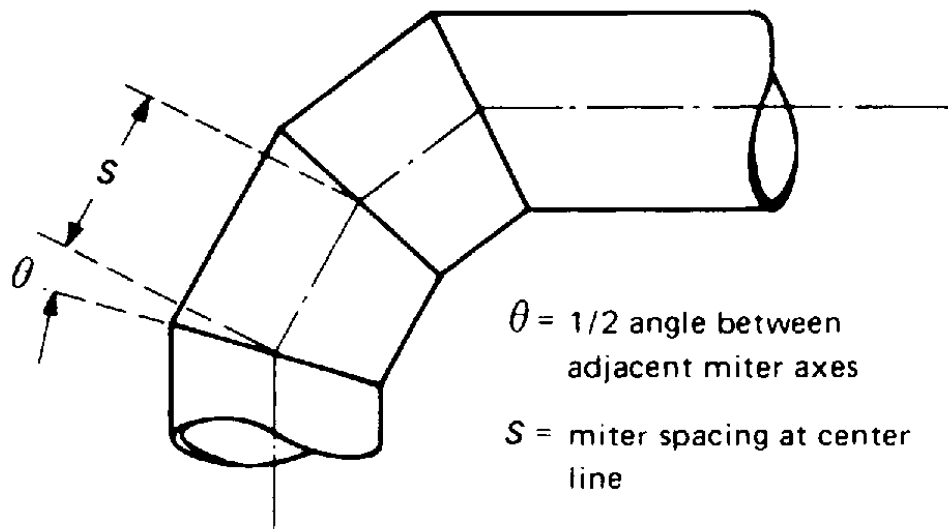


FIG. NB-3644(b)-1 MITER JOINT GEOMETRY

FIG. NB-3644(b)-1 MITER JOINT GEOMETRY

NB-3644 Miters

Mitered joints may be used in piping systems under the conditions stipulated in (a) through (d) below.

(a) The minimum thickness of a segment of a miter shall be determined in accordance with NB-3641. The minimum thickness thus determined does not allow for the discontinuity stresses that exist at the junction between segments. The discontinuity stresses are reduced for a given miter as the number of segments is increased.

(b) The angle θ in Fig. NB-3644(b)-1 shall not be more than $22\frac{1}{2}$ deg.

(c) The center line distance S between adjacent miters shall be in accordance with Fig. NB-3644(b)-1.

(d) Stress indices and flexibility factors shall be determined in accordance with the requirements of NB-3681(d).

NB-3646 Closures

(a) Closures in piping systems may be made by use of closure fittings, such as blind flanges or threaded or welded plugs or caps, either manufactured in accordance with standards listed in Table NB-3132-1 and used within the specified pressure-temperature ratings, or made in accordance with (b) below.

(b) Closures not manufactured in accordance with the standards listed in Table NB-3132-1 may be made in accordance with the rules for Class 2 vessels using the equation:

$$t_m = t + A$$

where

where

t	= pressure design thickness, in., calculated for the given closure shape and direction of
-----	---

Page 148

loading using appropriate equations and procedures for Class 2 Vessels, except that the symbols used to determine t shall be defined as:

A	= sum of mechanical allowances (NB-3613), in.
-----	---

P	= Design Pressure, psi
-----	------------------------

S	= applicable design stress intensity value S_m from Section II, Part D, Subpart 1, Tables 2A and 2B, psi
-----	--

t_m	= minimum required thickness, in.
-------	-----------------------------------

(c) Connections to closures may be made by welding or extruding. Connections to the closure shall be in accordance with the limitations provided for such connections in NB-3643 and Figs. NB-4243-1, NB-4244(a)-1, NB-4244(b)-1, and NB-4244(c)-1 for branch connections. If the size of the opening is greater than one-half the inside diameter of the closure, the opening should be considered as a reducer in accordance with NB-3648.

(d) Openings in closures may be reinforced in accordance with the requirements of NB-3643.

(e) Flat heads that have an opening with a diameter that does not exceed one-half of the head diameter shall have a total cross-sectional area of reinforcement not less than $dt/2$, where

d	= the diameter of the finished opening, in.
-----	---

t	= the design thickness for the closure, in.
-----	---

NB-3647 Pressure Design of Flanged Joints and Blanks

NB-3647.1 Flanged Joints

(a) Flanged joints manufactured in accordance with the standards listed in Table NB-3132-1, as limited by NB-3612.1, shall be considered as meeting the requirements of NB-3640.

(b) Flanged joints not included in Table NB-3132-1 shall be designed in accordance with XI-3000, including the use of the appropriate allowable stress given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

NB-3647.2 Permanent Blanks.

The minimum required thickness of permanent blanks (Fig. NB-3647.2-1) shall be calculated from the following equations:

$$t_m = t + A \quad (7)$$

(7)

where

A

= sum of the mechanical allowances, in. (NB-3613)

t

= pressure design thickness, in., calculated from Eq. (8)

t_m

= minimum required thickness, in.

$$t = d_6 \left(\frac{3P}{16S_m} \right)^{1/2} \quad (8)$$

(8)

where

d_6

= inside diameter of the gasket for raised or flat face flanges or the pitch diameter of the gasket for retained gasketed flanges, in.

P

= Design Pressure, psi

S_m

= the design stress intensity value in accordance with Section II, Part D, Subpart 1, Tables 2A and 2B, psi

[98]

NB-3647.3 Temporary Blanks.

Blanks to be used for test purposes only shall have a minimum thickness not less than the Design Pressure thickness t , calculated from Eq. (8) above, except that P shall not be less than the test pressure and the design stress intensity value S_m may be taken as 95% of the specified minimum yield strength of the blank material (Section II, Part D, Subpart 1, Table Y-1).

[98]

NB-3648 Reducers

Reducer fittings manufactured in accordance with the standards listed in Table NB-3132-1 shall be considered suitable for use. Where butt welding reducers are made to a nominal pipe thickness, the reducers shall be considered suitable for use with pipe of the same nominal thickness.

NB-3649 Pressure Design of Other Piping Products

Other piping products manufactured in accordance with the standards listed in Table NB-3132-1 shall be considered suitable for use provided the design is consistent with the design philosophy of this Subsection. Piping products not included in Table NB-3132-1 may be used if they satisfy the requirements of NB-3200. The pressure design shall be based on an analysis consistent with this Subsection, or experimental stress analysis as described in Appendix II, or an ANSI B16.9 type burst test. The bursting pressure in a B16.9 type burst test shall be equal to or greater than that of the weakest pipe to be attached to the piping product, where the burst pressure of the weakest pipe is calculated by the equation:

$$P = 2St/D_o$$

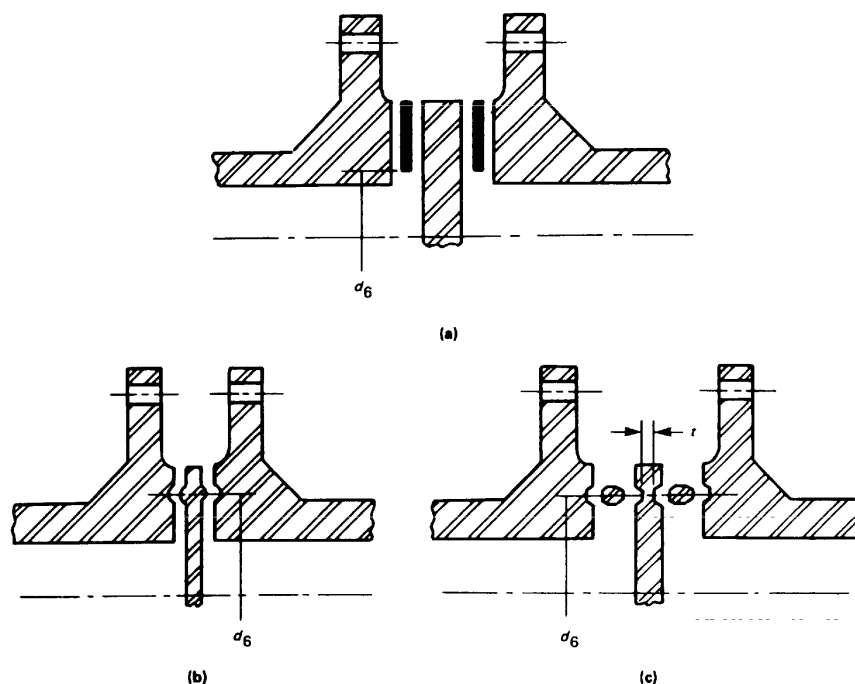


FIG. NB-3647.2-1 TYPES OF PERMANENT BLANKS

FIG. NB-3647.2-1 TYPES OF PERMANENT BLANKS

where

D_o	= outside diameter of pipe, in.
S	= specified minimum tensile strength of pipe material, psi
t	= minimum specified wall thickness of pipe, in.

NB-3649.1 Expansion Joints.

Rules are currently under development for the application of expansion joints in piping systems. Until these rules are available, expansion joints shall not be used in piping.

NB-3650 ANALYSIS OF PIPING PRODUCTS

NB-3651 General Requirements

NB-3651.1 Piping Products for Which Stress Indices Are Given.

Piping products, for which values of stress indices B , C , and K are given in NB-3683.2 and which meet the requirements of NB-3640, satisfy the design criteria of NB-3611 provided they comply with these rules. To validate a design in accordance with these rules, it is necessary to perform several flexibility analyses in accordance with the requirements of NB-3672 and to use the moments and forces obtained from these analyses as required in NB-3650.

NB-3651.2 Piping Products for Which Stress Indices Are Not Available.

For analysis of flanged joints, see NB-3658. For other piping products for which stress indices are not available, see NB-3680.

NB-3651.3 Attachments

(a) Lugs, brackets, stiffeners, and other attachments may be welded, bolted, and studded to, or bear upon the outside or inside of piping. The interaction effects of attachments on the pressure boundary, producing thermal gradients, localized bending stresses, stress concentrations, or restraint of the pressure boundary

Page 150

shall be considered by the piping designer. Standard clamps generally have a negligible effect on the pressure boundary. However, the effects of clamps on thin-wall piping may need to be evaluated.

(b) Attachments shall meet the requirements of NB-3135.

(c) Figure NB-4433-1 shows some typical types of attachment welds (NB-4430).

NB-3652 Consideration of Design Conditions

The primary stress intensity limit is satisfied if the requirement of Eq. (9) is met:

$$B_1 \frac{PD_o}{2t} + B_2 \frac{D_o}{2I} M_i \leq 1.5 S_m \quad (9)^{23}$$

(9)²³

where

B_1, B_2

= primary stress indices for the specific product under investigation (NB-3680)

D_o

= outside diameter of pipe, in. (NB-3683)

I

= moment of inertia, in.⁴ (NB-3683)

M_i

= resultant moment due to a combination of Design Mechanical Loads, in.-lb. All Design Mechanical Loads, and combinations thereof shall be provided in the Design Specification. In the combination of loads, all directional moment components in the same direction shall be combined before determining the resultant moment (i.e., resultant moments from different load sets shall not be used in calculating the moment M_i). If the method of analysis for earthquake or other dynamic loads is such that only magnitudes without relative algebraic signs are obtained, the most conservative combination shall be assumed.

P

= Design Pressure, psi

S_m

= allowable design stress intensity value, psi (Section II, Part D, Subpart 1, Tables 2A and 2B)

t

= nominal wall thickness of product, in. (NB-3683)

²³ For piping products, such as tees and branch connections, the second term of Eqs. (9), (10), and (11), namely that containing M_i is to be calculated as referred to in NB-3683.1(d).

NB-3653 Consideration of Level A Service Limits

All load sets, for which Level A Service Limits are to be evaluated, shall satisfy the fatigue requirements of NB-3653.1 through NB-3653.6 and the thermal stress ratchet requirement of NB-3653.7.

NB-3653.1 Satisfaction of Primary Plus Secondary Stress Intensity Range

(a) This calculation is based upon the effect of changes which occur in mechanical or thermal loadings which take place as the system goes from one load set, such as pressure, temperature, moment, and force loading, to any other load set which follows it in time. It is the range of pressure, temperature, and moment between two load sets which is to be used in the calculations. For example, one of the load sets to be included is that corresponding to zero pressure, zero moment, and room temperature. Equation (10) shall be satisfied for all pairs of load sets:

$$S_n = C_1 \frac{P_o D_o}{2t} + C_2 \frac{D_o}{2I} M_i + C_3 E_{ab}$$

$$\times | \alpha_a T_a - \alpha_b T_b | \leq 3S_m \quad (10)$$

(10)

(b) If for one or more pairs of load sets Eq. (10) is not met, the piping product may still be satisfactory, provided that the conditions of NB-3653.6 are met or provided that the requirements of NB-3200 are satisfied.

(c) The nomenclature used in Eq. (10) is defined as follows:

C_1, C_2, C_3	= secondary stress indices for the specific component under investigation (NB-3680)
D_o, t, I, S_m	= as defined for Eq. (9)
$d_a(d_b)$	= inside diameter on side $a(b)$ of a gross structural discontinuity or material discontinuity, in.
E_{ab}	= average modulus of elasticity of the two sides of a gross structural discontinuity or material discontinuity at room temperature, psi (Section II, Part D, Subpart 2, Tables TM)
M_i	= resultant range of moment which occurs when the system goes from one service load set to another, in.-lb. Service loads and combinations thereof shall be provided in the Design Specification. In the combination of moments from load sets, all directional moment components in the same direction shall be combined before determining the resultant moment (i.e., resultant moments from different load sets shall not be used in calculating the moment range M_i). Weight effects need not be considered in determining the

Page 151

loading range since they are noncyclic in character. If the method of analysis is such that only magnitudes without relative algebraic signs are obtained, the most conservative combination shall be assumed. If a combination includes reversing dynamic loads, M_i shall be either: (1) the resultant range of moment due to the combination of all loads considering one-half the range of the reversing dynamic loads; or (2) the resultant range of moment due to the full range of the reversing dynamic loads alone, which ever is greater.

P_o = range of service pressure, psi

$T(T)$ = range of average temperature on side $a(b)$ of gross structural

$t_a(t_b)$

$\alpha_a(\alpha_b)$

discontinuity or material discontinuity, °F. For generally cylindrical shapes, the averaging of T (NB-3653.2) shall be over a distance of $\sqrt{d_a t_a}$ for T_a and over a distance of $\sqrt{d_b t_b}$ for T_b .

= average wall thickness through the length $\sqrt{d_a t_a}$ ($\sqrt{d_b t_b}$), in. A trial and error solution for t_a and t_b may be necessary.

= coefficient of thermal expansion on side $a(b)$ of a gross structural discontinuity or material discontinuity, at room temperature, 1/°F (Section II, Part D, Subpart 2, Tables TE)

NB-3653.2 Satisfaction of Peak Stress Intensity Range

(a) For every pair of load sets (NB-3653), calculate S_p values using Eq. (11):

$$S_p = K_1 C_1 \frac{P_o D_o}{2t} + K_2 C_2 \frac{D_o}{2I} M_i + \frac{1}{2(1 - \nu)} K_3 E \alpha |\Delta T_1| + K_3 C_3 E_{ab} \times |\alpha_a T_a - \alpha_b T_b| + \frac{1}{1 - \nu} E \alpha |\Delta T_2| \quad (11)$$

(11)

NOTE: This simplified analysis is intended to provide a value of S_p that conservatively estimates the sum of $P_L + P_b + P_e + Q + F$ as required in Fig. NB-3222-1.

The nomenclature used in Eq. (11) is defined as follows:

$E\alpha$

= modulus of elasticity (E) times the mean coefficient of thermal expansion (α) both at room temperature, psi/°F

K_1, K_2, K_3

= local stress indices for the specific component under investigation (NB-3680)

$|\Delta T_2|$

= absolute value of the range for that portion of the nonlinear thermal gradient through the wall thickness not included in ΔT_1 as shown below, °F

$|\Delta T_1|$

= absolute value of the range of the temperature difference

between the temperature of the outside surface T_o and the temperature of the inside surface T_i of the piping product assuming moment generating equivalent linear temperature distribution, °F

For a quantitative definition of $|\Delta T_1|$ and $|\Delta T_2|$, see NB-3653.2(b) below. All other terms are as defined for Eq. (10).

(b) *Quantitative Definitions of $|\Delta T_1|$ and $|\Delta T_2|$.*

The following nomenclature is used:

T_i	= value of $T(y)$ at inside surface, °F = $T(-t/2)$
T_o	= value of $T(y)$ at outside surface, °F = $T(t/2)$
$T_j(y), T_k(y)$	= temperature, as a function of radial position, for load set j and load set k , respectively, °F
$T(y)$	= temperature distribution range from condition j to condition k , °F = $T_k(y) - T_j(y)$
t	= thickness of the wall of the pipe or element, in.
y	= radial position in the wall, measured positive outward from the midthickness position ($-t/2 \leq y \leq t/2$), in.

Then the temperature distribution range $T(y)$ may be thought of as being composed of three parts:

(1) a constant value:

$$T = (1/t) \int_{-t/2}^{t/2} T(y) dy$$

which is the average value through the thickness. T may be used in determining free thermal expansions. Also, the values of T determined (for the same pair of load sets) or two locations a and b on either side of a gross discontinuity may be used for T_a and T_b in Eqs. (10) and (11).

(2) a linear portion, with zero average value, having variation given by:

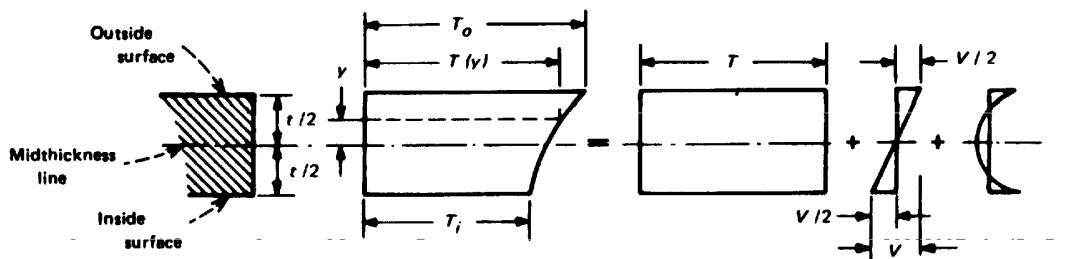


FIG. NB-3653.2(b)-1 DECOMPOSITION OF TEMPERATURE DISTRIBUTION RANGE

FIG. NB-3653.2(b)-1 DECOMPOSITION OF TEMPERATURE DISTRIBUTION RANGE

$$V = (12/t^2) \int_{-t/2}^{t/2} yT(y)dy$$

(3) a nonlinear portion with a zero average value and a zero first moment with respect to the mid-thickness. This decomposition of $T(y)$ into three parts is illustrated in Fig. NB-3653.2(b)-1. The value of ΔT_1 to be used in Eq. (11) is the variation V of the linear portion:

$$\Delta T_1 = V$$

The value of ΔT_2 to be used in Eq. (11) is as follows:

$$\Delta T_2 = \max. (|T_o - T_i - \frac{1}{2}V|, |T_i - T_o - \frac{1}{2}V|, 0)$$

NB-3653.3 Alternating Stress Intensity.

The alternating stress intensity S_{alt} is equal to one-half the value of S_p ($S_{alt} = S_p/2$) calculated in Eq. (11) above.

NB-3653.4 Use of Design Fatigue Curve.

Enter the applicable design fatigue curve, Figs. I-9.0, on the ordinate using $S_a = S_{alt}$ and find the corresponding number of cycles on the abscissa. If the service cycle being considered is the only one that produces significant fluctuating stresses, this is the allowable number of cycles.

NB-3653.5 Cumulative Damage.

The cumulative damage shall be evaluated in accordance with NB-3222.4(e)(5). If N_i is greater than the maximum number of cycles defined on the applicable design fatigue curve, the value of n_i/N_i may be taken as zero.

NB-3653.6 Simplified Elastic-Plastic Discontinuity Analysis.

If Eq. (10) cannot be satisfied for all pairs of load sets, the alternative analysis described below may still permit qualifying the component under NB-3650. Only those pairs of load sets which do not satisfy Eq. (10) need be considered.

(a) Equation (12) shall be met:

$$S_e = C_2 \frac{D_o}{2I} M_i^* \leq 3S_m \quad (12)$$

(12)

where

M_i^*

= same as M_i in Eq. (10), except that it includes only moments due to thermal expansion and thermal anchor movements, in.-lb

S_e

= nominal value of expansion stress, psi

(b) The primary plus secondary membrane plus bending stress intensity, excluding thermal bending and thermal expansion stresses, shall be $< 3S_m$. This requirement is satisfied by meeting Eq. (13) below:

$$C_1 \frac{P_o D_o}{2t} + C_2 \frac{D_o M_i}{2I} + C'_3 E_{ab} \times |\alpha_a T_a - \alpha_b T_b| \leq 3S_m \quad (13)$$

(13)

where

C_3

= values in Table NB-3681(a)-1

M_i

= as defined in NB-3652 and all other variables are as defined in NB-3653

(c) If these conditions are met, the value of S_{alt} shall be calculated by Eq. (14):

$$S_{alt} = K_e \frac{S_p}{2} \quad (14)$$

(14)

where

K_e

= 1.0 for $S_n \leq 3S_m$

= $1.0 + [(1 - n)/n(m - 1)](S_n/3S_m - 1)$, for $3S_m < S_n < 3mS_m$

= $1/n$, for $S_n \geq 3mS_m$

Page 153

m, n

= material parameters given in Table NB-3228.5(b)-1

S_{alt}

= alternating stress intensity, psi

S_n

= primary plus secondary stress intensity value calculated in Eq. (10), NB-3653.1, psi

S_p

= peak stress intensity value calculated by Eq. (11), (NB-3653.2), psi

S_{alt} for all load sets shall be calculated in accordance with NB-3653.3 or Eq. (14). Using the alternating stress intensity values calculated by the above procedures, determine the cumulative usage factor in accordance with NB-3653.4 and NB-3653.5. The cumulative usage factor shall not exceed 1.0.

NB-3653.7 Thermal Stress Ratchet.

For all pairs of load sets, the value of the range of ΔT_1 cannot exceed that calculated as follows:

$$\Delta T_1 \text{ range} \leq \frac{y' S_y}{0.7 E \alpha} C_4$$

where

C_4

= 1.1 for ferritic material

= 1.3 for austenitic material

$E\alpha$

= as defined for Eq. (11), psi/°F

P

= maximum pressure for the set of conditions under consideration, psi

S_y

= yield strength value, psi, taken at average fluid temperature of the transient under consideration

x

= $(PD_o/2t) (1/S_y)$

y'

= 3.33, 2.00, 1.20, and 0.80 for $x = 0.3, 0.5, 0.7$, and 0.8 , respectively

NB-3654 Consideration of Level B Service Limits

The procedures for analyzing Service Loadings for which Level B Service Limits are designated, are the same as those given in NB-3653 for Level A Service Limits. All load sets, including Level A and Level B Service Loadings, shall satisfy the fatigue requirements of NB-3653.1 through NB-3653.6 and the thermal stress ratchet requirement of NB-3653.7.

NB-3654.1 Permissible Pressure.

For Level B Service Limits [NCA-2142.4(b)(2)], the permissible pressure shall not exceed the pressure P_a calculated in accordance with Eq. (3) of NB-3641.1, by more than 10%.

NB-3654.2 Analysis of Piping Components.

For Service Loadings for which Level B Service Limits are designated, the requirements of (a) or (b) below shall apply.

(a) For Service Loadings for which Level B Service Limits are designated which do not include reversing dynamic loads (NB-3622.2) or have reversing dynamic loads combined with nonreversing dynamic loads (NB-3622.4), the

conditions of Eq. (9) shall be met using Service Level B coincident pressure P and moments M_i which result in the maximum calculated stress. The allowable stress to be used for this condition is $1.8S_m$, but not greater than $1.5S_y$.

S_y

= yield strength value, psi, taken at average fluid temperature of the transient under consideration

(b) For Service Loadings for which Level B Service Limits are designated which include reversing dynamic loads that are not required to be combined with nonreversing dynamic loads, the requirements of NB-3653 for Level A Service Limits shall be met. In addition, any deflection limits prescribed by the Design Specification must be satisfied.

NB-3655 Consideration of Level C Service Limits

NB-3655.1 Permissible Pressure.

When Level C Service Limits [NCA-2142.4(b)(3) and NB-3113(b)] are specified, the permissible pressure shall not exceed the pressure P_a calculated in accordance with Eq. (3) of NB-3641.1, by more than 50%.

NB-3655.2 Analysis of Piping Components.

For Service Loadings for which Level C Service Limits [NCA-2142.4(b)(3) and NB-3113(b)] are designated, the requirements of (a) or (b) below shall apply.

(a) For Service Loadings for which Level C Service Limits are designated which do not include reversing dynamic loads or have reversing dynamic loads combined with nonreversing dynamic loads, the conditions of Eq. (9) of NB-3652 shall be met using Service Level C coincident pressure P and moments M_i which result in the maximum calculated stress. The allowable stress to be used for this condition is $2.25S_m$ but not greater than $1.8S_y$.

(b) For Service Loadings for which Level C Service Limits are designated which include reversing dynamic loads that are not required to be combined with nonreversing dynamic loads, the requirements of NB-3656(b) shall be satisfied using the allowable stress in NB-3656(b)(2), 70% of the allowable stress in NB-3656(b)(3), and 70% of the allowable loads in NB-3656(b)(4).

NB-3655.3 Deformation Limits.

Any deformation or deflection limits prescribed by the Design Specifications

Page 154

shall be considered with respect to Level C Service Limits.

NB-3656 Consideration of Level D Service Limits

If the Design Specifications specify any Service Loading for which Level D Limits are designated [NCA-2142.2(b)(4)], the requirements of (a), (b), or (c) below shall apply.

(a) For Service Loadings for which Level D Service Limits are designated which do not include reversing dynamic loads or have reversing dynamic loads combined with nonreversing dynamic loads, the requirements of (1) and (2) below shall apply.

(1) The permissible pressure shall not exceed 2.0 times the pressure P_a calculated in accordance with Eq. (3) of NB-3641.1.

(2) The conditions of Eq. (9) of NB-3652 shall be met. The allowable stress to be used for this condition is $3.0S_m$, but not greater than $2.0S_y$.

(b) For piping fabricated from material designated P-No. 1 through P-No. 9 in Table 2A, Section II, Part D and limited to $D/t \leq 50$ if Level D Service Limits are designated which include reversing dynamic loads that are not required to be combined with nonreversing dynamic loads, the requirements of (1) through (5) below shall apply.

(1) The pressure occurring coincident with the earthquake or other reversing type loading shall not exceed the Design

Pressure.

(2) The sustained stress due to weight loading shall not exceed the following:

$$B_2 \frac{D_o}{2I} M_W \leq 0.5 S_m$$

where

M_W

= resultant moment due to weight effects (NB-3623)

(3) The stress due to weight and inertial loading due to reversing dynamic loads in combination with the Level D coincident pressure shall not exceed the following:

$$B_1 \frac{P_D D_o}{2I} + B_2 \frac{D_o}{2I} M_E \leq 4.5 S_m$$

where

M_E

= the amplitude of the resultant moment due to the inertial loading from the earthquake, other reversing type dynamic events and weight. Earthquake and other reversing dynamic loads shall be computed from a linear elastic response

spectrum analysis as defined in Appendix N-1226, except the spectrum peak broadening value Δf_g in N-1226.3 shall not be less than 15% and, in place of the damping values for both large and small diameter piping systems in Table N-1230-1 for Operating Basis Earthquake and Safe Shutdown Earthquake, a value of 5 shall be used. The ground motion design input for generating the floor response spectrum to be used in the linear elastic analysis shall meet the requirements of Appendix N-1211(a) and N-1211(b). Moments and forces may be computed using a methodology other than prescribed above if the alternate methodology is demonstrated to produce results which envelope the prescribed methodology results. In the combination of loads, all directional moment components in the same direction shall be combined before determining the resultant moment. If the method of analysis is such that only magnitude without algebraic signs is obtained, the most conservative combination shall be assumed.

P_D

= the pressure occurring coincident with the reversing dynamic load

(4) The range of the resultant moment M_{AM} and the amplitude of the longitudinal force F_{AM} resulting from the anchor motions due to earthquake and other reversing type dynamic loading shall not exceed the following:

$$C_2 \frac{M_{AM} D_O}{2I} < S_1$$

$$\frac{F_{AM}}{A_M} < S_2$$

where

A_M	= cross-sectional area of metal in the piping component wall
S_1	= $6S_m$
S_2	= $1.0S_m$

(5) Piping displacements shall satisfy Design Specification limitations.

(c) As an alternative to NB-3656(a) and (b), the rules contained in Appendix F may be used in evaluating these service loadings independently of all other Design and Service Loadings.

Page 155

NB-3657 Test Loadings

The evaluation of Test Loadings shall be carried out in accordance with NB-3226.

NB-3658 Analysis of Flanged Joints

The pressure design of flanged joints is covered by NB-3647.1. Flanged joints subjected to combinations of moment and pressure shall meet the requirements of this paragraph. In addition, the pipe-to-flange welds shall meet the requirements of NB-3652 through NB-3656 using appropriate stress indices from Table NB-3681(a)-1. Flanged joints using flanges, bolting, and gaskets as specified in ANSI B16.5 and using a bolt material having an S_m value at 100°F (38°C) not less than 20.0 ksi (138 MPa) may be analyzed in accordance with the following rules or in accordance with NB-3200. Other flanged joints shall be analyzed in accordance with NB-3200.

[98]

NB-3658.1 Design Limits, Levels A and B Service Limits

(a) The pressure shall not exceed the rated pressure for Level A Service Limits or 1.1 times the rated pressure for Level B Service Limits.

(b) The bolting shall meet the requirements of NB-3232. In addition, the limitations given by Eqs. (15) and (16) shall be met:

$$(15) M_{fs} \leq 3125 (S_y/36,000) C A_b$$

where

A_b	= total cross-sectional area of bolts at root of thread or section of least diameter under stress, sq in.
C	= diameter of bolt circle, in.
M_{fs}	= bending or torsional moment (considered separately) applied to the joint due to weight, thermal expansion of the piping, sustained anchor movements, relief valve steady-state thrust, and other sustained mechanical loads applied to the flanged joint during the design or service conditions, in.-lb. If cold springing is used, the moment may be reduced to the extent permitted by NB-3672.8.
S_y	= yield strength of flange material at Design Temperature (Section II, Part D, Subpart 1, Table Y-1), psi. The value of $S_y/36,000$ shall not be taken as greater than unity.

$$M_{fd} \leq 6250(S_y / 36,000) CA_b \quad (16)$$

(16)

where

M_{fd} = bending or torsional moment (considered separately) as defined for M_{fs} , but including dynamic loadings, in.-lb

[98]

[98]

NB-3658.2 Level C Service Limits

(a) The pressure shall not exceed 1.5 times the rated pressure.

(b) The limitation given by Eq. (17) shall be met:

$$M_{fd} \leq [11,250A_b - (\pi/16)D_f^2 P_{fd}] C(S_y / 36,000) \quad (17)$$

(17)

where

D_f = outside diameter of raised face, in.

P_{fd} = pressure concurrent with M_{fd} , psi

M_{fd} , C , S_y , the limitation on $S_y/36,000$, and A_b are defined in NB-3658.1(b).

[98]

[98]

NB-3658.3 Level D Service Limits

(a) The pressure shall not exceed 2.0 times the rated pressure.

(b) The limitation given by Eq. (17) of NB-3658.2(b) shall be met, where P_{fd} and M_{fd} are pressures, psi, and moments, in.-lb, occurring concurrently.

[98]

NB-3658.4 Test Loadings.

Analysis for Test Loadings is not required.

NB-3660 DESIGN OF WELDS

NB-3661 Welded Joints

NB-3661.1 General Requirements.

Welded joints shall be made in accordance with NB-4200.

NB-3661.2 Socket Welds²⁴

(a) Socket welded piping joints shall be limited to pipe sizes of 2 in. and less.

(b) Socket welded piping joints shall conform to the requirements specified in ANSI B16.11, the applicable standards listed in Table NB-3132-1, and Fig. NB-4427-1. A gap of approximately $\frac{1}{16}$ in. (1.6 mm) shall be provided between the end of the pipe and the bottom of the socket before welding.

24 Socket welds shall not be used where the existence of crevices could accelerate corrosion.

NB-3661.3 Partial Penetration Welds for Branch Connections

(a) Partial penetration welds are allowed for branch connections in which there are substantially no piping reactions transmitted from the branch, such as openings

Page 156

for instrumentation. The ratio of nominal pipe size of the main pipe to that of the branch shall not be less than 10. Maximum branch size shall not exceed 2 in. nominal pipe size (DN 50). For such branch connections, all reinforcing shall be an integral part of the pipe penetrated. Partial penetration welds shall be of sufficient size to develop the full strength of the branch. Reinforcing requirements of NB-3643 shall be met.

(b) Partial penetration branch connections shall be groove welds as shown in Fig. NB-4244(d)-1. These welds shall be capable of being examined in accordance with the requirements of NB-5245.

(c) The inner corners of finished openings, in which the branch does not extend beyond the inner surface of the pipe penetrated, shall be rounded to a minimum radius of one-fourth the thickness t_n of the penetrating part or $\frac{3}{4}$ in. (19 mm), whichever is smaller. The corners of the end of each branch extending less than $\sqrt{d}t_n$ beyond the inner surface of the pipe penetrated shall be rounded to radius of one-half the thickness t_n of the penetrating part or $\frac{3}{4}$ in. (19 mm), whichever is smaller.

NB-3670 SPECIAL PIPING REQUIREMENTS

NB-3671 Selection and Limitation of Nonwelded Piping Joints

The type of piping joint used shall be suitable for the Design Loadings and shall be selected with consideration of joint tightness, mechanical strength, and the nature of the fluid handled. Piping joints shall conform to the requirements of this Subsection with leak tightness being a consideration in selection and design of joints for piping systems to satisfy the requirements of the Design Specifications.

NB-3671.1 Flanged Joints.

Flanged joints are permitted.

NB-3671.2 Expanded Joints.

Expanded joints shall not be used.

NB-3671.3 Threaded Joints.

Threaded joints in which the threads provide the only seal shall not be used. If a seal weld is employed as the sealing medium, the stress analysis of the joint must include the stresses in the weld resulting from the relative deflections of the mated parts.

NB-3671.4 Flared, Flareless, and Compression Joints.

Flared, flareless, and compression type tubing fittings may be used for tubing sizes not exceeding 1 in. O.D. within the limitations of applicable standards and specifications listed in Table NB-3132-1 and requirements (b) and (c) below. In the absence of such standards or specifications, the Designer shall determine that the type of fitting selected is adequate and safe for the Design Loadings in accordance with the requirements of (a), (b), and (c) below.

(a) The pressure design shall meet the requirements of NB-3649.

(b) Fittings and their joints shall be suitable for the tubing with which they are to be used in accordance with the minimum wall thickness of the tubing and method of assembly recommended by the manufacturer.

(c) Fittings shall not be used in services that exceed the manufacturer's maximum pressure-temperature recommendations.

NB-3671.5 Caulked Joints.

Caulked or leaded joints shall not be used.

NB-3671.6 Brazed and Soldered Joints

(a) *Brazed Joints*

(1) Brazed joints of a maximum nominal pipe size of 1 in. may be used only at dead end instrument connections and in special applications where space and geometry conditions prevent the use of joints permitted under NB-3661.2, NB-3661.3, and NB-3671.4. The depth of socket shall be at least equal to that required for socket welding fittings and shall be of sufficient depth to develop a rupture strength equal to that of the pipe at Design Temperature (NB-4500).

(2) Brazed joints that depend upon a fillet rather than a capillary type filler addition are not acceptable.

(3) Brazed joints shall not be used in systems containing flammable fluids or in areas where fire hazards are involved.

(b) *Soldered Joints.* Soldered joints shall not be used.

NB-3671.7 Sleeve Coupled and Other Patented Joints.

Mechanical joints, for which no standards exist, and other patented joints may be used provided the requirements of (a), (b), and (c) below are met.

(a) Provision is made to prevent separation of the joints under all Service Loadings.

(b) They are accessible for maintenance, removal, and replacement after service.

(c) Either of the following two criteria are met.

(1) A prototype joint has been subjected to performance tests to determine the safety of the joint under simulated service conditions. When vibration, fatigue, cyclic conditions, low temperature, thermal expansion, or hydraulic shock is anticipated, the applicable conditions shall be incorporated in the tests. The mechanical joints shall be sufficiently leak tight to satisfy the requirements of the Design Specifications.

Page 157

(2) Joints are designed in accordance with the rules of NB-3200.

NB-3672 Expansion and Flexibility

(a) In addition to meeting the design requirements for pressure, weight, and other loadings, piping systems shall be

designed to absorb or resist thermal expansion or contraction or similar movements imposed by other sources and shall meet the criteria for allowable stress intensity as specified in NB-3611. Piping systems shall be designed to have sufficient flexibility to prevent the movements from causing:

- (1) failure of piping or anchors from overstress or overstrain;
- (2) leakage at joints;
- (3) detrimental distortion of connected equipment resulting from excessive thrusts and moments.

(b) The effects of stresses, caused by pressure, thermal expansion, and other loads and their stress intensification factors, shall be considered cumulatively.

NB-3672.1 Properties.

Thermal expansion data and moduli of elasticity shall be determined from Section II, Part D, Subpart 2, Tables TE and TM, which cover more commonly used piping materials. For materials not included in these tables, reference shall be to authoritative source data, such as publications of the National Institute of Standards and Technology.

NB-3672.2 Unit Thermal Expansion Range.

The unit thermal expansion range in in./100 ft, used in calculating the expansion range, shall be determined from Section II, Part D, Subpart 2, Tables TE as the algebraic difference between the unit expansion shown for the highest metal temperature and that for the lowest metal temperature resulting from service or shutdown conditions.

NB-3672.3 Moduli of Elasticity.

The moduli of elasticity for ferrous and nonferrous materials shall be as given in Section II, Part D, Subpart 2, Tables TM.

NB-3672.4 Poisson's Ratio.

When required for flexibility calculations, Poisson's ratio shall be taken as 0.3 for all metals at all temperatures.

NB-3672.5 Stresses.

Flexibility calculations of the moments and forces in the piping system due to thermal expansion and end motions shall be based on the hot modulus E_h . Calculations for the expansion stresses shall be based on the least cross-sectional area of the pipe or fitting, using nominal dimensions. The expansion stress computed from the forces and moments shall be multiplied by the ratio E_c/E_h . The effect of expansion stresses in combination with stresses from other causes shall be evaluated in accordance with NB-3611 or NB-3630.

NB-3672.6 Method of Analysis.

All systems shall be analyzed for adequate flexibility by a rigorous structural analysis unless they can be judged technically adequate by an engineering comparison with previously analyzed systems.

NB-3672.7 Basic Assumptions and Requirements

(a) When calculating the flexibility of a piping system between anchor points, the system between the anchor points shall be treated as a whole. The significance of all parts of the line and of all restraints, such as supports or guides, including intermediate restraints introduced for the purpose of reducing moments and forces on equipment or small branch lines, shall be considered.

(b) Comprehensive calculations shall take into account the flexibility factors and stress indices found to exist in piping products other than straight pipe. Credit may be taken where extra flexibility exists in the piping system. Flexibility factors and stress indices are given in NB-3680.

(c) The total expansion range shall be used in all calculations whether or not the piping is cold sprung. Not only the expansion of the line itself, but also linear and angular movements of the equipment and supports to which it is attached,

shall be considered.

(d) Where assumptions are used in calculations or model tests, the likelihood of underestimates of forces, moments, and stresses, including the effects of stress intensification, shall be evaluated.

NB-3672.8 Cold Springing.

Cold springing provides a beneficial effect in assisting a system to attain its most favorable position sooner. The effect of cold springing shall be analyzed as any other movement in the system is analyzed. The maximum stress allowed due to cold springing is $2.0S_m$ at the cold spring temperature. Since the usual erection procedures may not permit accurate determination of cold spring in a piping system, the allowable reduction of forces and moments at anchors or equipment caused by cold springing shall be limited to no more than two-thirds of the calculated reduction.

NB-3674 Design of Pipe Supporting Elements

Supporting elements, including hangers, anchors, and sliding supports, shall be designed in accordance with the requirements of Subsection NF.

Page 158

NB-3677 Pressure Relief Piping

NB-3677.1 General Requirements.

Pressure relief piping within the scope of this Subsection shall be supported to sustain reaction forces and shall conform to the requirements of the following subparagraphs.

NB-3677.2 Piping to Pressure Relieving Safety Devices

(a) Piping that connects a pressure relieving safety device to a piping system shall comply with all the requirements of the class of piping of the system which it is designated to relieve.

(b) There shall be no intervening stop valves between systems being protected and their protective device or devices except as provided for in NB-7142.

NB-3677.3 Discharge Piping From Pressure Relieving Safety Devices

(a) Discharge piping from pressure relieving safety devices shall comply with the requirements applicable to the conditions under which it operates.

(b) There shall be no intervening stop valve between the protective device or devices and the point of discharge except as provided for in NB-7142.

(c) The effluent from relief devices may be discharged outside the containment only if adequate provisions are made for the safe disposal of the effluent. It shall not impinge on other piping or structure or equipment and shall be directed away from platforms and other areas which might be used by personnel.

(d) It is recommended that individual discharge lines be used, but, if two or more reliefs are combined, the discharge piping shall be designed with sufficient flow area to prevent undue back pressure.

(e) When the umbrella or drip pan type of connection between the pressure relieving safety device and the discharge piping is used, the discharge piping shall be so designed as to prevent binding due to expansion movements and shall be so dimensioned as to prevent the possibility of blow back of the effluent. Individual discharge lines shall be used in this application. Drainage shall be provided to remove water collected above the safety valve seat.

(f) Discharge lines from pressure relieving safety devices within the scope of this Subsection shall be designed to facilitate drainage if there is any possibility that the effluent can contain liquid.

NB-3680 STRESS INDICES AND FLEXIBILITY FACTORS

NB-3681 Scope

(a) There are two types of analyses allowed by the rules of this Subarticle. The applicable B , C , and K indices to be used with Eqs. (9), (10), and (11) of NB-3650 are given in Table NB-3681(a)-1. The applicable indices to be used with the detailed analysis of NB-3200 are given in NB-3685 and NB-3338.

(b) Methods of determining flexibility factors for some commonly used piping products are given in NB-3686.

(c) Values of stress indices are tabulated for commonly used piping products and joints. Unless specific data, which shall be referenced in the Design Report, exist that would warrant lower stress indices than those tabulated or higher flexibility factors than those calculated by the methods of NB-3686, the stress indices given shall be used as minimums and the flexibility factors shall be used as maximums.

(d) For piping products not covered by NB-3680, stress indices and flexibility factors shall be established by experimental analysis (Appendix II) or theoretical analysis. Such test data or theoretical analysis shall be included in the Design Report.

(e) When determining stress indices by experimental methods, the nominal stress at the point under consideration (crack site, point of maximum stress intensity, etc.) shall be used.

NB-3682 Definitions of Stress Indices and Flexibility Factors

(a) The general definition of a stress index for mechanical loads is:

$$B, C, K, \text{ or } i = \frac{\sigma}{S}$$

where

S	= nominal stress, psi, due to load L
σ	= elastic stress, psi, due to load L

For B indices, σ represents the stress magnitude corresponding to a limit load. For C or K indices, σ represents the maximum stress intensity due to load L . For i factors, σ represents the principal stress at a particular point, surface, and direction due to load L . The nominal stress S is defined in detail in the tables of stress indices.

(b) The general definition of a stress index for thermal loads is:

$$C \text{ or } K = \frac{\sigma}{E\alpha\Delta T}$$

where

E

= modulus of elasticity, psi

Page 159

Page 160

α

= coefficient of thermal expansion

ΔT

= thermal difference, °F

σ

= maximum stress intensity, psi, due to thermal difference ΔT

**TABLE NB-3681(a)-1
STRESS INDICES¹ FOR USE WITH EQUATIONS IN NB-3650**

98

Piping Products and Joints [Note (3)]	Applicable for $D_o/t \leq 100$ for C or K Indices and $D_o/t \leq 50$ for B Indices									Notes
	Internal Pressure [Note (2)]			Moment Loading [Note (2)]			Thermal Loading			
	B_1	C_1 [Note (4)]	K_1 [Note (4)]	B_2	C_2 [Note (4)]	K_2 [Note (4)]	C_3	C'_3	K_3 [Note (4)]	
Straight pipe, remote from welds or other discontinuities	0.5	1.0	1.0	1.0	1.0	1.0	1.0	...	1.0	(5)
Longitudinal butt welds in straight pipe										
(a) flush	0.5	1.0	1.1	1.0	1.0	1.1	1.0	...	1.1	(6)
(b) as-welded $t > \frac{3}{16}$ in.	0.5	1.1	1.2	1.0	1.2	1.3	1.0	...	1.2	(6)
(c) as-welded $t \leq \frac{3}{16}$ in.	0.5	1.4	2.5	1.0	1.2	1.3	1.0	...	1.2	(6)
Girth butt welds between nominally identical wall thickness items										
(a) flush	0.5	1.0	1.1	1.0	1.0	1.1	0.60	0.50	1.1	(7)
(b) as-welded	0.5	1.0	1.2	1.0	...	1.8	0.60	0.50	1.7	(7)
Girth fillet weld to socket weld, fittings, socket weld valves, slip-on or socket welding flanges	...	...	3.0	...	...	2.0	2.0	1.0	3.0	(8)
NB-4250 Transitions										
(a) flush	0.5	...	1.1	1.0	...	1.1	...	1.0	1.1	(9)
(b) as-welded	0.5	...	1.2	1.0	...	1.8	...	1.0	1.7	(9)
Transitions within a 1:3 slope envelope										
(a) flush	0.5	...	1.2	1.0	...	1.1	...	0.60	1.1	(10)
(b) as-welded	0.5	...	1.2	1.0	...	1.8	...	0.60	1.7	(10)
Butt welding reducers per ANSI B16.9 or MSS SP-87	...	...	...	1.0	...	...	1.0	0.5	1.0	(11)
Curved pipe or butt welding elbows	...	...	1.0	...	...	1.0	1.0	0.5	1.0	(12)
Branch connections per NB-3643	0.5	...	2.0	...	...	...	1.8	1.0	1.7	(13)
Butt welding tees	0.5	1.5	4.0	...	...	...	1.0	0.5	1.0	(14)

- NOTES:**
- (1) For indices not listed, see the note referenced at the end of the applicable line.
 - (2) For the calculation of pressure and moment loads and special instructions regarding Eqs. (9) through (13), see NB-3683.1(d).
 - (3) For definitions, applicability, and specific restrictions, see NB-3683.
 - (4) For special instructions regarding the use of these indices for welded products, intersecting welds, abutting products, or out-of-round products, see NB-3683.2.
 - (5) See NB-3683.3, Straight Pipe Remote From Welds.
 - (6) See NB-3683.4(a), Longitudinal Butt Welds.
 - (7) See NB-3683.4(b), Girth Butt Welds.
 - (8) See NB-3683.4(c), Girth Fillet Welds.
 - (9) See NB-3683.5(a), NB-4250 Transitions.
 - (10) See NB-3683.5(b), Transitions Within a 1:3 Slope.
 - (11) See NB-3683.6, Concentric and Eccentric Reducers.
 - (12) See NB-3683.7, Curved Pipe or Butt Welding Elbows. See also NB-3683.2(a) and NB-3683.2(b).
 - (13) See NB-3683.8, Branch Connections per NB-3643. See also NB-3683.1(d).
 - (14) See NB-3683.9, Butt Welding Tees. See also NB-3683.1(d).

[98]

TABLE NB-3681(a)-1 STRESS INDICES¹ FOR USE WITH EQUATIONS IN NB-3650

The values of E , α , and ΔT are defined in detail in NB-3650.

(c) Flexibility factors are identified herein by k with appropriate subscripts. The general definition of a flexibility factor

is:

$$k = \theta_{ab} / \theta_{\text{nom}}$$

where

θ_{ab} = rotation of end a , with respect to end b , due to a moment load M and in the direction of the moment M

θ_{nom} = nominal rotation due to moment load M

The flexibility factor k and nominal rotation θ_{nom} are defined in detail for specific components in NB-3686.

NB-3683 Stress Indices for Use With NB-3650

The stress indices given herein and in Table NB-3681(a)-1 and subject to the additional restrictions specified herein are to be used with the analysis methods of NB-3650. For piping products outside the applicable range, stress indices shall be established in accordance with NB-3681.

[98]

NB-3683.1 Nomenclature

(a) *Dimensions.* Nominal dimensions as specified in the dimensional standards of Table NB-3132-1 shall be used for calculating the numerical values of the stress indices given herein and in Table NB-3681(a)-1, and for evaluating Eqs. (9) through (14) of NB-3650. For ANSI B16.9, ANSI B16.28, or MSS SP-87 piping products, the nominal dimensions of the equivalent pipe (for example, Schedule 40) as certified by the manufacturer shall be used. Not more than one equivalent pipe size shall be certified for given product items of the same size, shape, and weight.

For piping products such as reducers and tapered-wall transitions which have different dimensions at either end, the nominal dimensions of the large or small end, whichever gives the larger value of D_o/t , shall be used. Dimensional terms are defined as follows:

D_o	= nominal outside diameter of pipe, in.
D_i	= nominal inside diameter of pipe, in.
D_m	= mean diameter of designated run pipe, in. [see NB-3683.8(c) and Fig. NB-3643.3(a)-1] = $2R_m = (D_o - T_r)$
D_{max}	= maximum outside diameter of cross section, in.
D_{min}	= minimum outside diameter of cross section, in.
D_1	= nominal outside diameter at large end of concentric and eccentric reducers, in. (see NB-3683.6)
D_2	= nominal outside diameter at small end of concentric and eccentric reducers, in. (see NB-3683.6)
d_o	= nominal outside diameter of attached branch pipe, in.
d_i	= nominal inside diameter of branch, in.
d_m	= nominal mean diameter of reinforced or unreinforced branch, in. [see NB-3683.8(c)] = $(d_i + t_n)$
h	= characteristic bend parameter of a curved pipe or butt welding elbow

	$= tR/r_m^2$
I	= moment of inertia of pipe, in. ⁴ $= 0.0491 (D_o^4 - D_i^4)$
L_1	= height of nozzle reinforcement for branch connections, in. [see Fig. NB-3643.3(a)-1]
L_1, L_2	= length of cylindrical portion at the large end and small end of a reducer, respectively (see NB-3683.6)
R	= nominal bend radius of curved pipe or elbow, in.
R_m	= mean radius of designated run pipe, in. [see NB-3683.8 and Fig. NB-3643.3(a)-1] $= (D_o - T_r)/2$
r_i	= inside radius of branch, in. [see Fig. NB-3643.3(a)-1] $= d_i/2$
r_m	= mean pipe radius, in. $= (D_o - t)/2$
r'_m	= mean radius of attached branch pipe, in. [see Fig. NB-3643.3(a)-1] $= (d_o - T_b)/2$
r_p	= outside radius of reinforced nozzle or branch connection, in. [see Fig. NB-3643.3(a)-1]
r_1, r_2, r_3	= designated radii for reinforced branch connections, concentric and eccentric reducers, in. [see NB-3683.6, NB-3683.8, and Fig. NB-3643.3(a)-1]
T_b	= wall thickness of branch connection reinforcement, in. [see Fig. NB-3643.3(a)-1]
T_b	= nominal wall thickness of attached branch pipe, in. [see Fig. NB-3643.3(a)-1]
T_r	= nominal wall thickness of designated run pipe, in. [see Fig. NB-3643.3(a)-1]
t	= nominal wall thickness of pipe, in. For piping products purchased to a minimum wall specification, the nominal wall thickness

shall be taken as 1.14 times the minimum wall.

$t_{\max}$	= maximum wall thickness of a welding transition within a distance of $\sqrt{D_o t}$ from the welding end [see NB-3683.5(b)]
t_n	= wall thickness of nozzle or branch connection reinforcement, in. (see NB-3683.8; also used for concentric and eccentric reducers, see NB-3683.6)
t_1	= nominal wall thickness at large end of concentric and

	eccentric reducers, in. (see NB-3683.6)
t_2	= nominal wall thickness at small end of concentric and eccentric reducers, in. (see NB-3683.6)
t_{1m}, t_{2m}	= minimum wall thickness at the large end and small end of a reducer, respectively, that is required to resist the Design Pressure P in accordance with Eq. (1), NB-3641.1
Z	= section modulus of pipe, in. ³ = $2I/D_o$
Z_b	= approximate section modulus of attached branch pipe, in. ³ = $\pi(r'_m)^2 T'_b$
Z_r	= approximate section modulus of designated run pipe, in. ³ = $\pi(R_m)^2 T_r$
α	= cone angle of concentric and eccentric reducers, deg. (see NB-3683.6)
Δ	= radial weld shrinkage measured from the nominal outside surface, in.
θ_n	= slope of nozzle-to-pipe transition for branch connections, deg. [see Fig. NB-3643.3(a)-1]

(b) *Material Properties.* Unless otherwise specified, material properties at the appropriate temperature, as given in Section II, Part D, Subparts 1 and 2, shall be used. Terms are defined as follows:

E	= modulus of elasticity for the material at room temperature, psi, taken from Tables TM
M	= materials constant = 2, for ferritic steels and nonferrous materials except nickel-chrome-iron alloys and nickel-iron-chrome alloys = 2.7, for austenitic steel, nickel-chrome-iron alloys and nickel-iron-chrome alloys [see NB-3683.2(b)]
S_y	= yield strength of the material at the Design Temperature, psi, taken from Table Y-1
ν	= Poisson's ratio = 0.3

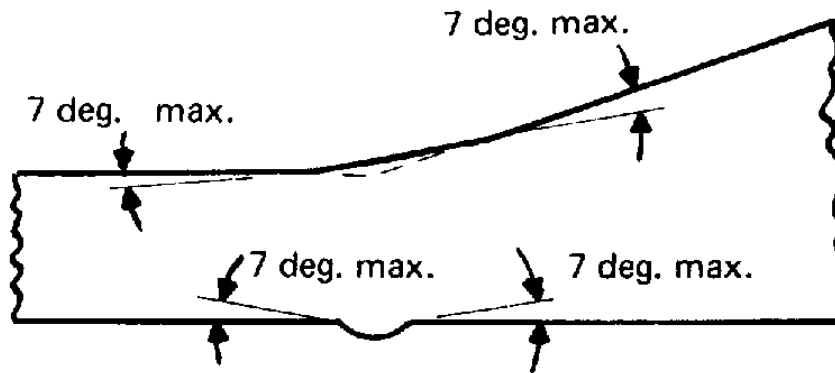


FIG. NB-3683.1(c)-1

FIG. NB-3683.1(c)-1

(c) *Connecting Welds.* Connecting welds in accordance with the requirements of this Subsection are defined as either *flush* or *as-welded* welds.

(1) *Flush welds* are those welds with contours as defined in Fig. NB-3683.1(c)-1. The total thickness (both inside and outside) of the weld reinforcement shall not exceed $0.1t$. There shall be no concavity on either the interior or exterior surfaces and the finished contour shall not have any slope greater than 7 deg. where the angle is measured from a tangent to the surface of the pipe or on the tapered transition side of the weld to the nominal transition surface.

(2) *As-welded welds* are those welds not meeting the special requirements of flush welds.

(d) *Loadings.* Loadings for which stress indices are given include internal pressure, bending and torsional moments, and temperature differences. The indices are intended to be sufficiently conservative to account also for the effects of transverse shear forces normally encountered in flexible piping systems. If, however, thrust or shear forces account for a significant portion of the loading on a given piping product, the effect of these forces shall be included in the design analysis. The values of the moments and forces shall be obtained from an analysis of the piping system in accordance with NB-3672. Loading terms are defined as follows:

$$M_1, M_2, M_3$$

= orthogonal moment loading components at a given position in a piping system, in.-lb

$$M_{ij}$$

= orthogonal moment components of a tee or branch connection as shown in Fig. NB-3683.1(d)-1 where $i = x, y, z$ and $j = 1, 2, 3$

$$M_t$$

= resultant moment loading applied during the specified operating cycle for straight-through products such as straight pipe, curved pipe or elbows, and concentric reducers

P

$$= \sqrt{M_1^2 + M_2^2 + M_3^2}$$

= Design Pressure, psi

Page 162

P_o

= range of service pressure, psi

P^*

= maximum value of pressure in the load cycle under consideration, psi

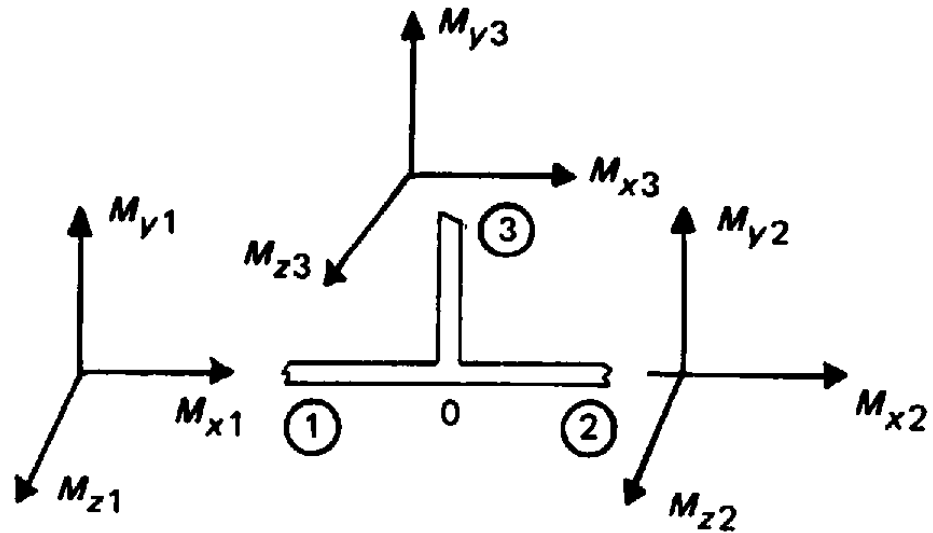


FIG. NB-3683.1(d)-1

FIG. NB-3683.1(d)-1

The moment components M_{x1} , M_{x2} , M_{y1} , M_{y2} , M_{z1} , and M_{z2} for the run are calculated at the intersection of the run and branch center lines. The moment components M_{x3} , M_{y3} , and M_{z3} for a branch connection where $d_o/D_o \leq 0.5$ may be calculated for a point on the branch center line at a distance $D_o/2$ from the intersection of the run and branch center lines. Otherwise, M_{x3} , M_{y3} , and M_{z3} are calculated at the intersection of the run and branch center lines.

M_b

= resultant moment on the branch for branch connections or tees, in.-lb

$$= \sqrt{M_{x3}^2 + M_{y3}^2 + M_{z3}^2}$$

M

b	expansion and thermal anchor movements
M_r	= resultant moment on the run for branch connections or tees, in.-lb $= \sqrt{M_{xr}^2 + M_{yr}^2 + M_{zr}^2}$
M_r^*	= same as M_r except it includes only moments due to thermal expansion and thermal anchor movements
M_{xr}, M_{yr}, M_{zr}	= run moment components for use with the stress indices of NB-3683.9. Their numerical values are calculated as follows. If M_{i1} and M_{i2} where $i = x, y, z$ have the same algebraic sign (+/-), then M_{ir} equals zero. If M_{i1} and M_{i2} have opposite algebraic signs, then M_{ir} equals the smaller of M_{i1} or M_{i2} . If M_{i1} and M_{i2} are unsigned, then M_{ir} may be taken as the smaller of M_{i1} or M_{i2} . Combination of signed and unsigned moments from different load sources shall be done after determination of M_{ir} .

For branch connections or tees, the pressure term of Eqs. (9), (10), (11), and (13) shall be replaced by the following terms:

For Eq. (9): $B_1 (PD_o/2T_r)$

For Eqs. (10) and (13): $C_1 (P_o D_o/2T_r)$

For Eq. (11): $K_1 C_1 (P_o D_o/2T_r)$

For branch connections or tees, the moment term of Eqs. (9) through (13) shall be replaced by the following pairs of terms:

For Eq. (9): $B_{2b} (M_b/Z_b) + B_{2r} (M_r/Z_r)$

For Eqs. (10) and (13): $C_{2b} (M_b/Z_b) + C_{2r} (M_r/Z_r)$

For Eq. (11): $C_{2b} K_{2b} (M_b/Z_b) + C_{2r} K_{2r} (M_r/Z_r)$

For Eq. (12): $C_{2b} (M_b^*/Z_b) + C_{2r} (M_r^*/Z_r)$

where the approximate section moduli are:

$$Z_b = \pi (t'_m)^2 T_b$$

$$Z_r = \pi (R_m)^2 T_r$$

[98]

[98]

NB-3683.2 Applicability of Indices - General.

The B , C , and K stress indices given herein and in Table NB-3681(a)-1 predict stresses at a weld joint or within the body of a particular product. The stress indices given for ANSI B16.9, ANSI B16.28, and MSS SP-87 piping products apply only to seamless products with no connections, attachments, or other extraneous stress raisers on the body thereof. The stress indices for welds are not applicable if the radial weld shrinkage Δ is greater than $0.25t$.

For products with longitudinal butt welds, the K_1 , K_2 , and K_3 indices shown shall be multiplied by 1.1 for flush welds or by 1.3 for as-welded welds. At the intersection of a longitudinal butt weld in straight pipe with a girth butt weld or girth fillet weld, the C_1 , K_1 , C_2 , K_2 , and K_3 indices shall be taken as the product of the respective indices.

(a) *Abutting Products.* In general and unless otherwise specified, it is not required to take the product of stress indices

for two piping products, such as a tee and a reducer when welded together, or a tee and a girth butt weld. The piping product and the weld shall be qualified separately.

For curved pipe or butt welding elbows welded together or joined by a piece of straight pipe less than one pipe diameter long, the stress indices shall be taken

Page 163

as the product of the indices for the elbow or curved pipe and the indices for the girth butt weld, except for B_1 and C_3 which are exempted.

(b) *Out-of-Round Products.* The stress indices given in Table NB-3681(a)-1 are applicable for products and welds with out-of-roundness not greater than $0.08t$ where out-of-roundness is defined as $D_{\max} - D_{\min}$. For straight pipe, curved pipe, longitudinal butt welds in straight pipe, girth butt welds, NB-4250 transitions, and 1:3 transitions not meeting this requirement, the stress indices shall be modified as specified below.

(1) If the cross section is out-of-round but with no discontinuity in radius, e.g., an elliptical cross section, an acceptable value of K_1 may be obtained by multiplying the tabulated values of K_1 by the factor F_{1a} :

$$F_{1a} = 1 + \frac{D_{\max} - D_{\min}}{t} \left[\frac{1.5}{1 + 0.455(D_o/t)^3(p/E)} \right]$$

where

D_o	= nominal outside diameter, in.
E	= modulus of elasticity of material at room temperature, psi
p	= internal pressure (use maximum value of pressure in the load cycle under consideration), psi

Other symbols are defined in (b) above.

(2) If there are discontinuities in radius, e.g., a flat spot, and if $D_{\max} - D_{\min}$ is not greater than $0.08D_o$, an acceptable value of K_1 may be obtained by multiplying the tabulated values of K_1 by the factor F_{1b} :

$$F_{1b} = 1 + MS_y/(PD_o/2t)$$

where

M	= 2, for ferritic steels and nonferrous materials except nickel-chromium-iron alloys and nickel-iron-chromium alloys = 2.7, for austenitic steel, nickel-chromium-iron alloys, and nickel-iron-chromium alloys
P	= Design Pressure, psi
S_y	= yield strength at Design Temperature (Section II, Part D, Subpart 1, Table Y-1), psi

D and t are defined in (a) and (b) above.

[98]

NB-3683.3 Straight Pipe Remote From Welds.

The stress indices given in Table NB-3681(a)-1 apply for straight pipe remote from welds or other discontinuities, except as modified by NB-3683.2.

[98]

NB-3683.4 Welds

(a) *Longitudinal Butt Welds.* The stress indices given in Table NB-3681(a)-1 are applicable for longitudinal butt welds in straight pipe, except as modified in NB-3683.2.

(b) *Girth Butt Welds.* The stress indices given in Table NB-3681(a)-1, except as modified herein and in NB-3683.2, are applicable to girth butt welds connecting abutting products for which the wall thickness is between $0.875t$ and $1.1t$ for an axial distance of $\sqrt{D_o t}$ from the welding ends. Girth welds may also exhibit a reduction in diameter due to shrinkage of the weld material during cooling. The indices are not applicable if Δ/t is greater than 0.25 where Δ is the radial shrinkage measured from the nominal outside surface.

For as-welded girth butt welds joining items with nominal wall thicknesses $t < 0.237$, the C_2 index shall be taken as:

$$C_2 = 1.0 + 0.094/t \text{ but not } > 2.1$$

(c) *Girth Fillet Welds.* The stress indices given in Table NB-3681(a)-1 are applicable to girth fillet welds used to attach socket welding fittings, socket welding valves, slip-on flanges, or socket welding flanges, except as added to or modified in NB-3683.1, and in (1) and (2) below.

(1) *Primary Stress Indices.* The B_1 and B_2 indices shall be taken as:

$$B_1 = 0.75(t_n/C_x) \geq 0.5$$

$$B_2 = 1.5(t_n/C_x) \geq 1.0$$

where C_x and t_n are defined in Fig. NB-4427-1, sketches (c) and (d). In Fig. NB-4427-1 sketch (c), C_x shall be taken as $X_{\min}$ and $C_x \geq 1.25t_n$. In Fig. NB-4427-1 sketch (d), $C_x \geq 0.75t_n$. For unequal leg lengths use the smaller leg length for C_x .

(2) *Primary Plus Secondary Stress Indices.* The C_1 and C_2 indices shall be taken as:

$$C_1 = 1.8(t_n/C_x) \geq 1.4$$

$$C_2 = 2.1(t_n/C_x) \geq 1.3$$

[98]

[98]

NB-3683.5 Welded Transitions.

The stress indices given in Table NB-3681(a)-1, except as modified herein and in NB-3683.2, are applicable for NB-4250 welded transitions as defined under NB-3683.5(a) and for 1:3 welded transitions as defined under NB-3683.5 (b). Girth butt welds may also exhibit a reduction in diameter

Page 164

due to shrinkage of the weld material during cooling. The indices are not applicable if Δ/t is greater than 0.25.

(a) *NB-4250 Transitions.* The stress indices given in Table NB-3681(a)-1, except as modified herein and in NB-3683.2, are applicable to girth butt welds between a product for which the wall thickness is between $0.875t$ and $1.1t$ for an axial distance of $\sqrt{D_o t}$ from the welding end and an abutting product for which the welding end is within the envelope of Fig. NB-4250-1, but with inside and outside surfaces that do not slope in the same direction. For transitions meeting these requirements, the C_1 , C_2 , and C_3 indices shall be taken as:

$$C_1 = 0.5 + 0.33 (D_o/t)^{0.3} + 0.047/t \text{ but not } > 1.8$$

$$C_2 = 1.7 + 0.094/t \text{ but not } > 2.1$$

$$C_3 = 1.0 + 0.03 (D_o/t) \text{ but not } > 2.0$$

For flush welds and for as-welded joints between items with $t > 0.237$, C_1 and C_2 shall be taken as:

$$C_1 = 0.5 + 0.33 (D_o/t)^{0.3} \text{ but not } > 1.8$$

$$C_2 = 1.7$$

(b) *Transitions Within a 1:3 Slope.* The stress indices given in Table NB-3681(a)-1, except as modified herein and in NB-3683.2, are applicable for girth butt welds between a product for which the wall thickness is between $0.875t$ and $1.1t$ for an axial distance of $\sqrt{D_o t}$ from the welding end and an abutting product for which the welding end is within an envelope defined by a 1:3 slope on the inside, outside, or both surfaces for an axial distance of $\sqrt{D_o t}$, but with inside and outside surfaces that do not slope in the same direction. For transitions meeting these requirements, the C_1 , C_2 and C_3 indices shall be taken as:

$$C_1 = 1.0 + 0.047/t \text{ but not } > 1.8$$

$$C_2 = t_{\max}/t + 0.094/t \text{ but not } > \text{the smaller of } (1.33 + 0.04\sqrt{D_o t}/t + 0.094/t) \text{ or } 2.1$$

$$C_3 = 0.35 (t_{\max}/t) + 0.25 \text{ but not } > 2.0$$

where $t_{\max}$ is the maximum wall thickness within the transition zone. If $(t_{\max}/t) \leq 1.10$, the stress indices given in NB-3683.4(b) for girth butt welds may be used. For flush welds and for as-welded joints between items with $t > 0.237$, C_1 and C_2 shall be taken as:

$$C_1 = 1.0$$

$$C_2 = t_{\max}/t \text{ but not } > \text{the smaller of } (1.33 + 0.04\sqrt{D_o t}/t) \text{ or } 2.1$$

[98]

[98]

NB-3683.6 Concentric and Eccentric Reducers.

The stress indices given in Table NB-3681(a)-1, except as modified herein and in NB-3683.2, are applicable to butt welding reducers manufactured to the requirements of ANSI B16.9 or MSS SP-87 if the cone angle α defined in Fig. NB-3683.6-1 is less than 60 deg. and if the wall thickness is not less than t_{lm} throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end where the thickness shall not be less than t_{2m} . The wall thicknesses t_{lm} and t_{2m} are the minimum thicknesses required to resist the Design Pressure P at the large end and small end, respectively, in accordance with Eq. (1) of NB-3641.1. For eccentric reducers, the dimensions shown in Fig. NB-3683.6-1 are to be taken at the location on the circumference where α is the maximum.

(a) *Primary Stress Indices.* The B_1 stress indices given in (1) or (2) below shall be used depending on the cone angle α .

(1) $B_1 = 0.5$ for $\alpha \leq 30$ deg.

(2) $B_1 = 1.0$ for $30 \text{ deg.} < \alpha \leq 60 \text{ deg.}$

(b) *Primary Plus Secondary Stress Indices.* The C_1 and C_2 stress indices given in (1) or (2) below shall be used depending on the dimensions of the transition radii r_1 and r_2 .

(1) For reducers with r and $r \geq 0.1 D$:

$$C_2 = 1.0 + 0.36 \alpha^{0.4} (D_n/t_n)^{0.4(D_2/D_1 - 0.5)}$$

where D_n/t_n is the larger of D_1/t_1 and D_2/t_2 .

(2) For reducers with r_1 and/or $r_2 < 0.1D_1$:

$$C_1 = 1.0 + 0.00465 \alpha^{1.285} (D_n/t_n)^{0.39}$$

$$C_2 = 1.0 + 0.0185 \alpha \sqrt{D_n/t_n}$$

where D_n/t_n is the larger of D_1/t_1 and D_2/t_2

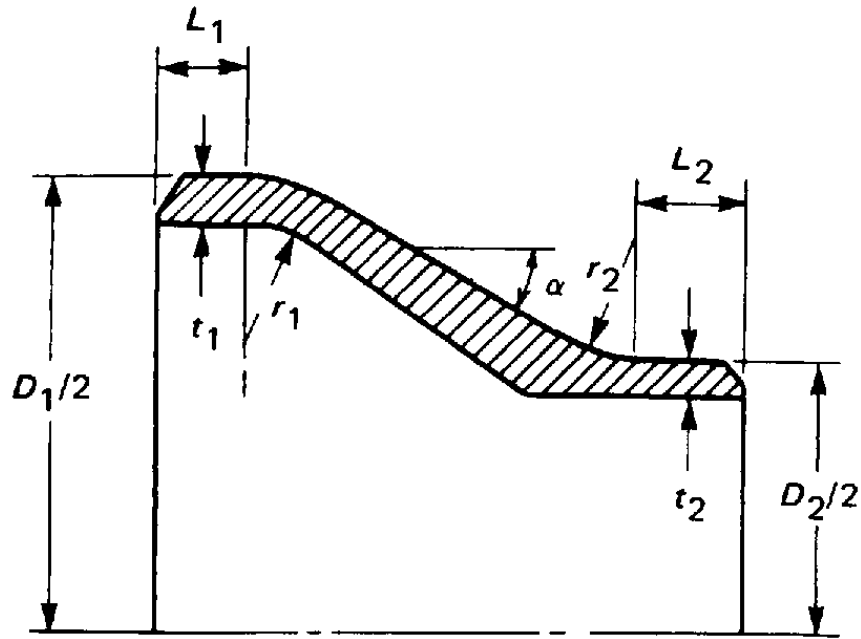


FIG. NB-3683.6-1

FIG. NB-3683.6-1

(c) *Peak Stress Indices.* The K_1 and K_2 indices given in (1), (2), or (3) below shall be used depending on the type of connecting weld and thickness dimensions.

(1) For reducers connected to pipe with flush girth butt welds:

$$K_1 = 1.1 - 0.1 \frac{L_m}{\sqrt{D_m} t_m} \text{ but not } < 1.0$$

$$K_2 = 1.1 - 0.1 \frac{L_m}{\sqrt{D_m} t_m} \text{ but not } < 1.0$$

where $\frac{L_m}{\sqrt{D_m} t_m}$ is the smaller of $\frac{L_1}{\sqrt{D_1} t_1}$ and $\frac{L_2}{\sqrt{D_2} t_2}$.

(2) For reducers connected to pipe with as-welded girth butt welds where t_1 and $t_2 > \frac{3}{16}$ in. (4.8 mm):

$$K_1 = 1.2 - 0.2 \frac{L_m}{\sqrt{D_m} t_m} \text{ but not } < 1.0$$

$$K_2 = 1.8 - 0.8 \frac{L_m}{\sqrt{D_m} t_m} \text{ but not } < 1.0$$

where $\frac{L_m}{\sqrt{D_m} t_m}$ is the smaller of $\frac{L_1}{\sqrt{D_1} t_1}$ and $\frac{L_2}{\sqrt{D_2} t_2}$.

(3) For reducers connected to pipe with as-welded girth butt welds where t_1 or $t_2 \leq \frac{3}{16}$ in. (4.8 mm):

$$K_1 = 1.2 - 0.2 \frac{L_m}{\sqrt{D_m} t_m} \text{ but not } < 1.0$$

$$K_2 = 2.5 - 1.5 L_m / \sqrt{D_m t_m} \text{ but not } < 1.0$$

where $L_m / \sqrt{D_m t_m}$ is the smaller of $L_1 / \sqrt{D_1 t_1}$ and $L_2 / \sqrt{D_2 t_2}$.

[98]

[98]

NB-3683.7 Curved Pipe or Butt Welding Elbows.

The stress indices given in Table NB-3681(a)-1, except as modified herein and in NB-3683.2, are applicable to curved pipe or butt welding elbows manufactured to the requirements of ANSI B16.9, ANSI B16.28, or MSS SP-87.

(a) *Primary Stress Index.* The B_1 and B_2 indices shall be taken as:

$$B_1 = -0.1 + 0.4h \text{ but not } < 0 \text{ nor } > 0.5$$

$$B_2 = 1.30/h^{2/3} \text{ but not } < 1.0$$

where

$$h = tR/r_m^2$$

(b) *Primary Plus Secondary Stress Indices.* The C_1 and C_2 indices shall be taken as:

$$C_1 = (2R - r_m)/2(R - r_m)$$

$$C_2 = 1.95/h^{2/3} \text{ but not } < 1.5$$

where

$$h = tR/r_m^2$$

[98]

[98]

NB-3683.8 Branch Connections per NB-3643.

The stress indices given in Table NB-3681(a)-1, except as modified herein and in NB-3683.2, are applicable to reinforced or unreinforced branch connections meeting the general requirements of NB-3643 and the additional requirements of NB-3683.8(a). Symbols are defined in NB-3683.1 and in Fig. NB-3643.3(a)-1.

(a) *Applicability.* The stress indices are applicable, provided the following limitations are met.

(1) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the outside surface of the run pipe is not less than three times the sum of the two adjacent branch inside radii in the longitudinal direction, or is not less than two times the sum of the two adjacent branch radii along the circumference of the run pipe.

(2) The axis of the branch connection is normal to the run pipe surface.

(3) The run pipe radius-to-thickness ratio R_m/T_r is less than 50, and the branch-to-run radius ratio r'_m/R_m is less than 0.50.

(4) The inside corner radius r_1 [Fig. NB-3643.3(a)-1] for nominal pipe sizes greater than 4 in. NPS (DN 100) shall be between 10% and 50% of T_r . The

radius r_1 is not required for branch pipe sizes smaller than 4 in. NPS (DN 100).

(5) The branch-to-run fillet radius r_2 is not less than the larger of $T_b/2$, $T_r/2$, or $(T_b + y)/2$ [Fig. NB-3643.3(a)-1 sketch (c)].

(6) The branch-to-pipe fillet radius r_3 is not less than the larger of $0.002 \theta d_o$ or $2(\sin\theta)^3$ times offset [Fig. NB-3643.3(a)-1], where θ is expressed in deg.

(7) If L_1 equals or exceeds $0.5\sqrt{r_1 T_b}$, then r'_m can be taken as the radius to the center of T_b .

(b) *Primary Stress Indices.* The primary stress indices B_{2b} and B_{2r} shall be taken as:

$$B_{2b} = 0.5C_{2b} \text{ but not } < 1.0$$

$$B_{2r} = 0.75C_{2r} \text{ but not } < 1.0$$

(c) *Primary Plus Secondary Stress Indices.* The C_1 , C_{2b} , and C_{2r} indices [for moment loadings, see NB-3683.1(d)] shall be taken as:

$$C_1 = 1.4 \left(\frac{D_m}{T_r} \right)^{0.182} \left(\frac{d_m}{D_m} \right)^{0.367} \left(\frac{T_r}{t_n} \right)^{0.382} \left(\frac{t_n}{r_2} \right)^{0.148}$$

but not < 1.2

If $r_2/t_n > 12$, use $r_2/t_n = 12$ for computing C_1 .

$$C_{2b} = 3 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{T'_b}{T_r} \right) \left(\frac{r'_m}{r_p} \right)$$

but not < 1.5

$$C_{2r} = 1.15 \left(\frac{r'_m}{t_n} \right)^{1/4}$$

but not < 1.5

where

For Figs. NB-3643.3(a)-1 sketches (a) and (b):

$$t_n = T_b \text{ if } L_1 \geq 0.5 (d_m T_b)^{1/2}$$

$$= T_b \text{ if } L_1 < 0.5 (d_m T_b)^{1/2}$$

For Fig. NB-3643.3(a)-1 sketch (c):

$$t_n = T_b + (2/3)y \text{ if } \theta \leq 30^\circ$$

$$= T_b + 0.385 L_1 \text{ if } \theta > 30^\circ$$

For Fig. NB-3643.3(a)-1 sketch (d):

$$t_n = T_b = T_b$$

(d) *Peak Stress Indices.* The peak stress indices K_{2b} and K_{2r} for moment loadings [see NB-3683.1(d)] shall be taken as:

$$K_{2b} = 1.0$$

$$K_{2r} = 1.75$$

and $K_{2r} C_{2r}$ shall be a minimum of 2.65.

[98]

[98]

NB-3683.9 Butt Welding Tees.

The stress indices given in Table NB-3681(a)-1, except as modified herein and in NB-3683.2, are applicable to butt welding tees manufactured to the requirements of ANSI B16.9 or MSS SP-87.

(a) *Primary Stress Indices.* The primary stress indices B_{2b} and B_{2r} shall be taken as:

$$B_{2b} = 0.4 (R_m/T_r)^{2/3} \text{ but not } < 1.0$$

$$B_{2r} = 0.50 (R_m/T_r)^{2/3} \text{ but not } < 1.0$$

(b) *Primary Plus Secondary Stress Indices.* The C_{2b} and C_{2r} stress indices for moment loadings [see NB-3683.1(d)] shall be taken as:

$$C_{2b} = 0.67 (R_m/T_r)^{2/3} \text{ but not } < 2.0$$

$$C_{2r} = 0.67 (R_m/T_r)^{2/3} \text{ but not } < 2.0$$

(c) *Peak Stress Indices.* The peak stress indices K_{2b} and K_{2r} for moment loadings [see NB-3683.1(d)] shall be taken as:

$$K_{2b} = 1.0$$

$$K_{2r} = 1.0$$

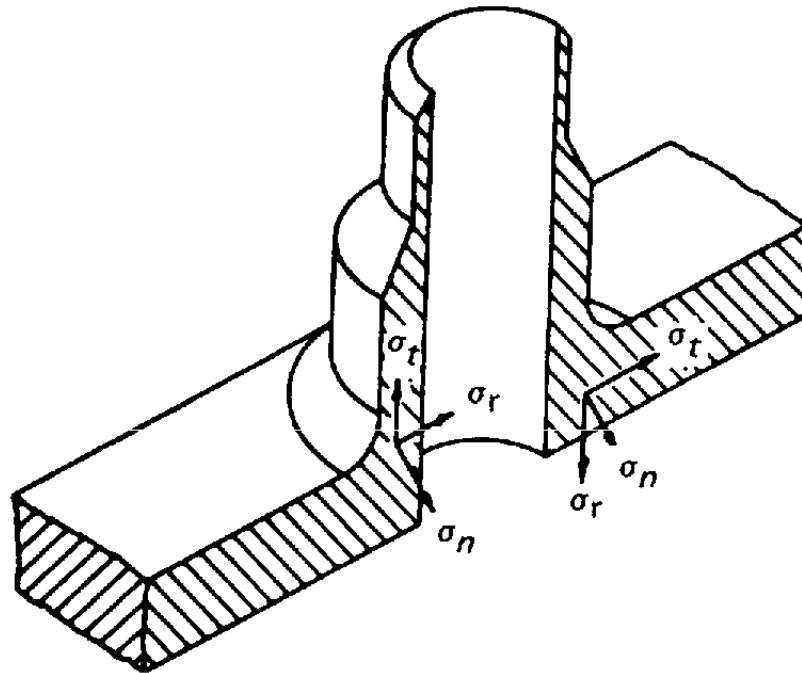
[98]

NB-3684 Stress Indices for Detailed Analysis

The symbols for the stress components and their definitions are given in Fig. NB-3684-1. These definitions are applicable to all piping products, and the

Page 167

stress indices given in the tables in NB-3685 and NB-3338 are so defined.



σ_t = stress component in the plane of the section under consideration and parallel to the boundary of the section
 σ_n = stress component normal to the plane of the section
 σ_r = stress component normal to the boundary of the section
 σ = stress intensity (combined stress) at the point under consideration

FIG. NB-3684-1 DIRECTION OF STRESS COMPONENTS

FIG. NB-3684-1 DIRECTION OF STRESS COMPONENTS

NB-3685 Curved Pipe or Welding Elbows

[98]

NB-3685.1 Applicability of Indices.

The indices given in Tables NB-3685.1-1 and NB-3685.1-2 give stresses in curved pipe or elbows at points remote from girth or longitudinal welds or other local discontinuities. Stresses in curved pipe or welding elbows with local discontinuities, such as longitudinal welds, support lugs, and branch connections in the elbow, shall be obtained by

appropriate theoretical analysis or by experimental analysis in accordance with Appendix II.
[98]

[98]

NB-3685.2 Nomenclature (Fig. NB-3685.2-1)

A	= an additional thickness, in. (NB-3641.1)
D_i	= $D_o - 2(t_m - A)$, in.
D_o	= nominal outside diameter of cross section, in.
$D_1(D_2)$	= maximum (minimum) outside diameter of elbow with out-of-round cross section essentially describable as an ellipse or oval shape (Fig. NB-3685.2-1), in.
E	= modulus of elasticity, psi (Section II, Part D, Subpart 1, Tables TM)
P	= internal pressure, psi
R	= bend radius, in.
r	= mean cross section radius, in.
t_m	= minimum specified wall thickness, in.
Z	= section modulus of cross section, in. ³ = $0.0982 (D_o^4 - D_i^4)/D_o$
λ	= $t_m R / r^2 \sqrt{1 - \nu^2}$ (Table NB-3685.1-2 limited to $\lambda \geq 0.2$)

[98]

NB-3685.3 Stress From Stress Indices.

To obtain stresses from stress index:

Load

Multiply Stress Index by

Internal Pressure

M_x	P
M_y	$M_x/2Z$
M_z	M_y/Z
	M_z/Z

NB-3685.4 Classification of Stresses.

For analysis of a curved pipe or welding elbow to NB-3210, the following rules shall apply to the classification of stresses developed under a load controlled in-plane or out-of-plane moment as distinguished from a displacement controlled loading.

(a) The entire membrane portion of the axial, circumferential, and torsional stresses shall be considered as primary (P_L).

(b) Seventy-five percent of the through-wall bending stresses in both the axial and the circumferential directions shall be classified as primary (P_b). The remaining 25% shall be classified as secondary (Q). The stresses induced by displacement controlled in-plane or out-of-plane moments shall be classified as secondary (Q).

NB-3686

NB-3686.1 Straight Pipe.

For $M = M_1$ or M_2 (see Fig. NB-3686.1-1):

$$k = 1.0 \theta_{\text{nom}} = \frac{Ml}{EI}$$

For $M = M_3$ (see Fig. NB-3686.1-1):

$$k = 1.0 \theta_{\text{nom}} = \frac{Ml}{GJ}$$

In both cases

E	= modulus of elasticity, psi
G	= shear modulus, psi
I	= plane moment of inertia, in. ⁴
J	= polar moment of inertia, in. ⁴
l	= one pipe diameter

**TABLE NB-3685.1-1
CURVED PIPE OR WELDING END ELBOWS, INTERNAL PRESSURE**

Location	Surface	Stress Direction	Stress Index [Note (1)]
Round Cross Section			
ϕ	Inside	σ_n	$\left[\frac{D_o - 0.8(t_m - A)}{2(t_m - A)} \right] \left[\frac{0.5(2R + r \sin \phi)}{R + r \sin \phi} \right] = i_1$
ϕ	Mid	σ_n	
ϕ	Outside	σ_n	
ϕ	Inside	σ_t	$\frac{D_i}{4(t_m - A)} = i_2$
ϕ	Mid	σ_t	
ϕ	Outside	σ_t	
Out-of-Round Cross Section [Note (2)]			
α	Inside	σ_n	$i_1 + i_3$
α	Mid	σ_n	i_1
α	Outside	σ_n	$i_1 - i_3$
α	Inside	σ_t	$i_2 + 0.3 i_3$
α	Mid	σ_t	i_2
α	Outside	σ_t	$i_2 - 0.3 i_3$

NOTES:

(1) The radial stress σ_r is equal to $-P$ on the inside surface, to $-P/2$ on the midsurface, and to 0 on the outside surface.

(2) For out-of-round cross section:

$$i_3 = \left[\frac{D_o(D_3 - D_2)}{2t_m^2} \right] \left[\frac{1.5}{1 + 0.455(D_o/t_m)^3 (P/E)} \right] \cos 2\alpha$$

TABLE NB-3685.1-1 CURVED PIPE OR WELDING END ELBOWS, INTERNAL PRESSURE

NB-3686.2 Curved Pipe and Welding Elbows.

The flexibility factors may be calculated by the equations given below for k , provided²⁵ that:

(a) R/r is not less than 1.7;

(b) center line length $R\alpha$ is greater than $2r$;

²⁵ The flexibility of a curved pipe or welding elbow is reduced by end effects, provided either by the adjacent straight pipe or by the proximity of other relatively stiff members which inhibit ovalization of the cross section. In certain cases, these end effects may also reduce the stress. Additional work is underway to provide guidance for both flexibility factors and stress indices where end effects are significant.

(c) there are no flanges or other similar stiffeners within a distance r from either end of the curved section of pipe or from the ends of welding elbows. For M_1 or M_2 (see Fig. NB-3686.2-1):

$$k = \frac{1.65}{h} \left[\frac{1}{1 + (Pr/tE)X_k} \right]$$

but not less than 1.0, and

$$\theta_{\text{nom}} = \frac{R}{EI} \int_0^a M(d\alpha)$$

For M_3 (see Fig. NB-3686.2-1):

$$k = 1.0$$

$$\theta_{\text{nom}} = \frac{R}{GJ} \int_0^a M(d\alpha)$$

In both cases

E	= modulus of elasticity, psi
G	= shear modulus of elasticity, psi
h	= tR/r^2
I	= plane moment of inertia of cross section, in. ⁴
J	= polar moment of inertia of cross section, in. ⁴
P	= internal pressure, psi
R	= bend radius, in.
r	= pipe or elbow mean radius, in.
t	= pipe or elbow nominal wall thickness, in.

Page 169

X_k	= $6(r/t)^{4/3} (R/r)^{1/3}$
α	= arc angle, rad

TABLE NB-3685.1-2
CURVED PIPE OR WELDING END ELBOWS, MOMENT LOADING ($\lambda \geq 0.2$)

Location	Surface	Stress Direction	Stress Index [Note (1)]
Torsional Moment M_x			
All	All	τ_{nt} [Note (2)]	1.0
In-Plane or Out-of-Plane Moments M_y or M_z [Note (3)]			
ϕ	Outside	σ_n	$\nu\sigma_{tm} + \sigma_{nb}$
ϕ	Mid	σ_n	$\nu\sigma_{tm}$
ϕ	Inside	σ_n	$\nu\sigma_{tm} - \sigma_{nb}$
ϕ	Outside	σ_t	$\sigma_{tm} + \nu\sigma_{nb}$
ϕ	Mid	σ_t	σ_{tm}
ϕ	Inside	σ_t	$\sigma_{tm} - \nu\sigma_{nb}$

NOTES:

- (1) The radial stress σ_r is zero for all surfaces.
(2) τ_{nt} is a shear stress in the n - t plane and must be appropriately combined with the principal stresses σ_n and σ_t to obtain principal stresses due to combinations of M_x with M_y or M_z .
(3) Nomenclature for stress indices:

ν = Poisson's ratio

$$\left. \begin{aligned} \sigma_{tm} &= \sin \phi + [(1.5X_2 - 18.75) \sin 3\phi + 11.25 \sin 5\phi]/X_4 \\ \sigma_{nb} &= \lambda (9X_2 \cos 2\phi + 225 \cos 4\phi)/X_4 \end{aligned} \right\} \text{In-plane } M_z$$

$$\left. \begin{aligned} \sigma_{tm} &= \cos \phi + [(1.5X_2 - 18.75) \cos 3\phi + 11.25 \cos 5\phi]/X_4 \\ \sigma_{nb} &= -\lambda (9X_2 \sin 2\phi + 225 \sin 4\phi)/X_4 \end{aligned} \right\} \text{Out-of-plane } M_y$$

$$X_1 = 5 + 6\lambda^2 + 24\psi$$

$$X_2 = 17 + 600\lambda^2 + 480\psi$$

$$X_3 = X_1X_2 - 6.25$$

$$X_4 = (1 - \nu^2)(X_3 - 4.5X_2)$$

$$\lambda = t_m R / (r^2 \sqrt{1 - \nu^2}) \text{ (Equations are valid for } \lambda \geq 0.2 \text{ only.)}$$

$$\psi = PR^2 / Ert_m$$

TABLE NB-3685.1-2 CURVED PIPE OR WELDING END ELBOWS, MOMENT LOADING ($\lambda \geq 0.2$)

NB-3686.3 Miter Bends.

The requirements of NB-3681(d) apply.

NB-3686.4 Welding Tee or Branch Connections.

For welding tees (ANSI B16.9) or branch connections (NB-3643) not included in NB-3686.5, the load displacement relationships shall be obtained by assuming that the run pipe and branch pipe extend to the intersection of the run pipe center line with the branch pipe center line. The imaginary juncture is to be assumed rigid, and the imaginary length of branch pipe from the juncture to the run pipe surface is also to be assumed rigid.

[98]

NB-3686.5 Branch Connections in Straight Pipe.

(For branch connections in straight pipe meeting the dimensional limitations of NB-3683.8.) The load displacement relationships may be obtained by modeling the branch connections in the piping system analysis (NB-3672) as shown in (a) through (d) below. (See Fig. NB-3686.5-1.)

(a) The values of k are given below.

For M_{x3} :

$$k = 0.1 (D/T_r)^{1.5} [(T_r/t_n) (d/D)]^{1/2} (T'_b/T_r)$$

For M_{z3} :

$$k = 0.2(D/T_r)[(T_r/t_n)(d/D)]^{1/2}(T'_b/T_r)$$

where

D = run pipe outside diameter, in.

d = branch pipe outside diameter, in.

Page 170

Page 171

E = modulus of elasticity, psi

I_b = moment of inertia of branch pipe, in.⁴ (to be calculated using d and T_b)

M = M_{x3} or M_{z3} , as defined in NB-3683.1(d)

T_r = run pipe wall thickness, in.

ϕ = rotation in direction of moment, rad

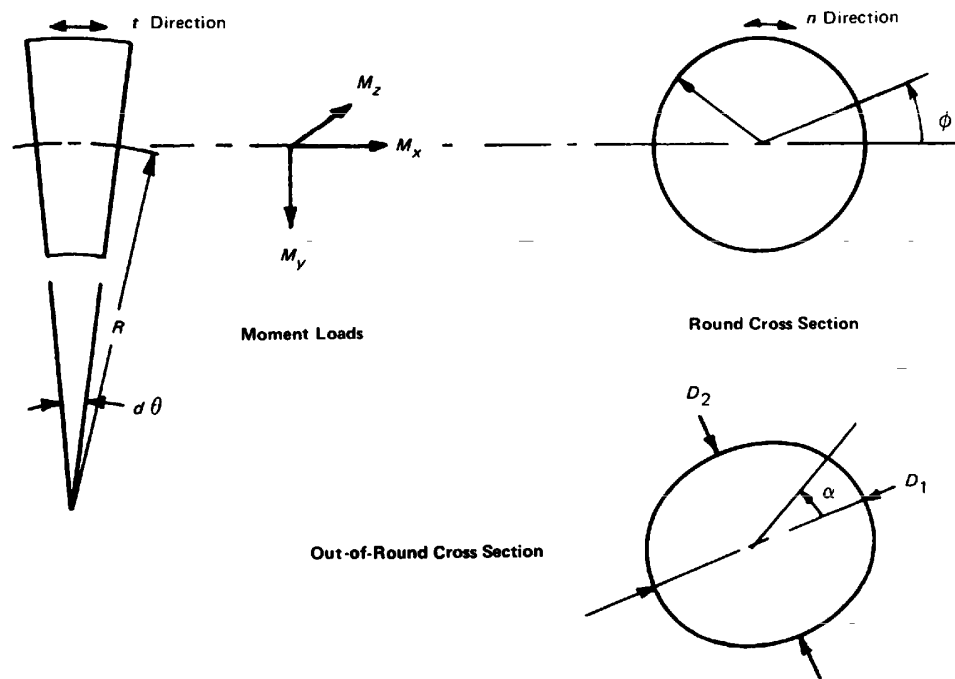


FIG. NB-3685.2-1 ELBOW NOMENCLATURE

FIG. NB-3685.2-1 ELBOW NOMENCLATURE

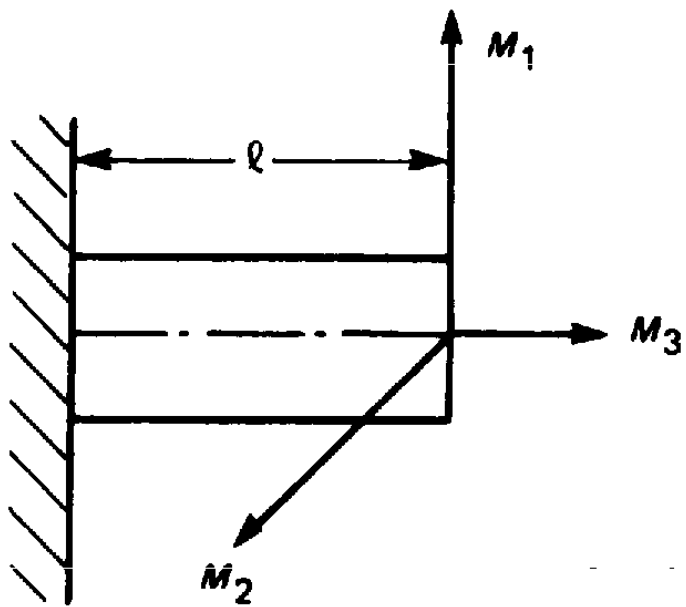


FIG. NB-3686.1-1

FIG. NB-3686.1-1

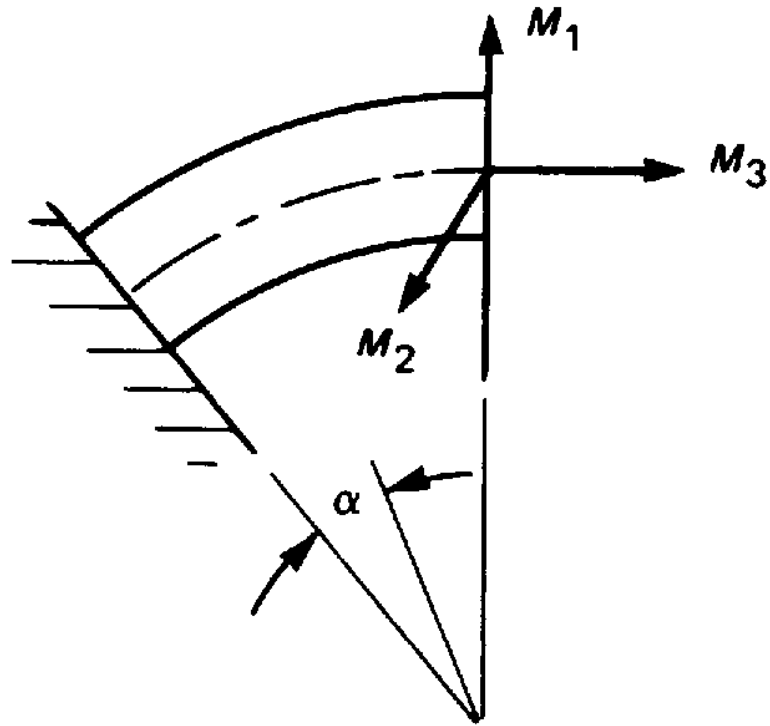


FIG. NB-3686.2-1

FIG. NB-3686.2-1

(b) For branch connections per Fig. NB-3643.3(a)-1 sketches (a) and (b):

$$t_n = T_b \text{ if } L_1 \geq 0.5 [(2r_i + T_b)T_b]^{1/2}$$

1/

$$= T_b \text{ if } L_1 < 0.5 [(2r_i + T_b)T_b]^{1/2}$$

(c) For branch connections per Fig. NB-3643.3(a)-1 sketch (c):

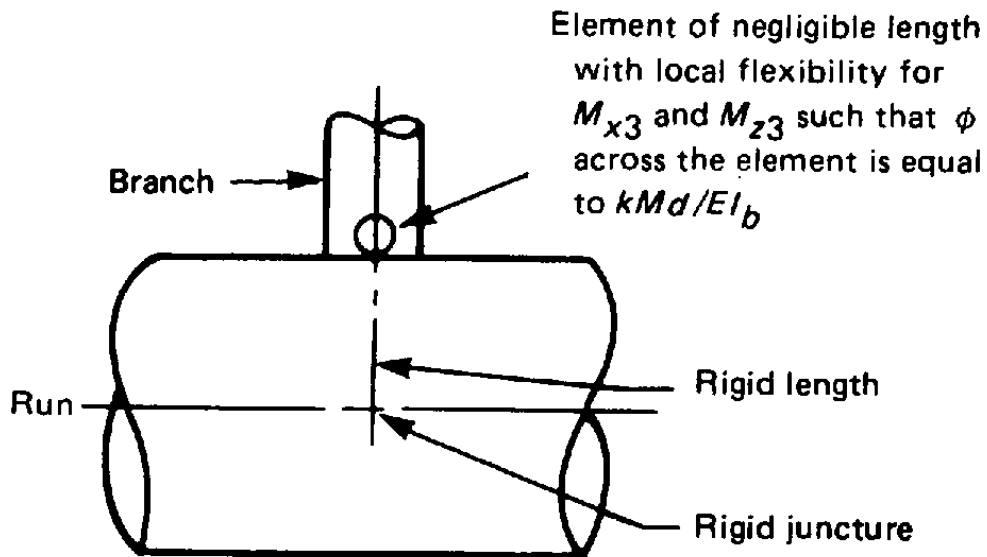
$$t_n = T_b + (\frac{2}{3})y \text{ if } \theta_n \leq 30 \text{ deg.}$$

$$= T_b + 0.385L_1 \text{ if } \theta_n > 30 \text{ deg.}$$

(d) For branch connections per Fig. NB-3643.3(a)-1 sketch (d):

$$t_n = T_b = T_b$$

[98]



**FIG. NB-3686.5-1 BRANCH CONNECTIONS
IN STRAIGHT PIPE**

FIG. NB-3686.5-1 BRANCH CONNECTIONS IN STRAIGHT PIPE

NB-3690 DIMENSIONAL REQUIREMENTS FOR PIPING PRODUCTS

NB-3691 Standard Piping Products

Dimensions of standard piping products shall comply with the standards and specifications listed in Table NB-3132-1.

However, compliance with these standards does not replace or eliminate the requirements of NB-3625.

NB-3692 Nonstandard Piping Products

The dimensions of nonstandard piping products shall be such as to provide strength and performance as required by this Subsection. Nonstandard piping products shall be designed in accordance with NB-3640.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NB-4000

ARTICLE NB-4000 FABRICATION AND INSTALLATION

Page 173

NB-4100 GENERAL REQUIREMENTS

NB-4110 INTRODUCTION

Components, parts, and appurtenances shall be fabricated and installed in accordance with the requirements of this Article and shall be manufactured from materials which meet the requirements of NB-2000.

NB-4120 CERTIFICATION OF MATERIALS AND FABRICATION BY CERTIFICATE HOLDER

NB-4121 Means of Certification

The Certificate Holder for an item shall certify, by application of the appropriate Code Symbol and completion of the appropriate Data Report in accordance with NCA-8000, that the materials used comply with the requirements of NB-2000 and that the fabrication or installation complies with the requirements of this Article.

NB-4121.1 Certification of Treatments, Tests, and Examinations.

If the Certificate Holder or Subcontractor performs treatments, tests, repairs, or examinations required by other Articles of this Subsection, the Certificate Holder shall certify that this requirement has been fulfilled (NCA-3862). Reports of all required treatments and of the results of all required tests, repairs, and examinations performed shall be available to the Inspector.

NB-4121.2 Repetition of Tensile or Impact Tests.

If during the fabrication or installation of the item the material is subjected to heat treatment that has not been covered by treatment of the test coupons (NB-2200) and that may reduce either tensile or impact properties below the required values, the tensile and impact tests shall be repeated by the Certificate Holder on test specimens taken from test coupons which have been taken and treated in accordance with the requirements of NB-2000.

NB-4121.3 Repetition of Surface Examination After Machining.

If, during the fabrication or installation of an item, materials for pressure-containing parts are machined, then the Certificate Holder shall reexamine the surface of the material in accordance with NB-2500 when:

(a) the surface was required to be examined by the magnetic particle or liquid penetrant method in accordance with NB-2500; and

(b) the amount of material removed from the surface exceeds the lesser of $\frac{1}{8}$ in. (3.2 mm) or 10% of the minimum required thickness of the part.

NB-4122

NB-4122 Material Identification

(a) Material for pressure-retaining parts shall carry identification markings which will remain distinguishable until the component is assembled or installed. If the original identification markings are cut off or the material is divided, the marks shall either be transferred to the parts cut or a coded marking shall be used to ensure identification of each piece of material during subsequent fabrication or installation. In either case, an as-built sketch or a tabulation of materials shall be made identifying each piece of material with the Certified Material Test Report, where applicable, and the coded marking. For studs, bolts, nuts, and heat exchanger tubes it is permissible to identify the Certified Material Test Reports for material in each component in lieu of identifying each piece of material with the Certified Material Test Report and the coded marking. Material supplied with a Certificate of Compliance, and welding and brazing material, shall be identified and controlled so that they can be traced to each component or installation of a piping system, or else a control procedure shall be employed which ensures that the specified materials are used.

Page 180

(b) Material from which the identification marking is lost shall be treated as non-conforming material until appropriate tests or other verifications are made and documented to assure material identification. Testing is required unless positive identification can be made by other documented evidence. The material may then be re-marked upon establishing positive identification.

NB-4122.1 Marking Material.

Material shall be marked in accordance with NB-2150.

NB-4123 Examinations

Visual examination activities that are not referenced for examination by other specific Code paragraphs, and are performed solely to verify compliance with requirements of NB-4000, may be performed by the persons who perform or supervise the work. These visual examinations are not required to be performed by personnel and procedures qualified to NB-5500 and NB-5100, respectively, unless so specified.

NB-4125 Testing of Welding and Brazing Material

All welding and brazing material shall meet the requirements of NB-2400.

NB-4130 REPAIR OF MATERIAL

NB-4131 Elimination and Repair of Defects

Material originally accepted on delivery in which defects exceeding the limits of NB-2500 are known or discovered during the process of fabrication or installation is unacceptable. The material may be used provided the condition is corrected in accordance with the requirements of NB-2500 for the applicable product form, except:

- (a) the limitation on the depth of the weld repair does not apply;
- (b) the time of examination of the weld repairs to weld edge preparations shall be in accordance with NB-5130;
- (c) radiographic examination is not required for weld repairs to seal membrane material when the material thickness is $\frac{1}{4}$ in. (6 mm) or less.

NB-4132 Documentation of Repair Welds of Base Material

The Certificate Holder who makes a repair weld exceeding in depth the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness, shall prepare a report which shall include a chart which shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results of repair welds.

NB-4200 FORMING, FITTING, AND ALIGNING

NB-4210 CUTTING, FORMING, AND BENDING

NB-4211 Cutting

Materials may be cut to shape and size by mechanical means, such as machining, shearing, chipping, or grinding, or by thermal cutting.

NB-4211.1 Preheating Before Thermal Cutting.

When thermal cutting is performed to prepare weld joints or edges, to remove attachments or defective material, or for any other purpose, consideration shall be given to preheating the material, using preheat schedules such as suggested in Appendix D.

NB-4212 Forming and Bending Processes

Any process may be used to hot or cold form or bend pressure-retaining material (NB-4223), including weld metal, provided the required dimensions are attained (see NB-4214 and NB-4220), and provided the impact properties of the material, when required, are not reduced below the minimum specified values, or they are effectively restored by heat treatment following the forming operation. *Hot forming* is defined as forming with the material temperature higher than 100°F (121°C) below the lower transformation temperature of the material. When required, the process shall be qualified for impact properties as outlined in NB-4213. When required, the process shall be qualified to meet thickness requirements as outlined in NB-4223.1.

NB-4213 Qualification of Forming Processes for Impact Property Requirements

A procedure qualification test shall be conducted using specimens taken from material of the same specification, grade or class, heat treatment, and with similar impact properties, as required for the material in the component. These specimens shall be subjected to the equivalent forming or bending process and heat treatment as the material in the component.

Applicable tests

Page 181

shall be conducted to determine that the required impact properties of NB-2300 are met after straining.

NB-4213.1 Exemptions.

Procedure qualification tests are not required for materials listed in (a) through (f) below:

(a) hot formed material, such as forgings, in which the hot forming is completed by the Material Organization prior to removal of the impact test specimens;

(b) hot formed material represented by test coupons which have been subjected to heat treatment representing the hot forming procedure and the heat treatments to be applied to the parts;

(c) material which does not require impact tests in accordance with NB-2300;

(d) material which has a final strain less than 0.5%;

(e) material where the final strain is less than that of a previously qualified procedure for that material;

(f) material from which the impact testing is required by NB-2300 is performed on each heat and lot, as applicable, after forming.

NB-4213.2 Procedure Qualification Test.

The procedure qualification test shall be performed in the manner stipulated in (a) through (f) below.

(a) The tests shall be performed on three different heats of material both before straining and after straining and heat treatment to establish the effects of the forming and subsequent heat treatment operations.

(b) Specimens shall be taken in accordance with the requirements of NB-2000 and shall be taken from the tension side of the strained material.

(c) The percent strain shall be established by the following formulas.

For cylinders:

$$\% \text{ strain} = \frac{50t}{R_f} \left(1 - \frac{R_f}{R_o} \right)$$

For spherical or dished surfaces:

$$\% \text{ strain} = \frac{75t}{R_f} \left(1 - \frac{R_f}{R_o} \right)$$

For pipe:

$$\% \text{ strain} = \frac{100r}{R}$$

where

R	= nominal bending radius to the center line of the pipe, in.
R_f	= final radius to center line of shell, in.
R_o	= original radius (equal to infinity for a flat part), in.
r	= nominal radius of the pipe, in.
t	= nominal thickness, in.

(d) The procedure qualification shall simulate the maximum percent surface strain, employing a bending process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient C_v test specimens shall be taken from each of the three heats of material to establish a transition curve showing both the upper and lower shelves. On each of the three heats, tests consisting of three impact specimens shall be conducted at a minimum of five different temperatures distributed throughout the transition region. The upper and lower shelves may be established by the use of one test specimen for each shelf. Depending on the product form, it may be necessary to plot the transition curves using both lateral expansion and energy level data (NB-2300). In addition, drop weight tests shall be made when required by NB-2300.

(f) Using the results of the impact test data from each of three heats, taken both before and after straining, determine either:

(1) the maximum change in *NDT* temperature along with:

(a) the maximum change of lateral expansion and energy at the temperature under consideration; or

(b) the maximum change of temperature at the lateral expansion and energy levels under consideration; or

(2) when lateral expansion is the acceptance criterion (NB-2300), either the maximum change in temperature or the maximum change in lateral expansion.

NB-4213.3 Acceptance Criteria for Formed Material.

To be acceptable, the formed material used in the component shall have impact properties before forming sufficient to compensate for the maximum loss of impact properties due to the qualified forming processes used.

NB-4213.4 Requalification.

A new procedure qualification test is required when any of the changes in (a), (b), or (c) below are made.

(a) The actual postweld heat treatment time at temperature is greater than previously qualified considering NB-2211. If the material is not postweld heat treated, the procedure must be qualified without postweld heat treatment.

(b) The maximum calculated strain of the material exceeds the previously qualified strain by more than 0.5%.

Page 182

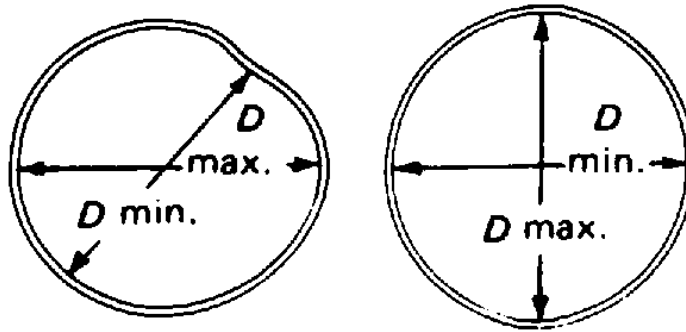


FIG. NB-4221.1-1 MAXIMUM DIFFERENCE IN CROSS-SECTIONAL DIAMETERS

FIG. NB-4221.1-1 MAXIMUM DIFFERENCE IN CROSS-SECTIONAL DIAMETERS

(c) Preheat over 250°F (121°C) is used in the forming or bending operation but not followed by a subsequent postweld heat treatment.

NB-4214 Minimum Thickness of Fabricated Material

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of NB-3000, the material may be repaired in accordance with NB-4130.

NB-4220 FORMING TOLERANCES

NB-4221 Tolerance for Vessel Shells

Cylindrical, conical, or spherical shells of a completed vessel, except formed heads covered by NB-4222, shall meet the requirements of the following subparagraphs at all cross sections.

NB-4221.1 Maximum Difference in Cross-Sectional Diameters.

The difference in inches between the maximum and minimum diameters at any cross section shall not exceed the smaller of $(D + 50)/200$ and $D/100$, where D is the nominal inside diameter, in., at the cross section under consideration. The diameters may be measured on the inside or outside of the vessel. If measured on the outside, the diameters shall be corrected for the plate thickness at the cross section under consideration (Fig. NB-4221.1-1). When the cross section passes through an opening, the permissible difference in inside diameters given herein may be increased by 2% of the

inside diameter of the opening.

NB-4221.2 Maximum Deviation From True Theoretical Form for External Pressure.

Vessels designed for external pressure shall meet the tolerances given in (a) through (c) below.

(a) The maximum plus or minus deviation from the true circular form of cylinders or the theoretical form of other shapes, measured radially on the outside or inside of the component, shall not exceed the maximum permissible deviation obtained from Fig. NB-4221.2(a)-1. Measurements shall be made from a segmental circular template having the design inside or outside radius depending on where the measurements are taken and a chord length equal to twice the arc length obtained from Fig. NB-4221.2(a)-2. For Fig. NB-4221.2(a)-1, the maximum permissible deviation e need not be less than $0.3t$. For Fig. NB-4221.2(a)-2, the arc length need not be greater than $0.30D_o$. Measurements shall not be taken on welds or other raised parts.

(b) The value of t , in., at any cross section is the nominal plate thickness less corrosion allowance for sections of constant thickness and the nominal thickness of the thinnest plate less corrosion allowance for sections having plates of more than one thickness.

(c) The value of L in Figs. NB-4221.2(a)-1 and NB-4221.2(a)-2 is determined by (1) through (3) below.

(1) For cylinders, L is as given in NB-3133.2.

(2) For cones, L is the axial length of the conical section if no stiffener rings are used or, if stiffener rings are used, the axial length from the head bend line at the large end of the cone to the first stiffener ring, with D_o taken as the outside diameter in inches of the cylinder at the large end of the cone.

(3) For spheres, L is one-half of the outside diameter D_o , in.

NB-4221.3 Deviations From Tolerances.

Deviations from the tolerance requirements stipulated in NB-4221.1 and NB-4221.2 are permitted, provided the drawings are modified and reconciled with the Design Report (NCA-3551) and provided the modifications are certified by a registered Professional Engineer in an addendum to the Design Report.

NB-4221.4 Tolerance Deviations for Vessel Parts Fabricated From Pipe.

Vessel parts subjected to either internal or external pressure and fabricated from pipe, meeting all other requirements of this Subsection, may have variations of diameter and deviations from circularity permitted by the specification for such pipe.

NB-4222 Tolerances for Formed Vessel Heads

The tolerance for formed vessel heads shall be as set forth in the following subparagraphs.

NB-4222.1 Maximum Difference in Cross-Sectional Diameters.

The skirt or cylindrical end of a formed head shall be circular to the extent that the difference in inches between the maximum and minimum diameters does not exceed the lesser of $(D + 50)/200$ and $(D + 12)/100$,

Page 183

Page 184

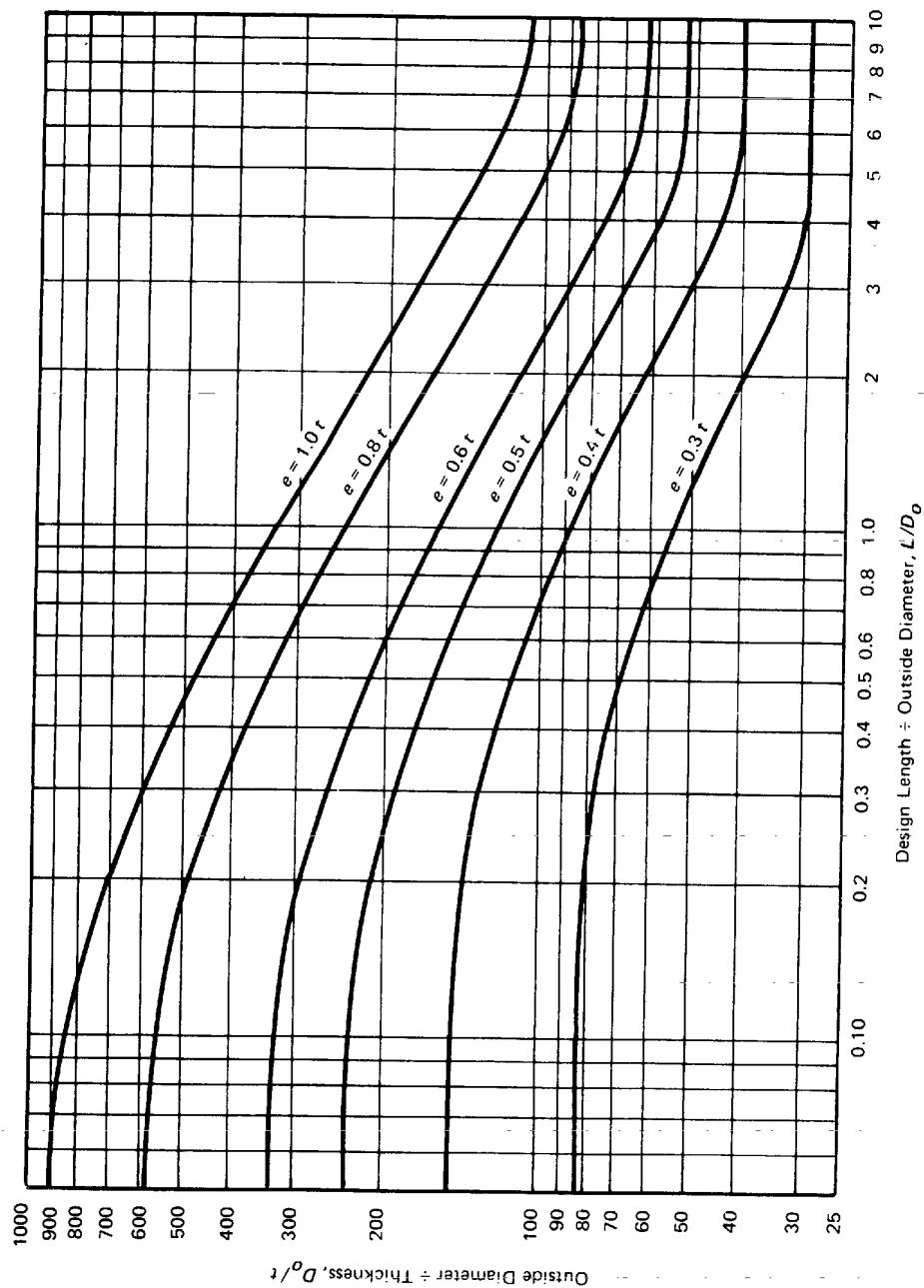


FIG. NB-4221.2(a)-1 MAXIMUM PERMISSIBLE DEVIATION e FROM A TRUE CIRCULAR FORM

FIG. NB-4221.2(a)-1 MAXIMUM PERMISSIBLE DEVIATION e FROM A TRUE CIRCULAR FORM

where D is the nominal inside diameter, in., and shall match the cylindrical edge of the adjoining part within the

alignment tolerance specified in NB-4232.

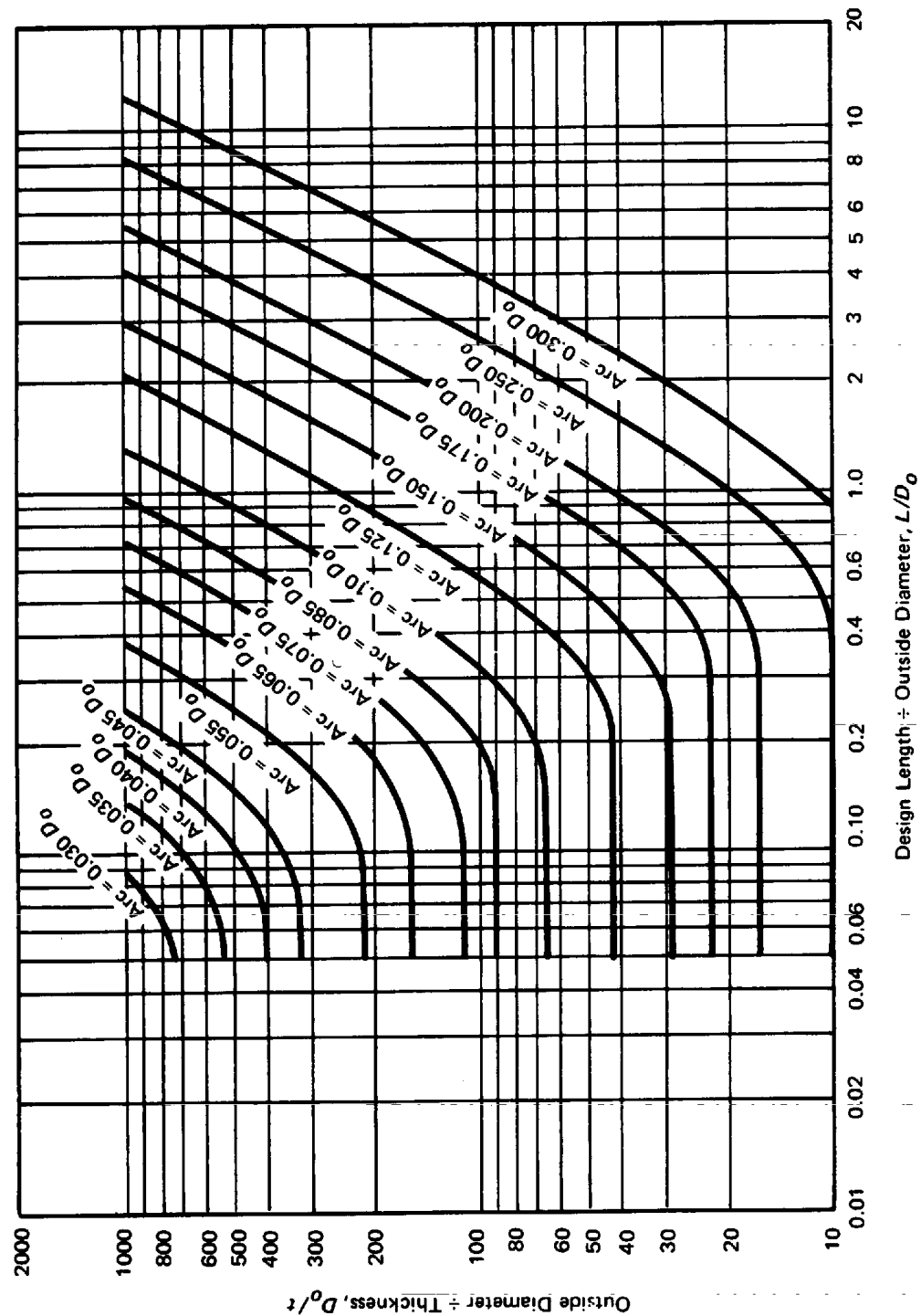


FIG. NB-4221.2(a)-2

NB-4222.2 Deviation From Specified Shape

(a) The inner surface of a torispherical or ellipsoidal head shall not deviate outside the specified shape by more than $1\frac{1}{4}\%$ of D , inside the specified shape by more than $\frac{5}{8}\%$ of D , where D is the nominal inside diameter of the vessel. Such deviations shall be measured perpendicular to the specified shape and shall not be abrupt. The knuckle radius shall not be less than specified. For 2:1 ellipsoidal heads, the knuckle radius may be considered to be 17% of the diameter of the vessel.

(b) Hemispherical heads and any spherical portion of a formed head shall meet the local tolerances for spheres as given in NB-4221.2, using L as the outside spherical radius, in., and D_o as two times L .

(c) Deviation measurements shall be taken on the surface of the base material and not on welds.

NB-4223 Tolerances for Formed or Bent Piping

The tolerances for formed or bent piping shall be as set forth in the following subparagraphs.

NB-4223.1 Minimum Wall Thickness

(a) In order to assure that the wall thickness requirements of the design calculations are met, the actual thickness shall be measured, or the process shall be qualified by demonstrating that it will maintain the required wall thickness.

(b) As an alternative to (a) above, the requirements of Table NB-3642.1(b)-1 shall be followed.

NB-4223.2 Ovality Tolerance.

Unless otherwise justified by the Design Report, the ovality of piping after bending shall not exceed 8% as determined by:

$$100 \times (D_{\max} - D_{\min}) / D_o$$

where

D_o = nominal pipe outside diameter, in.

$D_{\min}$ = minimum outside diameter after bending or forming, in.

$D_{\max}$ = maximum outside diameter after bending or forming, in.

NB-4230 FITTING AND ALIGNING

NB-4231 Fitting and Aligning Methods

Parts that are to be joined by welding may be fitted, aligned, and retained in position during the welding operation by the use of bars, jacks, clamps, tack welds, or temporary attachments.

NB-4231.1 Tack Welds.

Tack welds used to secure alignment shall either be removed completely, when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified welders using qualified welding procedures. When tack welds are to become part of the finished weld, they shall be visually examined and defective tack welds shall be removed.

NB-4232 Alignment Requirements When Components Are Welded From Two Sides

(a) Alignment of sections which are welded from two sides shall be such that the maximum offset of the finished weld

will not be greater than the applicable amount listed in Table NB-4232-1, where t is the nominal thickness of the thinner section at the joint.

(b) Joints in spherical vessels, joints within heads, and joints between cylindrical shells and hemispherical heads shall meet the requirements in Table NB-4232-1 for longitudinal joints.

NB-4232.1 Fairing of Offsets.

Any offset within the allowable tolerance provided above shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld. In addition, offsets greater than those stated in Table NB-4232-1 are acceptable provided the requirements of NB-3200 are met.

NB-4233 Alignment Requirements When Inside Surfaces Are Inaccessible

(a) When the inside surfaces of items are inaccessible for welding or fairing in accordance with NB-4232, alignment of sections shall meet the requirements of (1) and (2) below:

(1)(a) For circumferential joints the inside diameters shall match each other within $\frac{1}{16}$ in. (1.6 mm). When the items are aligned concentrically, a uniform mismatch of $\frac{1}{32}$ in. (0.8 mm) all around the joint can result as shown in Fig.

NB-4233(a)-1 sketch (a).

Page 186

However, other variables not associated with the diameter of the item often result in alignments that are offset rather than concentric. In these cases, the maximum misalignment at any one point around the joint shall not exceed $\frac{3}{32}$ in. (2.4 mm) as shown in Fig. NB-4233(a)-1 sketch (b). Should tolerances on diameter, wall thickness, out-of-roundness, etc., result in inside diameter variations which do not meet these limits, the inside diameters shall be counterbored, sized, or ground to produce a bore within these limits, provided the requirements of NB-4250 are met.

**TABLE NB-4232-1
MAXIMUM ALLOWABLE OFFSET IN
FINAL WELDED JOINTS**

Section Thickness, in.	Direction of Joints	
	Longitudinal	Circumferential
Up to $\frac{1}{2}$, incl.	$\frac{1}{4}t$	$\frac{1}{4}t$
Over $\frac{1}{2}$ to $\frac{3}{4}$, incl.	$\frac{1}{8}$ in.	$\frac{1}{4}t$
Over $\frac{3}{4}$ to $1\frac{1}{2}$, incl.	$\frac{1}{8}$ in.	$\frac{3}{16}$ in.
Over $1\frac{1}{2}$ to 2, incl.	$\frac{1}{8}$ in.	$\frac{1}{8}t$
Over 2	Lesser of $\frac{1}{16}t$ or $\frac{3}{8}$ in.	Lesser of $\frac{1}{8}t$ or $\frac{3}{4}$ in.

TABLE NB-4232-1 MAXIMUM ALLOWABLE OFFSET IN FINAL WELDED JOINTS

(b) Offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(2) For longitudinal joints the misalignment of inside surfaces shall not exceed $\frac{3}{32}$ in. (2.4 mm) and the offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(b) Single welded joints may meet the alignment requirements of (a)(1) and (a)(2) above in lieu of the requirements of NB-4232.

NB-4240 REQUIREMENTS FOR WELD JOINTS IN COMPONENTS

NB-4241 Category A Weld Joints in Vessels and Longitudinal Weld Joints in Other Components

Category A weld joints in vessels and longitudinal weld joints in other components shall be full penetration butt joints. Joints that have been welded from one side with backing that has been removed and those welded from one side without backing are acceptable as full penetration welds provided the weld root side of the joints meets the requirements of NB-4424.

NB-4242 Category B Weld Joints in Vessels and Circumferential Weld Joints in Other Components

Category B weld joints in vessels and circumferential weld joints in other components shall be full penetration butt joints, except that piping 2 in. nominal pipe size (DN 50) and smaller may be socket welded. When used, backing strips shall be continuous in cross section. Joints prepared with opposing lips to form an integral backing strip and joints with backing strips which are not later removed are acceptable provided the requirements of NB-3352.2 are met.

NB-4243 Category C Weld Joints in Vessels and Similar Weld Joints in Other Components

Category C weld joints in vessels and similar weld joints in other components shall be full penetration joints, except that 2 in. nominal pipe size (DN 50) and smaller socket welded joints may be used on component nozzles and in piping. Joints that have been welded from one side with backing that has been removed and those welded from one side without backing are acceptable as full penetration welds provided the weld root side of the joints meets the requirements of NB-4424. Either a butt welded joint or a full penetration corner joint as shown in Fig. NB-4243-1 shall be used.

NB-4244 Category D Weld Joints in Vessels and Branch Piping Weld Joints in Other Components

Category D weld joints in vessels and similar weld joints in other components shall be full or partial penetration weld joints using one of the details of (a) through (e) below.

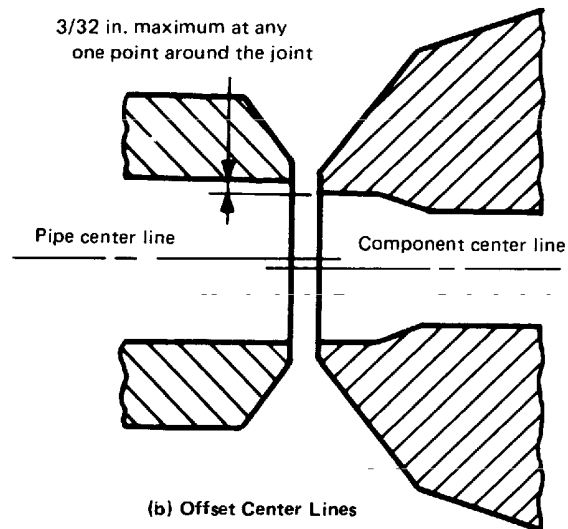
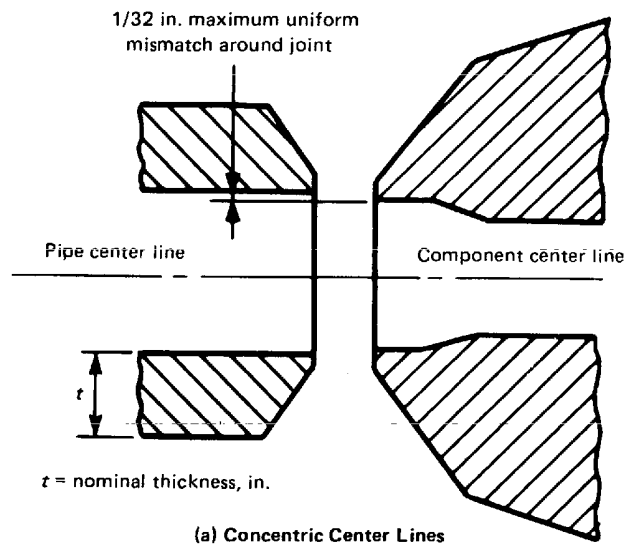
(a) *Butt Welded Nozzles and Branch Piping Connections.* Nozzles and branch piping connections shall be attached by full penetration butt welds through the wall of the component, nozzle, or branch as shown in Fig. NB-4244(a)-1. Backing strips, if used, shall be removed.

(b) *Corner Welded Nozzles and Branch Piping Connections.* Nozzles and branch piping connections shall be joined to the component by full penetration welds through the wall of the component, nozzle, or branch similar to those shown in Fig. NB-4244(b)-1. Backing strips, if used, shall be removed.

(c) *Deposited Weld Metal of Openings for Nozzles and Branch Piping Connections.* Nozzles and branch piping connections shall be joined to the component

Page 187

Page 188



GENERAL NOTE:

The weld end transitions are typical and are not intended as requirements. Refer to NB-4250 for weld end transition requirements.

FIG. NB-4233(a)-1 BUTT WELD ALIGNMENT AND MISMATCH TOLERANCES FOR UNEQUAL I.D. AND O.D. WHEN COMPONENTS ARE WELDED FROM ONE SIDE AND FAIRING IS NOT PERFORMED

FIG. NB-4233(a)-1 BUTT WELD ALIGNMENT AND MISMATCH TOLERANCES FOR UNEQUAL I.D. AND O.D. WHEN COMPONENTS ARE WELDED FROM ONE SIDE AND FAIRING IS NOT PERFORMED

Page 189

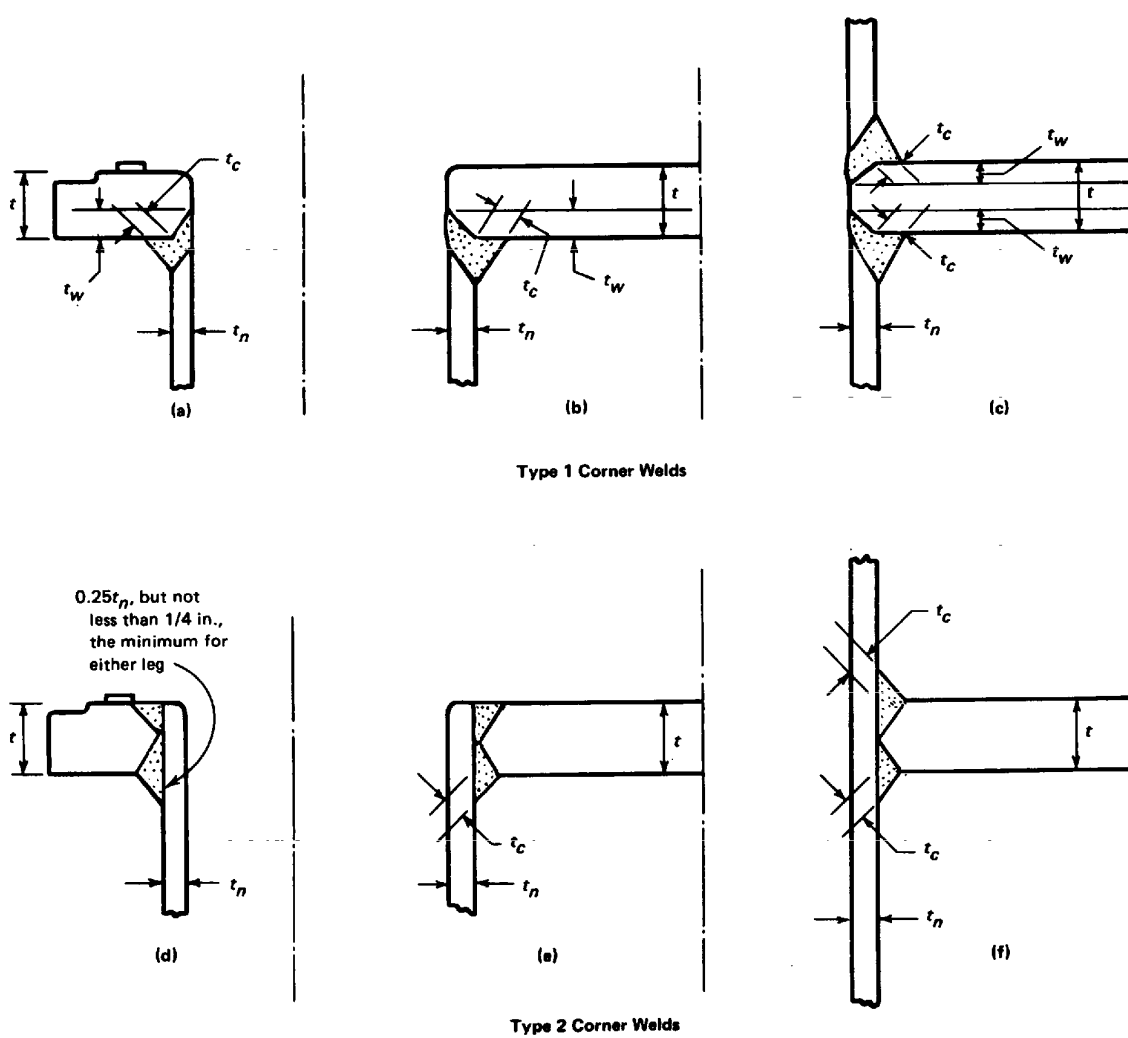
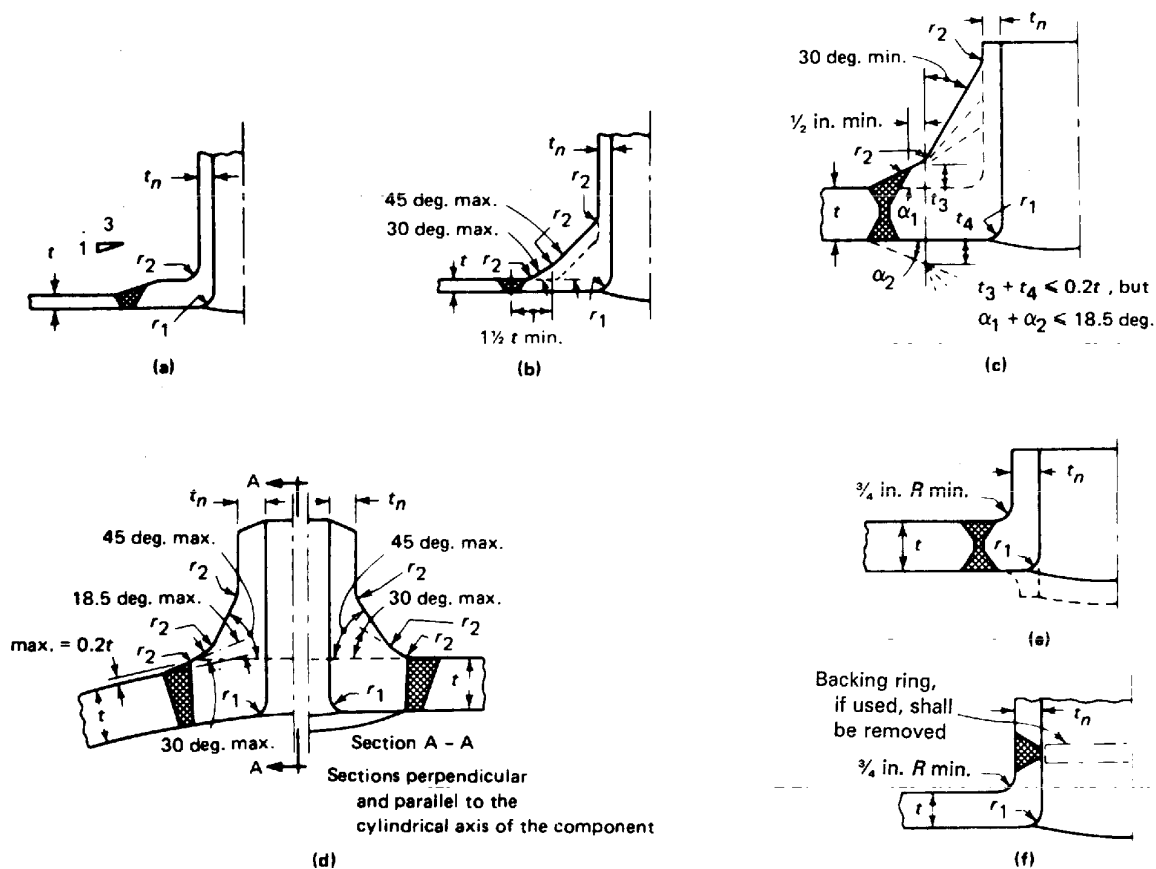


FIG. NB-4243-1 ACCEPTABLE FULL PENETRATION WELD DETAILS FOR CATEGORY C JOINTS (NB-3352.3)

FIG. NB-4243-1 ACCEPTABLE FULL PENETRATION WELD DETAILS FOR CATEGORY C JOINTS (NB-3352.3)

Page 190



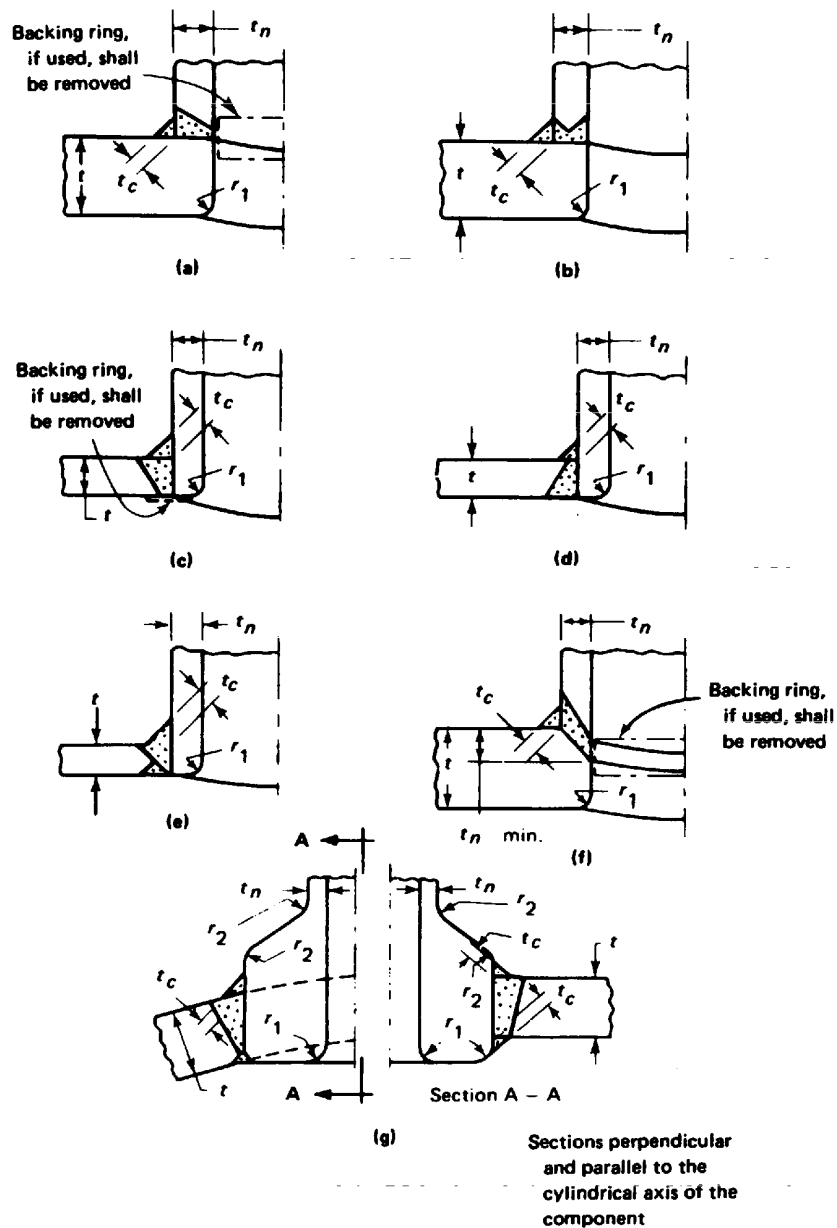
GENERAL NOTES:

- (a) For definitions of symbols, see NB-3352.4(a) for vessels and NB-3643 for piping.
- (b) Reinforcement may be distributed within the limits prescribed by the Code.

FIG. NB-4244(a)-1 NOZZLE, BRANCH, AND PIPING CONNECTIONS JOINED BY FULL PENETRATION BUTT WELDS

FIG. NB-4244(a)-1 NOZZLE, BRANCH, AND PIPING CONNECTIONS JOINED BY FULL PENETRATION BUTT WELDS

by full penetration weld to built-up weld deposits applied to the component, nozzle, or branch as shown in Fig. NB-4244(c)-1. Backing strips, if used, shall be removed. Fillet welds shall be used only to provide a transition between the parts joined or to provide a seal. The fillet welds, when used, shall be finished by grinding to provide a smooth surface having a transition radius at its intersection with either part being joined.



GENERAL NOTE: For definitions of symbols, see NB-3352.4(b) for vessels and NB-3643 for piping.

FIG. NB-4244(b)-1 NOZZLE, BRANCH, AND PIPING CONNECTIONS JOINED BY FULL PENETRATION CORNER WELDS

FIG. NB-4244(b)-1 NOZZLE, BRANCH, AND PIPING CONNECTIONS JOINED BY FULL PENETRATION CORNER WELDS

(d) *Partial Penetration Welded Nozzles and Branch Piping Connections.* Partial penetration welds in components and branch piping connections shall meet the weld design requirements of NB-3352.4(d) for vessels or NB-3643 for piping branch connections. Nozzles shall be attached as shown in Figs. NB-4244(d)-1 and NB-4244(d)-2.

(e) *Oblique Nozzles and Branch Piping Connections.* Oblique nozzles and branch piping connections shall be joined to the component by full penetration welds through the nozzle or branch as shown in Fig. NB-4244(e)-1. Backing rings, if used, shall be removed.

NB-4250 WELDING END TRANSITIONS - MAXIMUM ENVELOPE

The welding ends of items shall provide a gradual change in thickness from the item to the adjoining item. Any welding end transition which lies entirely within the envelope shown in Fig. NB-4250-1 is acceptable provided:

- (a) the wall thickness in the transition region is not less than the minimum wall thickness of the adjoining pipe;
- (b) sharp reentrant angles and abrupt changes in slope in the transition region are avoided. When the included angle between any two adjoining surfaces of a taper transition is less than 150 deg., the intersection or corner (except for the weld reinforcement) shall be provided with a radius of at least $0.05t_{\min}$; and
- (c) if the weld is subject to preservice inspection, the length of the counterbore shall be $2t_{\min}$ for pipe and $t_{\min}$ for components and fittings, as shown in Fig. NB-4250-2 or Fig. NB-4250-3.

NB-4300 WELDING QUALIFICATIONS

NB-4310 GENERAL REQUIREMENTS

NB-4311 Types of Processes Permitted

Only those welding processes which are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Subsection may be used for welding pressure-retaining material or attachments thereto. Any process used shall be such that the records required by NB-4320 can be prepared, except that records for stud welds shall be traceable to the welders and welding operators and not necessarily to each specific weld.

NB-4311.1 Stud Welding Restrictions.

Stud welding is acceptable only for nonstructural and temporary attachments (NB-4435). Studs shall be limited to 1 in. (25 mm) maximum diameter for round studs and an equivalent cross-sectional area for studs of other shapes when welding in the flat position and $\frac{3}{4}$ in. (19 mm) diameter for all other welding positions. Postweld heat treatment shall comply with NB-4600, except that time at temperature need not exceed $\frac{1}{2}$ hr regardless of base material thickness. Welding procedure and performance qualification shall comply with the requirements of Section IX.

NB-4311.2 Capacitor Discharge Welding.

Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments provided:

- (a) temporary attachments are removed in accordance with the provisions of NB-4435(b); and
- (b) the energy output for permanent nonstructural attachments such as strain gages and thermocouples is limited to 125 W-sec, and the minimum thickness of the material to which the attachment is made is greater than 0.09 in. (2.9 mm); and
- (c) a Welding Procedure Specification is prepared describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required.

NB-4311.4 Inertia and Continuous Drive Friction Welding

- (a) Inertia and continuous drive friction welding shall not be used for the fabrication of vessels and piping.
- (b) The weld between the two members shall be a full penetration weld.

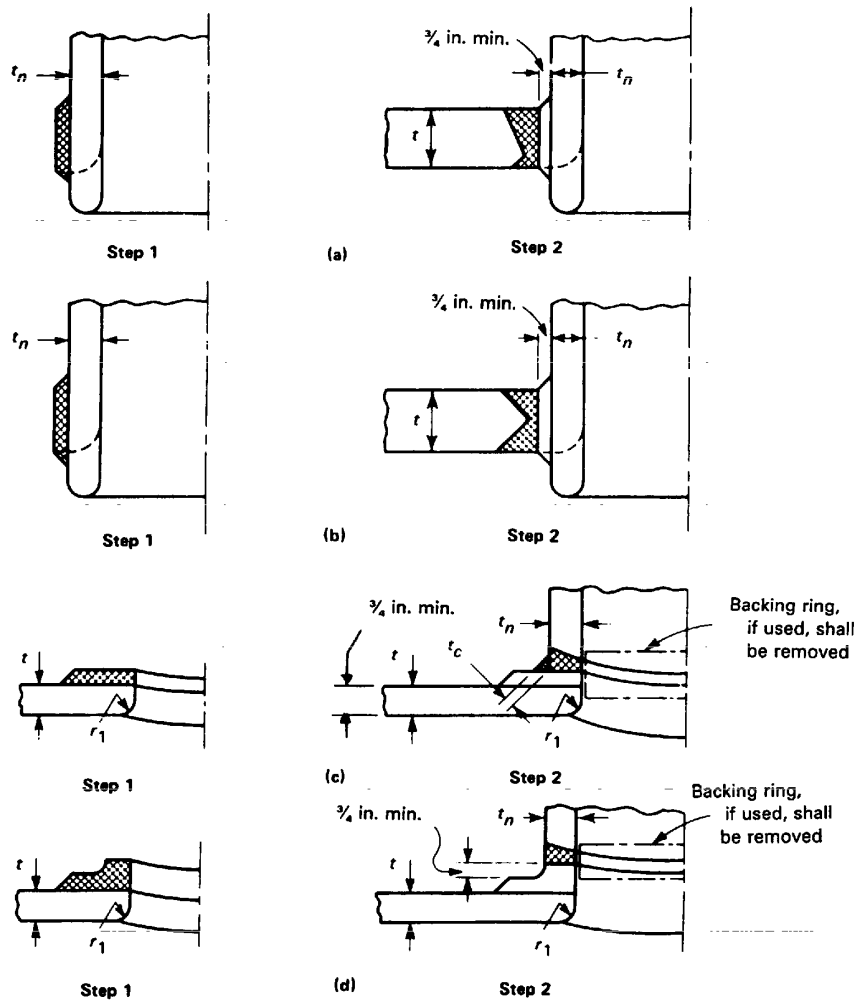
NB-4320 WELDING QUALIFICATIONS, RECORDS, AND IDENTIFYING STAMPS

NB-4321 Required Qualifications

(a) Each Certificate Holder is responsible for the welding done by his organization, and each Certificate Holder shall establish the procedure and conduct the tests required by this Article and by Section IX in

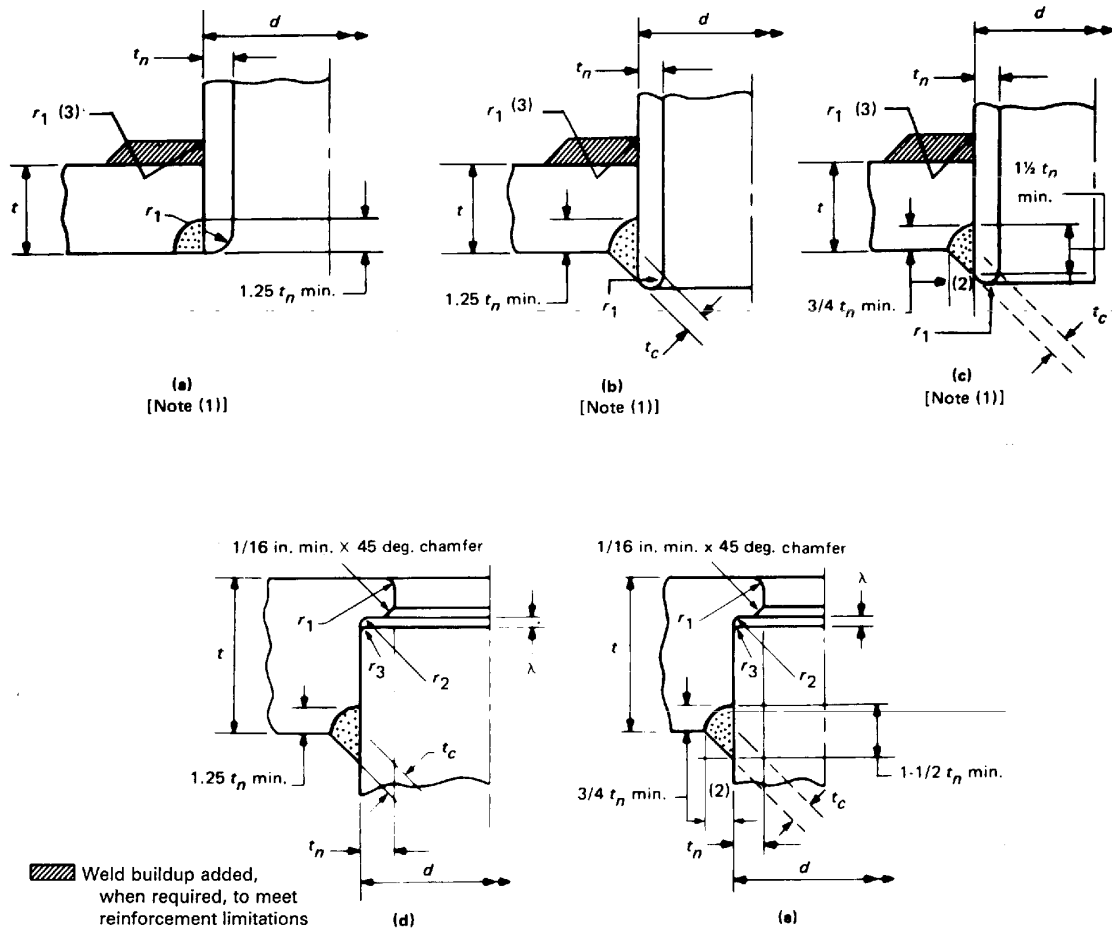
Page 192

Page 193



GENERAL NOTE: For definitions of symbols, see NB-3352.4(c) for vessels and NB-3643 for piping.

FIG. NB-4244(c)-1 DEPOSITED WELD METAL USED AS REINFORCEMENT OF OPENINGS FOR NOZZLE, BRANCH, AND PIPING CONNECTIONS



GENERAL NOTES:

- Weld deposit reinforcement, if used, shall be examined as required in NB-5244.
- The $3/4 t_n$ min. dimension applies to the fillet leg and the J-groove depth.
- Weld groove design for oblique nozzles of this type requires special consideration to achieve the $1.25 t_n$ minimum depth of weld and adequate access for welding inspection. With due regard to the requirements in Fig. NB-4244(c)-1, the welds shown in the sketches may be on either the inside or the outside. Weld preparation may be J-groove as shown or straight bevel. If weld deposit reinforcement is not used, r_1 shall apply to I.D. of base material instead of I.D. of weld buildup.
- For definitions of symbols, see NB-3352.4(d) for vessels and NB-3643 for piping.

FIG. NB-4244(d)-1 PARTIAL PENETRATION NOZZLE AND BRANCH PIPING CONNECTIONS

FIG. NB-4244(d)-1 PARTIAL PENETRATION NOZZLE AND BRANCH PIPING CONNECTIONS

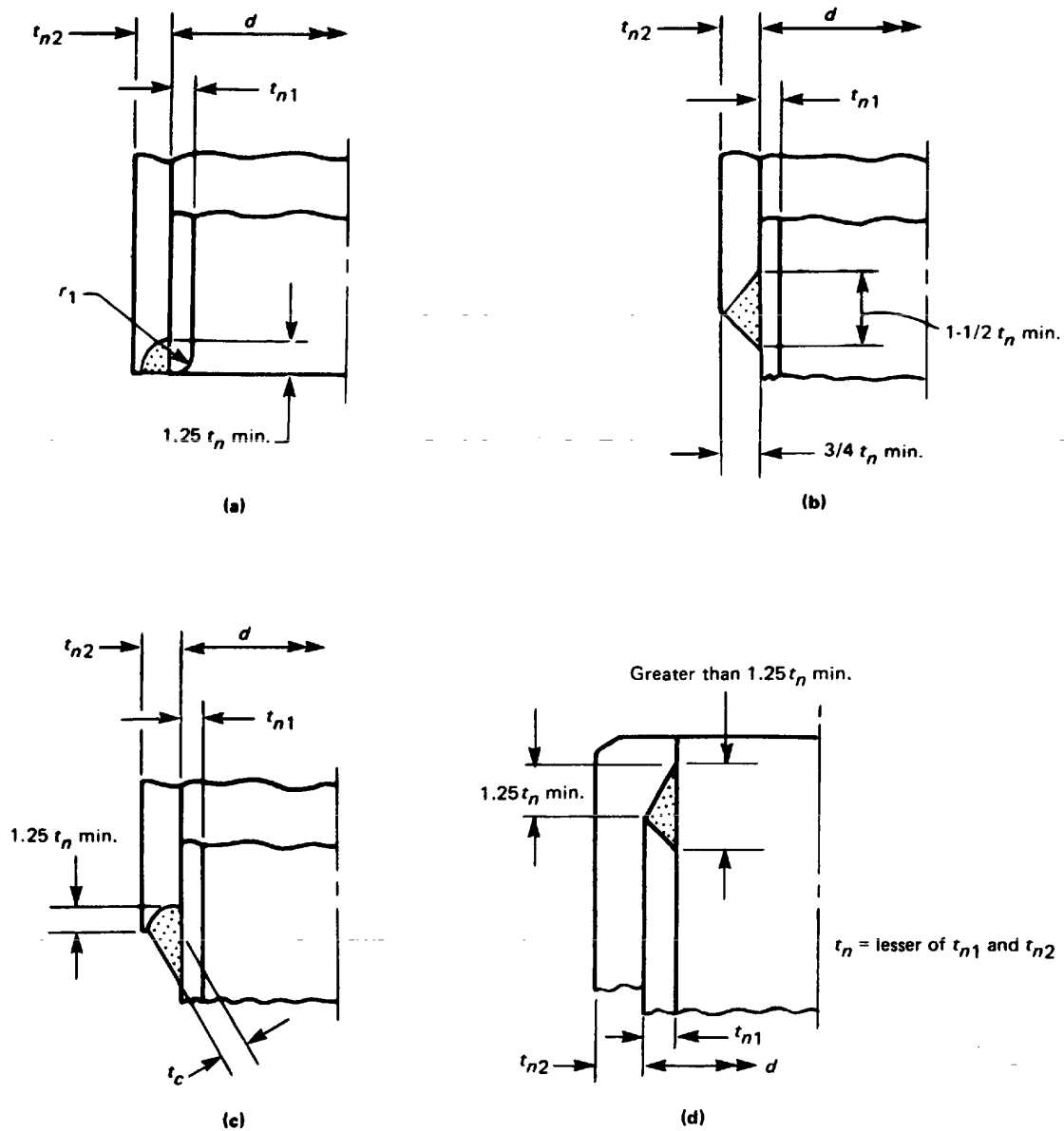
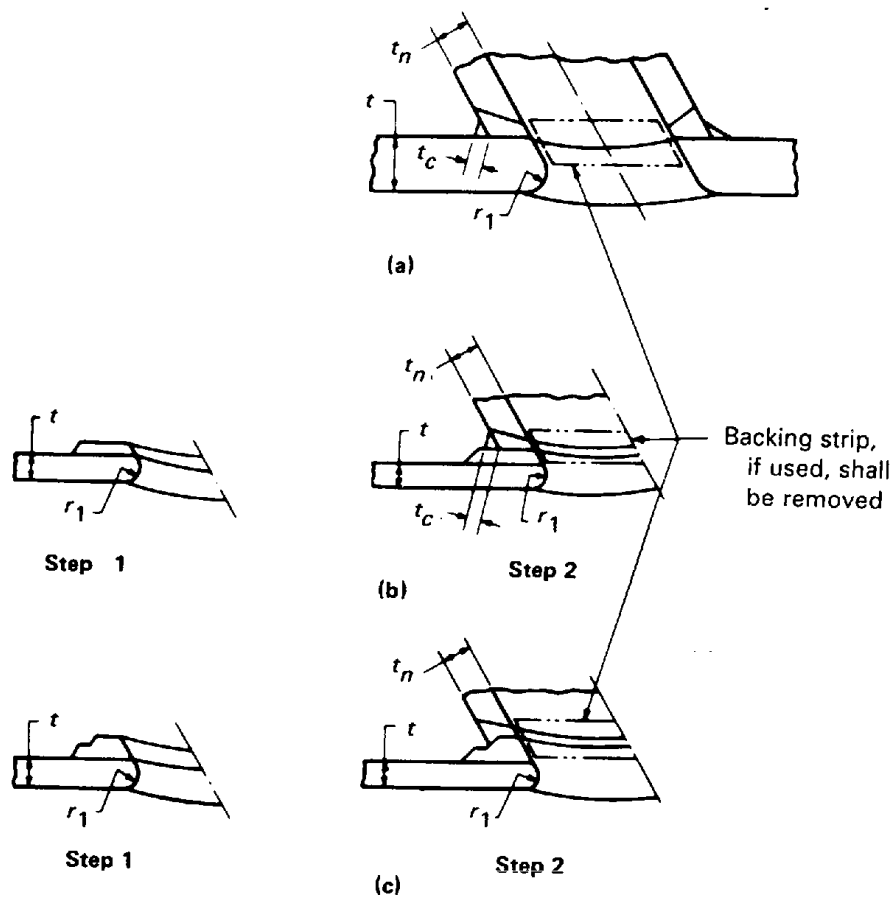


FIG. NB-4244(d)-2 PARTIAL PENETRATION NOZZLE FOR COAXIAL CYLINDERS

FIG. NB-4244(d)-2 PARTIAL PENETRATION NOZZLE FOR COAXIAL CYLINDERS

order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures.



GENERAL NOTES:

(a) Step 1 examination required before assembly.

(b) For definitions of symbols, see NB-3352.4(e) for vessels and NB-3643 for piping.

FIG. NB-4244(e)-1 OBLIQUE CONNECTIONS

FIG. NB-4244(e)-1 OBLIQUE CONNECTIONS

(b) Procedures, welders, and welding operators used to join permanent or temporary attachments to pressure parts and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Article.

(c) When making procedure test plates for butt welds, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. This applies particularly to material and weld metal of 80.0 ksi (552 MPa) tensile strength or higher and heavy sections of both low and high tensile strength material. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

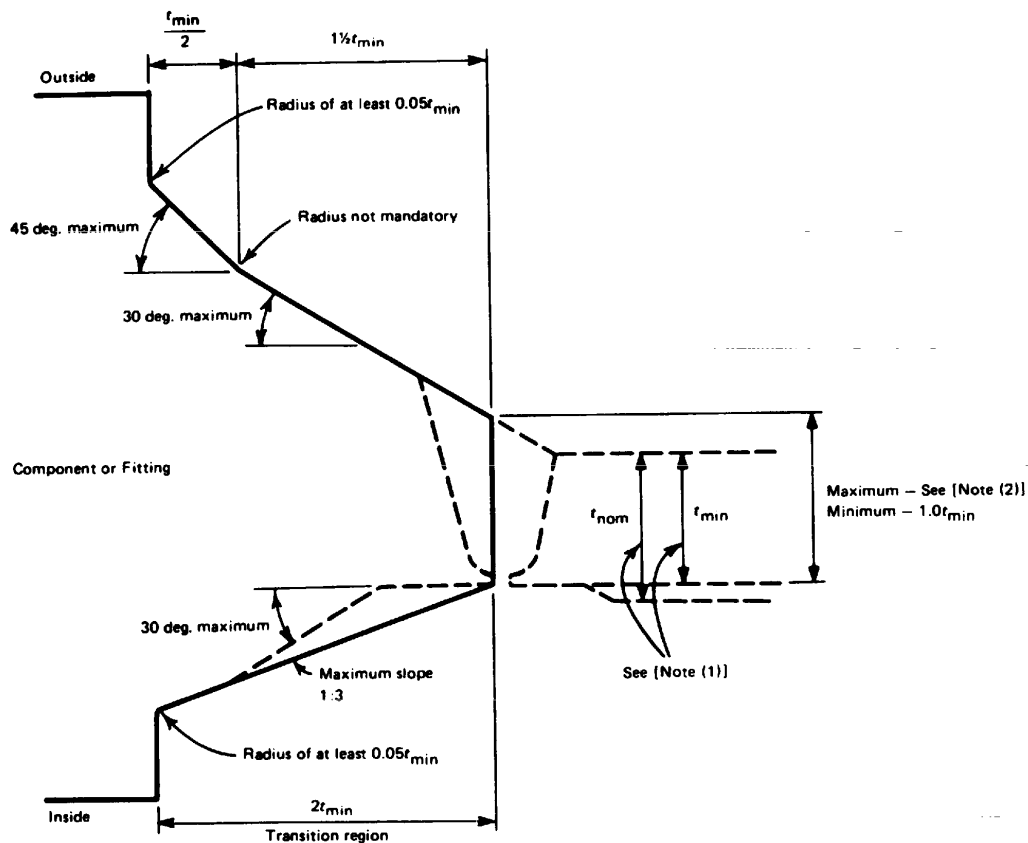
(d) NCA-3131 provides specific additional requirements when welding services are subcontracted to or through organizations not holding an appropriate Certificate of Accreditation.

NB-4322 Maintenance and Certification of Records

The Certificate Holder shall maintain a record of the qualified welding procedures and of the welders and welding operators qualified by him, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and signed by any authorized individual assigned by the Certificate Holder, and they shall be accessible to the Owner and to the Inspector.

Page 196

Page 197



GENERAL NOTES:

- (a) Weld bevel is shown for illustration only
- (b) The weld reinforcement permitted by NC-4426 may lie outside the maximum envelope.

NOTES:

- (1) The value of t_{min} is whichever of the following is applicable:
 - (a) the minimum ordered wall thickness of the pipe;
 - (b) 0.875 times the nominal wall thickness of pipe ordered to a pipe schedule wall thickness which has an under tolerance of 12.5%;
 - (c) the minimum ordered wall thickness of the cylindrical welding end of a component or fitting (or the thinner of the two) when the joint is between two components.
- (2) The maximum thickness at the end of the component is:
 - (a) the greater of $t_{min} + 0.15$ in. or $1.15t_{min}$ when ordered on a minimum wall basis;
 - (b) the greater of $t_{min} + 0.15$ in. or $1.0t_{nom}$ when ordered on a nominal wall basis.

FIG. NB-4250-1 WELDING END TRANSITIONS — MAXIMUM ENVELOPE

FIG. NB-4250-1 WELDING END TRANSITIONS - MAXIMUM ENVELOPE

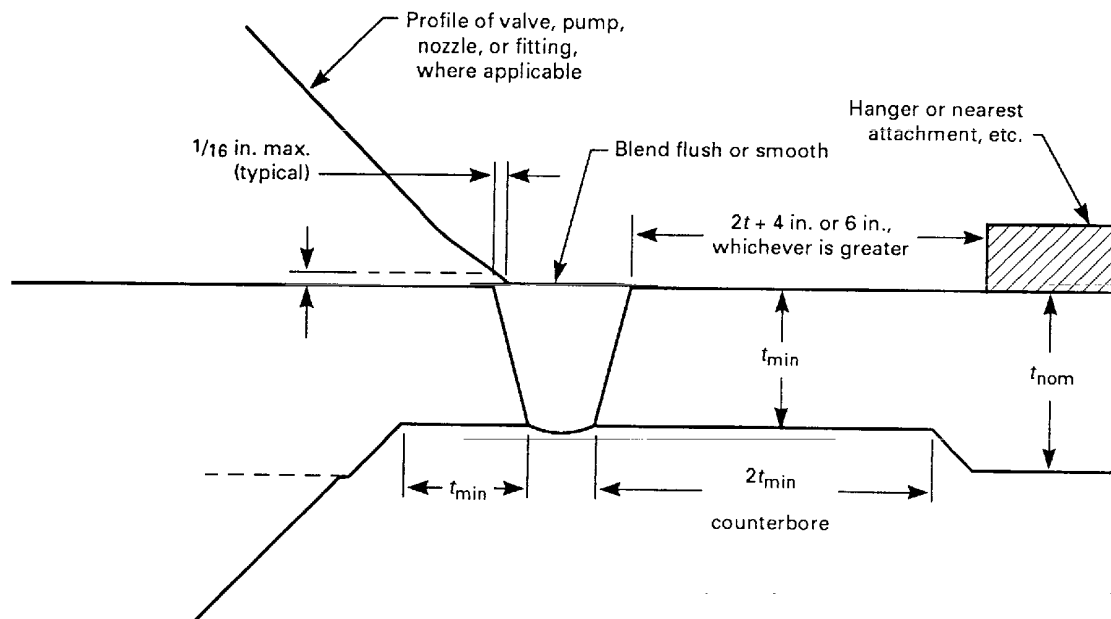


FIG. NB-4250-2 COMPONENT TO PIPE WELD

FIG. NB-4250-2 COMPONENT TO PIPE WELD

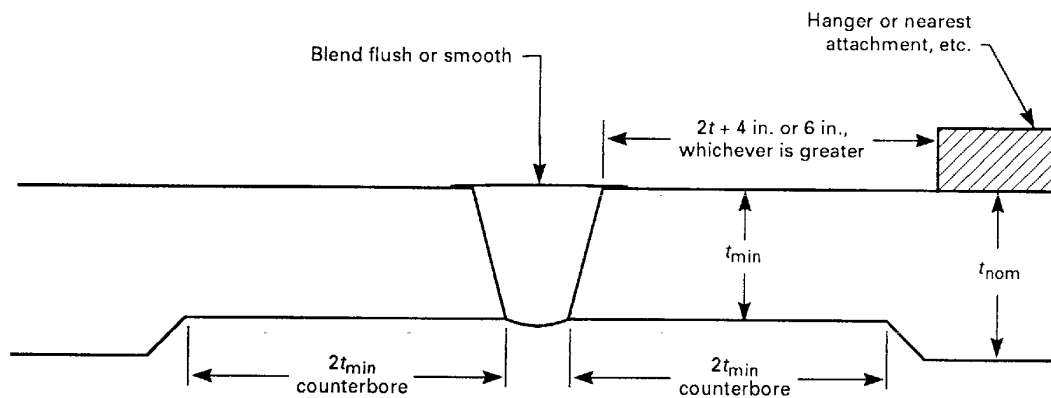


FIG. NB-4250-3 PIPE TO PIPE WELD

FIG. NB-4250-3 PIPE TO PIPE WELD

NB-4322.1 Identification of Joints by Welder or Welding Operator

(a) Each welder or welding operator shall apply the identification mark assigned by the Certificate Holder on or adjacent to all permanent welded joints or series of joints on which he welds. The marking shall be at intervals of 3 ft (0.9 m) or less and shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps. As an alternative, the Certificate Holder shall keep a record of permanent welded joints in each item and of the welders and welding operators used in making each of the joints.

(b) When a multiple number of permanent structural attachment welds, nonstructural welds, fillet welds, socket welds, welds of specially designed seals, weld metal cladding, hard surfacing, and tube-to-tubesheet welds are made on an item, the Certificate Holder need not identify the welder or welding operator who welded each individual joint, provided:

(1) the Certificate Holder maintains a system that will identify the welders or welding operators who made such welds on each item so that the Inspector can verify that the welders or welding operators were all properly qualified;

(2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification.

(c) The identification of welder or welding operator is not required for tack welds.

NB-4323 Welding Prior to Qualifications

No welding shall be undertaken until after the welding procedures which are to be used have been qualified. Only welders and welding operators who are qualified in accordance with NB-4320 and Section IX shall be used.

NB-4324 Transferring Qualifications

The welding procedure qualifications and the performance qualification tests for welders and welding operators conducted by one Certificate Holder shall not qualify welding procedures and shall not qualify welders or welding operators to weld for any other Certificate Holder, except as provided in Section IX, QW-201 and QW-300.2.

NB-4330 GENERAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION TESTS

NB-4331 Conformance to Section IX Requirements

All welding procedure qualification tests shall be in accordance with the requirements of Section IX as supplemented or modified by the requirements of this Article.

NB-4333 Heat Treatment of Qualification Welds for Ferritic Materials

Postweld heat treatment of procedure qualification welds shall conform to the applicable requirements of NB-4620 and Section IX. The postweld heat treatment time at temperature shall be at least 80% of the maximum time to be applied to the component weld material. The postweld heat treatment total time may be applied in one heating cycle.

NB-4334 Preparation of Test Coupons and Specimens

(a) Removal of test coupons from the test weld and the dimensions of specimens made from them shall conform to the requirements of Section IX, except that the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with (b) below.

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test specimens. When each process cannot be included in the full-size impact test specimen at the $\frac{1}{4}t$ location required by this Section, additional full-size specimens shall be obtained from locations in the test weld that will ensure that at least a portion of each process has been included in full-size test specimens. As an alternative, additional test welds can be made with each process so that full-size specimens can be tested for each process.

NB-4334.1 Coupons Representing the Weld Deposit.

Impact test specimens and testing methods shall conform to NB-2321. The impact specimen shall be located so that the longitudinal axis of the specimen is at least $0.25t$ and, where the thickness of the test assembly permits, not less than $\frac{3}{8}$ in. (10 mm) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified in NB-4620 and the test assembly is cooled at an accelerated rate, the

Page 199

longitudinal axis of the specimen shall be a minimum of t from the edge of the test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the weld. The length of the notch of the Charpy V-notch specimen shall be normal to the surface of the weld. Where drop weight specimens are required, the tension surface of the specimen shall be oriented parallel to the surface of the test weld assembly.

NB-4334.2 Coupons Representing the Heat Affected Zone.

Where impact tests of the heat affected zone are required by NB-4335.2, specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through (c) below.

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented in the direction parallel to the principal direction of rolling or forging.

(b) The heat affected zone impact test specimens and testing methods shall conform to the requirements of NB-2321.2. The specimens shall be removed from a location as near as practical to a depth midway between the surface and center thickness. The coupons for heat affected zone impact specimens shall be taken transverse to the axis of the weld and etched to define the heat affected zone. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much heat affected zone as possible in the resulting fracture. Where the material thickness permits, the axis of a specimen may be inclined to allow the root of the notch to align parallel to the fusion line. When a grain refining heat treatment is not performed on welds made by the electroslog or electrogas welding process, the notch for the impact specimens shall be located in the grain coarsened region.

(c) For the comparison of heat affected zone values with base material values [NB-4335.2(b)], Charpy V-notch specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the heat affected zone specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the heat affected zone specimens, and the axis of the notch shall be normal to the surface of the base material. When required by NB-4335.2(b)(1), drop-weight specimens shall be removed from a depth as near as practical to midway between the surface and center thickness of the unaffected base material and shall be tested in accordance with the requirements of NB-2321.1.

NB-4335 Impact Test Requirements

When materials are required to be impact tested per NB-2300, impact tests of the weld metal and heat affected zone shall be performed in accordance with the following subparagraphs. The weld procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of NB-2330 and NB-4334. Retests in accordance with the provisions of NB-2350 are permitted.

NB-4335.1 Impact Tests of Weld Metal

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding $\frac{5}{8}$ in. (16 mm) in thickness when the weld will be made on the surface or penetrate base material that requires impact testing in accordance with NB-2310. In addition, such testing of the weld metal is required for the welding procedure qualification tests for any weld repair to base material that requires impact testing in accordance with NB-2310, regardless of the depth of the repair.

(b) The impact test requirements and acceptance standards for welding procedure qualification weld metal shall be the same as specified in NB-2330 for the base material to be welded or repaired. Where two materials are to be joined by welding and have different fracture toughness requirements, the test requirements and acceptance standards of either material may be used for the weld metal except where this is otherwise specified by NCA-1280 or other parts of this

Subsection.

NB-4335.2 Impact Tests of Heat Affected Zone

(a) Charpy V-notch tests of the heat affected zone of the welding procedure qualification test assembly are required whenever the thickness of the weld exceeds $\frac{5}{8}$ in. (16 mm) and either of the base materials require impact testing in accordance with the rules of NB-2310. The only exceptions to the requirements are the following:

- (1) the qualification for welds in P-Nos. 1 and 3 and SA-336 F12 materials that are postweld heat treated and are made by any process other than electroslog, electrogas, or thermit;
- (2) the qualification for weld deposit cladding or hard-facing on any base material.

(b) Impact testing of the welding procedure qualification test heat affected zone, where required by this paragraph, shall be conducted in accordance with (b)(1) through (b)(3), or (b)(4) through (b)(6), and (c), if applicable.

- (1) For tests of welding procedure qualifications for material that requires testing in accordance with NB-2331 and NB-2332(b), the T_{NDT} of the unaffected

Page 200

base material shall be determined to establish the test temperature for the Charpy V-notch tests. The Charpy V-notch specimens representing the heat affected zone material and the unaffected base material shall be tested at the ($T_{NDT} + 60^{\circ}\text{F}$) temperature of the unaffected base material. The Charpy V-notch impact tests of the unaffected base material shall meet the requirements of NB-2331(a). If the average lateral expansion values of the three HAZ specimens are equal to or greater than the average value for the unaffected base material Charpy V-notch specimens, the qualification test shall be considered acceptable, and the values and testing temperature shall be recorded on the Welding Procedure Qualification Record.

(2) If the average Charpy V-notch lateral expansion for the heat affected zone of (b)(1) above is less than that for the unaffected base material, and the qualification test meets the other criteria of acceptance, the Charpy V-notch test results may be recorded on the Welding Procedure Qualification Record. Data shall then be obtained as specified in (b)(3) below to provide an additive temperature for any base material for which the welding procedure is being qualified, and shall be included. Alternatively, the welding procedure qualification may be rewelded and retested.

(3) The data for use in (b)(2) above shall be developed by performing additional Charpy V-notch tests on either the welding procedure qualification heat affected zone or the unaffected base material, or both, at temperatures which provide lateral expansion values equal to or greater than 35 mils (0.89 mm). The average lateral expansion data for the heat affected zone and the unaffected base material shall be plotted on a lateral expansion-temperature chart. The temperatures at which these two sets of data exhibit a common lateral expansion value equal to or greater than 35 mils shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the heat affected zone. This difference shall be used in (b)(2) above as the adjustment temperature. The adjustment temperature shall be added to the highest RT_{NDT} temperature established by the tests of NB-2331 and NB-2332(b) for all of the base material to be welded by this procedure in production. If the temperature difference is zero or is a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by the tests for NB-2331 and NB-2332(b) will still apply as stated in (b)(1) above. Where the actual RT_{NDT} is not required for the production material to be welded, for example, where a testing temperature is established by the Design Specification to determine that the RT_{NDT} is at or below the specified temperature, the adjustment temperature determined by the curves shall be used to establish a reduction in the specified testing temperature for the production material. The adjustment temperature shall be used to lower the specified testing temperature for any production material on which the procedure will be used.

(4) For tests of welding procedure qualifications for materials that require tests in accordance with NB-2332(a), the three Charpy V-notch heat affected zones and three Charpy V-notch unaffected base material specimens shall be tested at a temperature in accordance with NB-2332(a)(1). The Charpy V-notch impact test of the unaffected base material shall meet the requirements of Table NB-2332-1. If the average lateral expansion values of the three HAZ specimens are equal to or greater than the average value of the unaffected base material Charpy V-notch specimens, the test shall be considered acceptable, and the values and testing temperature shall be recorded on the Welding Procedure Qualification Record.

(5) If the heat affected zone Charpy V-notch average lateral expansion values of (b)(4) above are less than the unaffected base material and the welding procedure qualification test meets the other criteria of acceptance, the Charpy V-notch test results may be recorded on the Welding Procedure Qualification Record. Data shall then be obtained as specified in (b)(6) below to provide an additive temperature for the adjustment of the lowest service temperature of the base material that is to be welded in production with the welding procedure that is being qualified. Alternatively, the welding procedure qualification may be rewelded and retested.

(6) The data for use in (b)(5) above shall be developed by performing additional Charpy V-notch tests on either the welding procedure qualification heat affected zone or the unaffected base material, or both, at temperatures which provide lateral expansion values that meet or exceed those required for the thickness of the material to be welded in production (Table NB-2332-1). The average lateral expansion data for the heat affected zone and unaffected base material shall be plotted on a lateral expansion-temperature chart. The temperatures at which these two sets of data exhibit a common acceptable value of lateral expansion for the production thickness involved shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the heat affected zone. This difference, if a positive number, shall be used in (b)(5) above as the adjustment temperature. The welding procedure adjustment temperature shall be added to the

Page 201

highest Lowest Service Temperature established by the tests of NB-2332 for all of the base material to be welded by this procedure in production. If the temperature difference is zero or a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by the tests for NB-2332 will still apply as stated in (b)(4) above.

Where the actual Lowest Service Temperature is not required for the product material to be welded, for example where a testing temperature is established by specification to determine that the material has adequate lateral expansion to meet the requirements of Table NB-2332-1 at the specified test temperature, the adjustment temperature determined by the curves shall be used to establish a reduction in the specified testing temperature for the production material. The adjustment temperature shall be used to lower the specified testing temperature for any production material upon which the procedure will be used.

(c) Should the unaffected base material Charpy V-notch impact test results fail to meet the applicable requirements referenced in (b)(1) or (b)(4) above, additional unaffected base material Charpy V-notch impact tests shall be tested at higher temperatures until the applicable requirements are met. Charpy V-notch impact specimens of the heat affected zone shall be tested at the same temperature at which acceptable unaffected base material properties were achieved. The rules governing the average lateral expansion of the heat affected zone relative to the average lateral expansion of the unaffected base material shall be followed as in (b)(1) through (b)(3) or (b)(4) through (b)(6) above, as applicable, to determine the data which are to be recorded on the Welding Procedure Qualification Record.

NB-4336 Qualification Requirements for Built-Up Weld Deposits

Built-up weld deposits for base metal reinforcement shall be qualified in accordance with the requirements of NB-4331 through NB-4335.

NB-4350 SPECIAL QUALIFICATION REQUIREMENTS FOR TUBE-TO-TUBESHEET WELDS

NB-4351 General Requirements

The welding procedure for tube-to-tubesheet welds shall be qualified as a new procedure specification and shall be completely requalified when any of the changes listed below are made in the procedure. Changes other than those so given may be made in a procedure without the necessity for requalification, provided the procedure specification is amended to show these changes.

NB-4352 Essential Variables for All Welding Processes

Essential variables for all welding processes shall be as listed in (a) through (k) below:

- (a) a change from one welding process to any other welding process or combination of welding processes;
- (b) a change in the P-Number classification of tube material in Section IX, QW-422; separate qualification is required for each tube material which is not included under any P-Number;
- (c) a change in the P-Number of the tubesheet base material. The base material may be a homogeneous material or a cladding material of wrought type or weld overlay type. If welding is performed between the tube and cladding, the cladding shall be considered the base material. A separate qualification is required for welding tubes to base material or cladding material which is not included under any P-Number;
- (d) changes in the weld metal analysis of the deposited weld metal as given in (1) and (2) below:
 - (1) a change from any A-Number in Section IX, QW-442, to any other A-Number or to any F-Number in QW-432 or to any analysis not listed in the tables, except that each AISI type similar to A-No. 7 or A-No. 8 of QW-442 shall require separate qualifications;
 - (2) a change from any F-Number in QW-432 to any other F-Number or to any A-Number in QW-442 or to any analysis not listed in the tables;
- (e) for tubes of specified wall thicknesses of 0.100 in. (2.54 mm) or less, an increase or decrease of 10% of specified wall thickness or specified diameter;
- (f) for specified wall thicknesses greater than 0.100 in. (2.54 mm), only one qualification test is required;
- (g) a decrease of 10% or more in the specified width of the ligament between tube holes when the specified width of the ligament is less than the greater of $\frac{3}{8}$ in. (10 mm) or three times the specified tube wall thickness;
- (h) the addition of other welding positions than those already qualified (Section IX, QW-461.1);
- (i) a change in the specified preheating temperature range;
- (j) a change in the specified postweld heat treating temperature;
- (k) a change from multiple pass to single pass or vice versa.

NB-4353 Essential Variables for Shielded Metal-Arc Welding

An additional essential variable for shielded metal-arc welding is an increase in electrode diameter.

NB-4354 Essential Variables for Gas Tungsten-Arc and Gas Metal-Arc Welding

Additional essential variables for gas tungsten-arc and gas metal-arc welding are as given in (a) through (f) below:

- (a) a change in the configuration of the tube sheet at the tube hole edges, including the addition or omission of preplaced metal inserts;
- (b) a change in the size or shape of preplaced metal inserts;
- (c) a change from one shielding gas to another shielding gas or to a mixture of shielding gases;
- (d) when using mixed shielding gas, a change of plus or minus 25% or 5 cu ft/hr (0.14 m³/hr), whichever is the larger, in the rate of flow of the minor gas constituent;
- (e) for gas tungsten-arc welding process, the addition or omission of filler metal;
- (f) a change in the nominal diameter of the filler metal.

NB-4355 Essential Variables for Explosive Welding

Additional essential variables for explosive welding are as given in (a) through (e) below:

- (a) an increase or decrease in the specified tube wall thickness or diameter of 10% for all diameters and wall thicknesses

instead of the provision of NB-4352(e);

- (b) a change in the method of pressure application;
- (c) a change in the type of explosive or a change in energy content of $\pm 10\%$;
- (d) a change of $\pm 10\%$ in the placement of the charge from the tubesheet face;
- (e) a change in the specified clearance between the tube and the tubesheet of $\pm 10\%$.

NB-4356 Test Assembly

The procedure qualification shall be made on a test assembly which simulates the conditions to be used in production with respect to the tube hole pattern and the essential variables listed in NB-4351. In addition, the thickness of the tubesheet in the test assembly shall be as thick as the production tubesheet, except it need not exceed 2 in. (51 mm). The minimum required number of weld joints shall be 10.

NB-4357 Examination of Test Assembly

The assembly shall be examined by a liquid penetrant method in accordance with the requirements of NB-5110 and shall meet the acceptance standards of NB-5350. Following this, the assembly shall be sectioned longitudinally through each tube. The thickness of the assembly may be reduced to $\frac{1}{2}$ in. (13 mm) prior to this sectioning. The four faces of each tube exposed by sectioning shall be polished and etched with a suitable etchant, and shall be visually examined for cracks. The weld throat, minimum leakage path, shall be not less than two-thirds of the specified tube wall thickness, and the weld shall be free from cracks on visual examination with $\times 10$ magnification.

NB-4358 Performance Qualification

NB-4358.1 Welders.

The requirements for the performance qualification test for welders shall be the same as those for the procedure qualification, except that the minimum required number of tubes in the test assembly shall be six.

NB-4358.2 Welding Operators.

The requirements for the performance qualification test for welding operators (automatic weld process) shall be the same as those for the procedure qualification except that:

- (a) the essential variables for performance qualification are those detailed in NB-4352(a), (b), (c), (d), and (h), and
- (b) the minimum required number of tubes in the test assembly shall be six.

NB-4360 QUALIFICATION REQUIREMENTS FOR WELDING SPECIALLY DESIGNED WELDED SEALS

NB-4361 General Requirements

(a) Specially designed welded seals are defined as the walls or membranes, such as an omega shaped seal membrane, which confine the fluid and where strength is provided by a separate device.

(b) The welding procedure shall be qualified as a new procedure specification and shall be completely requalified when any of the essential variables specified or listed in the following paragraphs are made in the procedure. Changes other than those so given may be made in the procedure without the necessity for

Page 203

requalification provided the procedure is amended to show these changes. In addition, the essential variables specified in Section IX shall apply for both procedure and performance qualification.

NB-4362 Essential Variables for Automatic, Machine, and Semiautomatic Welding

The welding procedure shall be qualified as a new procedure specification and shall be completely requalified when any of the changes listed in this paragraph or the applicable portions of Section IX are made:

- (a) when preplaced filler metal is melted to form all or part of a weld, a change from one alloy type or classification to any other alloy type or classification of base material or filler metal, even though previously qualified base materials and filler metals are of the same P-Number or A-Number;
- (b) a change of any dimension of the weld joint for automatic or machine welding or a change of any dimension of the weld joint by more than 10% for semiautomatic welding beyond that qualified;
- (c) a change in the nominal size or shape of any filler metal added to the arc;
- (d) for automatic welding, an increase or decrease in the length of the seal weld by more than 30%;
- (e) for automatic welding, a change in the welding current greater than 50% of the difference between the maximum and minimum amperages used during qualification; only two test assemblies need to be welded for requalification;
- (f) any change in the angular relationship or distance between the welding electrode and the work and the filler metal beyond the range qualified;
- (g) the addition or deletion of the use of tack welds or locating fixtures to facilitate alignment or to maintain the root opening of the weld joint;
- (h) the addition or deletion of consumable inserts.

NB-4363 Essential Variables for Manual Welding

The welding procedure must be qualified as a new procedure specification and shall be completely requalified when any of the changes listed in (a) and (b) below are made in the procedure:

- (a) a change of more than $\pm 10\%$ of any dimension of the weld joint cross section other than the included angle of the groove, except that base material thickness may vary from minus 10% to 2.5 times the thickness qualified when welding parts of the same material thickness, or the thin member may vary from minus 10% to 2 times the thickness qualified when welding a thin seal membrane to a thick member;
- (b) when preplaced filler metal is melted to form all or part of a weld, a change from one alloy type or classification to any other alloy type or classification of base material or filler metal, even though previously qualified base materials and filler metals are of the same P-Number or A-Number.

NB-4366 Test Assembly

The test assembly shall consist of a duplicate of the production weld except that tolerances as stated in NB-4362(b) or NB-4363(a) are permitted. Except for automatic welding, the Certificate Holder may use a 12 in. (305 mm) length to qualify, if the length of the production weld is considered to be greater than necessary to qualify.

NB-4366.1 Automatic Welding.

For automatic welding, at least six consecutive test assemblies representing the range of dimensions to be qualified shall be required to establish the reproducibility of the welding procedure. In addition, the Certificate Holder making the production welds shall verify this capability of making two consecutive test assemblies prior to production welding using the previously qualified procedure.

NB-4366.2 Manual, Machine, and Semiautomatic Welding.

For manual, machine, and semiautomatic welding, two test assemblies shall be required.

NB-4367 Examination of Test Assembly

- (a) Where 100% weld penetration is required, the test assembly shall be sectioned, if necessary, to permit examination of the entire underside weld surface.

(b) A minimum of four cross sections shall be taken from each test assembly. One cross section shall be made in a weld start and stop area and the others shall be taken at random. Each cross section shall be examined at $\times 10$ to $\times 15$ magnification in accordance with ASTM Standard E2. All surfaces shall be free of cracks, incomplete penetration, incomplete melting of insert on consumable type welds, and porosity or inclusions in excess of one rounded void with the maximum dimension not greater than 10% of the thickness of the weld. When doubt exists as to the acceptability of the weld, after examination of four cross sections, the Inspector may require that additional metallographic cross sections be prepared for examination of the weld and adjacent base material.

Page 204

NB-4368 Performance Qualification Test

The performance qualification test assembly shall meet the same requirements specified for the procedure qualification test assembly in NB-4366 and shall be examined in accordance with NB-4367. Furthermore, welding operators shall qualify using the welding machine which will be used to make production welds and shall be required to set up the machine with regard to adjustments and settings which affect the welding characteristics. One test assembly is required.

NB-4400 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS

NB-4410 PRECAUTIONS TO BE TAKEN BEFORE WELDING

NB-4411 Identification, Storage, and Handling of Welding Material

Each Certificate Holder is responsible for control of the welding electrodes and other material which is used in the fabrication and installation of components (NB-4120). Suitable identification, storage, and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by electrodes and flux.

NB-4412 Cleanliness and Protection of Welding Surfaces

The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

NB-4420 RULES FOR MAKING WELDED JOINTS

NB-4421 Backing Rings

When used in components other than piping, backing rings shall conform to the requirements of NB-4240. Backing rings shall not be used in piping unless removed after welding and the inside surfaces of the roots are examined by a magnetic particle or liquid penetrant method, in accordance with NB-5110, and meeting the acceptance standards of NB-5340 or NB-5350. The material for backing rings, when used, shall be compatible with the base metal. Permanent backing rings, when permitted by NB-3352, shall be continuous, and any splices shall be made by full penetration welds. Spacer pins shall not be incorporated into the welds.

NB-4422 Peening

Controlled peening may be performed to minimize distortion. Peening shall not be used on the initial layer, root of the weld metal, or on the final layer unless the weld is postweld heat treated.

NB-4423 Miscellaneous Welding Requirements

(a) Before applying weld metal on the second side to be welded, the root of full penetration double welded joints shall be prepared by suitable methods, such as chipping, grinding, or thermal gouging, except for those processes of welding by which proper fusion and penetration are otherwise obtained and demonstrated to be satisfactory by welding procedure qualification.

(b) If the welding is stopped for any reason, extra care shall be taken in restarting to get the required penetration and fusion. For submerged arc welding, chipping out a groove in the crater is recommended.

(c) Where single welded joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joint for its full length.

NB-4424 Surfaces of Welds

NB-4424.1 General.

As-welded surfaces are permitted, except for inertia and continuous drive friction welding where the flash shall be removed to sound metal. For piping, the appropriate stress indices given in Table NB-3681(a)-1 shall be applied. However, the surface of welds shall be sufficiently free from coarse ripples, grooves, overlaps, and abrupt ridges and valleys to meet (a) through (f) below.

(a) The surface condition of the finished weld shall be suitable for the proper interpretation of radiographic and other required nondestructive examinations of the weld. In those cases where there is a question regarding the surface condition of the weld on the interpretation of a radiographic film, the film shall be compared to the actual weld surface for interpretation and determination of acceptability.

(b) Reinforcements are permitted in accordance with NB-4426.1 for vessels, pumps, and valves, and NB-4426.2 for piping only for those welds that do not require preservice examination.

Page 205

(c) Undercuts shall not exceed $\frac{1}{32}$ in. (0.8 mm) and shall not encroach on the required section thickness.

(d) Concavity on the root side of a single-welded circumferential butt weld is permitted when the resulting thickness of the weld meets the requirements of NB-3000.

(e) If the surface of the weld requires grinding to meet the above criteria, care shall be taken to avoid reducing the weld or base material below the required thickness.

(f) Diametrical weld shrinkage is permissible provided an acceptable ultrasonic examination can be performed.

NB-4424.2 Preservice Examination

(a) The surface finish shall be 6.3 Ra or better for a distance of at least $2t^1$ plus 4 in. or 6 in., whichever is greater (Fig. NB-4250-2 or Fig. NB-4250-3), from the edge of the weld crown on at least one side of the weld where an ultrasonic examination is required.

(b) Provide welds a circumferential clearance distance of 15 in. (minimum) for long seam welds. This measurement shall be from the toe of the weld.

(c) A reference system shall be established for all piping and vessel welds subject to surface or volumetric examination.

(1) For piping, each side of each weld joint shall be permanently marked at a minimum of two points in suitable increments from the edge prep. These marks shall be repeated at 90 deg. intervals around the pipe. For welds joining pipes to components, other than vessels where punching is not feasible, punching on the pipe side only is permitted.

(2) For vessels, each side of each weld joint shall be permanently marked at a minimum of two points in suitable increments from the edge prep. These marks shall be repeated along the weld length at 1 ft (0.3 m) intervals for vessel to nozzle welds, and at 3 ft (0.9 m) intervals for all other vessel welds that are subject to preservice examination.

NB-4425 Welding Items of Different Diameters

When items of different diameters are welded together, there shall be a gradual transition between the two surfaces in accordance with NB-4250, unless greater slopes are shown to be acceptable by analysis in accordance with NB-3200. The length of the transition may include the weld.

l equals nominal wall thickness.

NB-4426 Reinforcement of Welds

NB-4426.1 Thickness of Weld Reinforcement for Vessels, Pumps, and Valves.

The surface of the reinforcement of all butt welded joints in vessels, pumps, and valves may be flush with the base material or may have uniform crowns. The height of reinforcement on each face of the weld shall not exceed the thickness in the following tabulation.

Nominal Thickness, in.	Maximum Reinforcement, in.
Up to 1, incl.	$\frac{3}{32}$
Over 1 to 2, incl.	$\frac{1}{8}$
Over 2 to 3, incl.	$\frac{5}{32}$
Over 3 to 4, incl.	$\frac{7}{32}$
Over 4 to 5, incl.	$\frac{1}{4}$
Over 5	$\frac{5}{16}$

NB-4426.2 Thickness of Weld Reinforcement for Piping.

For double-welded butt joints, the limitation on the reinforcement given in Column 1 of the following tabulation shall apply separately to both inside and outside surfaces of the joint. For single-welded butt joints, the reinforcement given in Column 2 shall apply to the inside surface and the reinforcement given in Column 1 shall apply to the outside surface. The reinforcement shall be determined from the higher of the abutting surfaces involved.

Material Nominal Thickness, in.	Column 1	Maximum Reinforcement Thickness, in. Column 2
Up to $\frac{1}{8}$ incl.	$\frac{3}{32}$	$\frac{3}{32}$
Over $\frac{1}{8}$ to $\frac{3}{16}$ incl.	$\frac{1}{8}$	$\frac{3}{32}$
Over $\frac{3}{16}$ to $\frac{1}{2}$ incl.	$\frac{5}{32}$	$\frac{1}{8}$
Over $\frac{1}{2}$ to 1, incl.	$\frac{3}{16}$	$\frac{5}{32}$
Over 1 to 2, incl.	$\frac{1}{4}$	$\frac{5}{32}$
Over 2	Greater of $\frac{1}{4}$ in. or $\frac{1}{8}$ times the width of the weld, in inches	$\frac{5}{32}$

NB-4427 Shape and Size of Fillet Welds

Fillet welds may vary from convex to concave. The shape and size of the weld shall be in accordance with the requirements of Fig. NB-4427-1. A fillet weld in any single continuous weld may be less than the specified fillet weld dimension by not more than $\frac{1}{16}$

Page 206

in. (1.6 mm), provided that the total undersize portion of the weld does not exceed 10% of the length of the weld. Individual undersize weld portions shall not exceed 2 in. (51 mm) in length. In making socket welds, a gap as shown in Fig. NB-4427-1 shall be provided prior to welding. The gap need not be present nor be verified after welding.

NB-4428 Seal Welds of Threaded Joints

Where seal welding of threaded pipe joints is performed, the exposed threads shall be either removed entirely or covered with weld metal.

NB-4429 Welding of Clad Parts²

The joint types and welding procedures used for cladding shall be such as to prevent the formation of brittle weld composition.

NB-4430 WELDING OF ATTACHMENTS

NB-4431 Materials for Attachments

Nonpressure-retaining attachments (NB-1132.1) welded to pressure-retaining components shall be of materials which meet the requirements of NB-2190. Materials for pressure-retaining attachments shall meet the requirements of NB-2120.

NB-4432 Welding of Structural Attachments

The rules of NB-4321 governing welding qualifications shall apply to the welding of structural attachments to pressure-retaining material.

2 Welds that are exposed to corrosive action should have a resistance to corrosion that is not substantially less than that of the cladding. The use of filler metal that weld metal which is similar to the composition of the cladding material is recommended. If weld metal of different composition is used, it should have properties compatible with the application.

NB-4433 Structural Attachments

Structural attachments shall conform reasonably to the curvature of the surface to which they are to be attached and shall be attached by full penetration, fillet, or partial penetration continuous welds. When fillet and partial penetration welds are used on components, the requirements of NB-3123.2 shall be met. Attachments to the internal surfaces of reactor vessels shall be made only with full penetration welds. Figure NB-4433-1 illustrates some of the typical details for attaching structural attachments to a component using full penetration welds. Valve seats may be attached to the pressure boundary part by fillet or partial penetration welds provided the valve seat is shouldered against the pressure boundary part.

NB-4434 Welding of Internal Structural Supports to Clad Components

Internal structural supports on clad components shall be welded to the base metal and not to the cladding, except for weld overlay cladding.

NB-4435 Welding of Nonstructural and Temporary Attachments and Their Removal

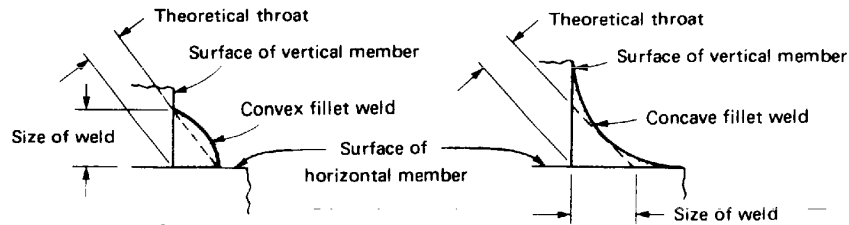
(a) Nonstructural attachments (NB-1132.1) welded to the pressure-retaining portion of the component need not comply with NB-2000 and may be welded with continuous or intermittent fillet or partial penetration welds, provided the requirements of (1) through (4) below are met.

- (1) The welding procedure and the welders have been qualified in accordance with NB-4321.
- (2) The material is identified and is compatible with the material to which it is attached.
- (3) The welding material is identified and compatible with the materials joined.
- (4) The welds are postweld heat treated when required by NB-4620.

(b) Removal of nonstructural attachments, when temporary, shall be accomplished as follows.

- (1) The immediate area around the temporary attachment is marked in a suitable manner so that after removal the area can be identified until after it has been examined in accordance with (3) below.
- (2) The temporary attachment is completely removed in accordance with the procedures of NB-4211.
- (3) After the temporary attachment has been removed, the marked area is examined by the liquid penetrant or magnetic particle method in accordance with the requirements of NB-5110, and meets the acceptance standards of NB-5340 or NB-5350, whichever is applicable.

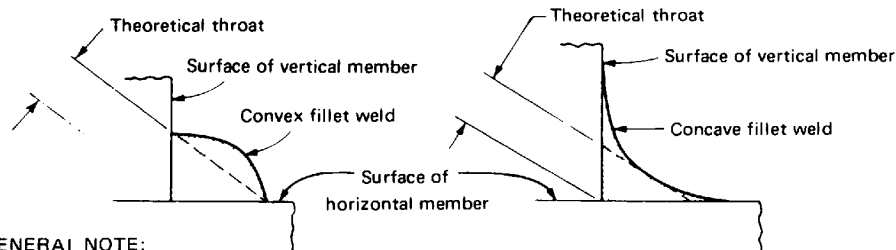
(4) As an alternative to (a)(4) above, postweld heat treatment may be deferred until after removal of the attachment.

**GENERAL NOTE:**

The size of an equal leg fillet weld is the leg length of the largest inscribed right isosceles triangle.

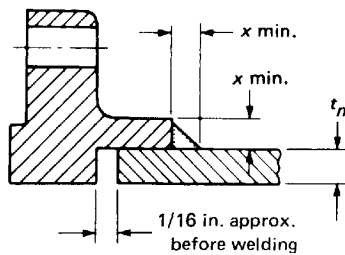
Theoretical throat = $0.7 \times$ size of weld.

(a) Equal Leg Fillet Weld

**GENERAL NOTE:**

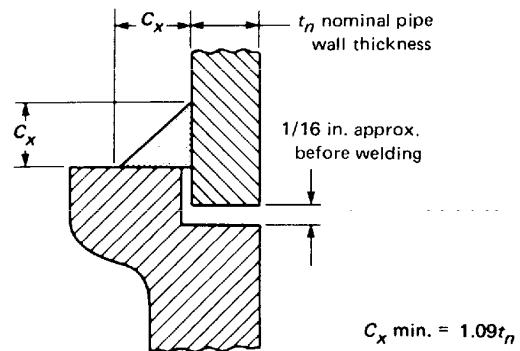
The size of an unequal leg fillet weld is the shorter leg length of the largest right triangle which can be inscribed within the fillet weld cross section.

(b) Unequal Leg Fillet Weld



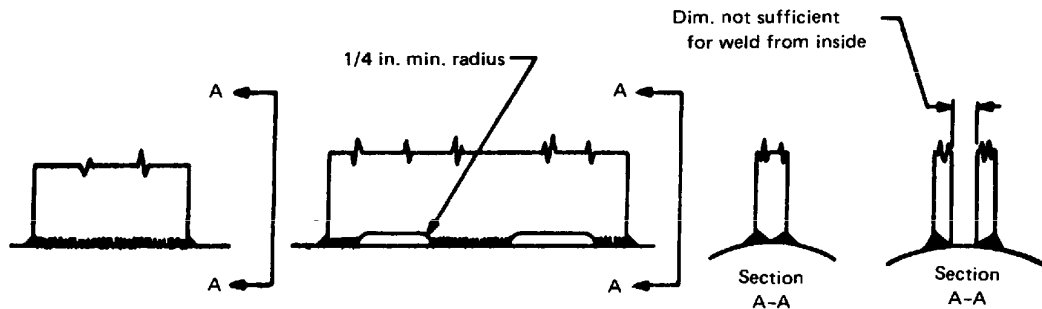
$x \text{ min.} = 1.4t_n$ or the thickness of the hub, whichever is smaller, but not less than $1/8 \text{ in.}$, where t_n = nominal pipe wall thickness

(c) Minimum Welding Dimensions for Socket Welding Flanges

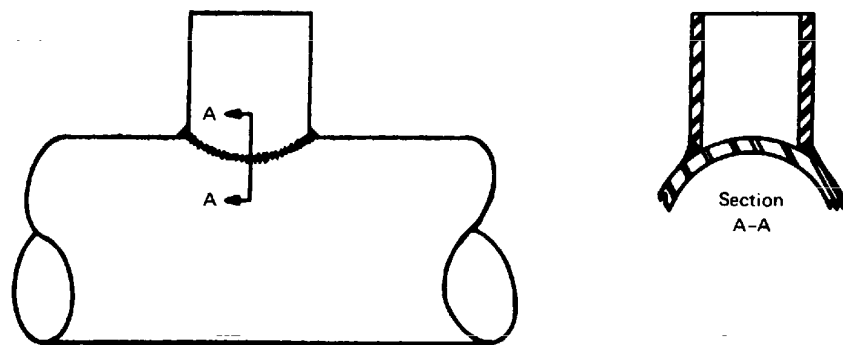


(d) Minimum Welding Dimensions for Socket Welding Fittings

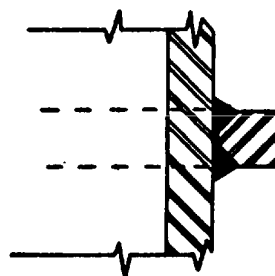
FIG. NB-4427-1 FILLET AND SOCKET WELD DETAILS AND DIMENSIONS
(See NB-3661.2 for Limitation on Socket Weld Pipe Size.)



(a) Attachment of Lugs, Shoes, and Brackets



(b) Attachment of Trunnions



(c) Attachment of Rings

FIG. NB-4433-1 TYPES OF ATTACHMENT WELDS

FIG. NB-4433-1 TYPES OF ATTACHMENT WELDS

NB-4436 Installation of Attachments to Piping Systems After Testing

Attachments may be welded to the piping system after performance of the pressure test provided that:

- (a) the welds do not require PWHT under NB-4622.7;
- (b) welds shall be restricted to fillet welds not exceeding $\frac{3}{8}$ in. (10 mm) throat thickness and to full penetration welds attaching materials not exceeding $\frac{1}{2}$ in. (13 mm) in thickness;
- (c) welds shall not exceed a total length of 24 in. (610 mm) for fillet welds or 12 in. (305 mm) for full penetration welds;
- (d) welds shall be examined as required by NB-5000.

NB-4450 REPAIR OF WELD METAL DEFECTS

NB-4451 General Requirements

Defects in weld metal detected by the examinations required by NB-5000, or by the tests of NB-6000, shall be eliminated and repaired when necessary.

NB-4452 Elimination of Surface Defects

Weld metal surface defects may be removed by grinding or machining, and need not be repaired by welding, provided that the requirements of (a) through (c) below are met.

- (a) The remaining thickness of the section is not reduced below that required by NB-3000.
- (b) The depression, after defect elimination, is blended uniformly into the surrounding surface.
- (c) The area is examined by a magnetic particle or liquid penetrant method in accordance with NB-5110 after blending and meets the acceptance standards of NB-5300 to ensure that the defect has been removed or reduced to an imperfection of acceptable limit. Defects detected by visual or volumetric method and located on an interior surface need only be reexamined by the method which initially detected the defect when the interior surface is inaccessible for surface examination.

NB-4453 Requirements for Making Repairs of Welds

Excavations in weld metal, when repaired by welding, shall meet the following requirements.

NB-4453.1 Defect Removal.

Defects may be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined by a liquid penetrant or magnetic particle method in accordance with NB-5110, and meet the acceptance standards of NB-5340 or NB-5350. This examination is not required where defect elimination removes the full thickness of the weld and where the backside of the weld joint is not accessible for removal of examination materials.

NB-4453.2 Requirements for Welding Material, Procedures, and Welders.

The weld repair shall be made using welding material, welders, and welding procedures qualified in accordance with NB-4125 and NB-4300.

NB-4453.3 Blending of Repaired Areas.

After repair, the surface shall be blended uniformly into the surrounding surface.

NB-4453.4 Examination of Repair Welds

- (a) The examination of a weld repair shall be repeated as required for the original weld, except that when the defect

was originally detected by the liquid penetrant or magnetic particle method, and when the repair cavity does not exceed the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the thickness, it need only be reexamined by the liquid penetrant or magnetic particle method.

(b) When repairs to welds joining P-No. 1 and P-No. 3 materials require examination by radiography as required in (a) above, but construction assembly prevents meaningful radiographic examination, ultrasonic examination may be substituted provided:

(1) the weld had been previously radiographed and met the applicable acceptance standards;

(2) the ultrasonic examination is performed using a procedure in accordance with Section V, Article 5, to the acceptance standards of NB-5330;

(3) the substitution is limited to Category A and B welds in vessels, and similar type welds in other items.

The absence of suitable radiographic equipment is not justification for the substitution.

NB-4453.5 Heat Treatment of Repaired Areas.

The area shall be heat treated in accordance with NB-4620.

NB-4500 BRAZING

NB-4510 RULES FOR BRAZING

NB-4511 Where Brazing May Be Used

(a) Brazing is permitted for the attachment of cladding to base material, of tubes to tubesheets, and as

Page 210

specified in NB-3671.6(a). Appurtenances and piping with outside diameter equal to that of 1 in. nominal pipe size (DN 25) and less may be fabricated using brazed joints in accordance with Fig. NB-4511-1.

(b) Valves with inlet piping connections of 4 in. nominal pipe size (DN 100) and less may have seats brazed to the valve body or bonnet provided the seat is shouldered against the pressure boundary part [Fig. NB-3544.1(c)-1].

NB-4512 Brazing Material

Where brazing is permitted, the brazing filler material and fluxes shall conform to the rules covering identification in NB-2150 and to the requirements of (a), (b), and (c) below.

(a) The filler material used in brazing shall be a nonferrous metal or alloy with a solidus temperature above 800°F (427°C) and at least 500°F (260°C) above the highest temperature of the joint in service.

(b) The filler material shall melt and flow freely by capillary action within the desired temperature range, and, in conjunction with a suitable flux or controlled atmosphere, the filler material shall wet and adhere to the surfaces to be joined.

(c) Fluxes that are fluid and chemically active at the brazing temperature shall be used, when necessary, to prevent oxidation of the filler metal and the surfaces to be joined, and to promote free flowing of the filler material.

NB-4520 BRAZING QUALIFICATION REQUIREMENTS

NB-4521 Brazing Procedure and Performance Qualification

Qualification of the brazing procedure to be used and of the performance of brazers and brazing operators is required and shall comply with the requirements of Section IX, except that validation of the procedure qualification per QB-451.5 Note (1) is not required for the furnace brazing of seat rings to bodies or bonnets of valves having inlet piping connections of 4 in. nominal pipe size (DN 100) and less. When the Design Temperature is greater than 200°F (93°C), tension testing shall be performed at the Design Temperature.

NB-4522 Brazing Requalification Requirements

In addition to the requirements of Section IX, the brazing procedure shall be set up as a new procedure specification and shall be completely requalified when the construction of the brazed components includes reheating of any portion of the completed brazed joint to a temperature that is within 300°F (167°C) of the solidus temperature of the filler metal.

NB-4530 FITTING AND ALIGNING OF PARTS TO BE BRAZED

Parts to be joined by brazing shall be fitted, aligned, and retained in position during the brazing operation within the tolerances specified in the brazing procedure specification. Brazed joints shall be assembled in a sequence which will permit the maximum number of joints to be visually examined on both sides of the joint after brazing.

NB-4540 EXAMINATION OF BRAZED JOINTS

The completed brazed joints shall be visually examined on all accessible surfaces in accordance with NB-5275.

NB-4600 HEAT TREATMENT

NB-4610 WELDING PREHEAT REQUIREMENTS

NB-4611 When Preheat Is Necessary

The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, elevated temperature, physical properties, and material thicknesses. Some practices used for preheating are given in Appendix D as a general guide for the materials listed by P-Numbers of Section IX. It is cautioned that the preheating suggested in Appendix D does not necessarily ensure satisfactory completion of the welded joint and that the preheating requirements for individual materials within the P-Number may be more or less restrictive. The Welding Procedure Specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.

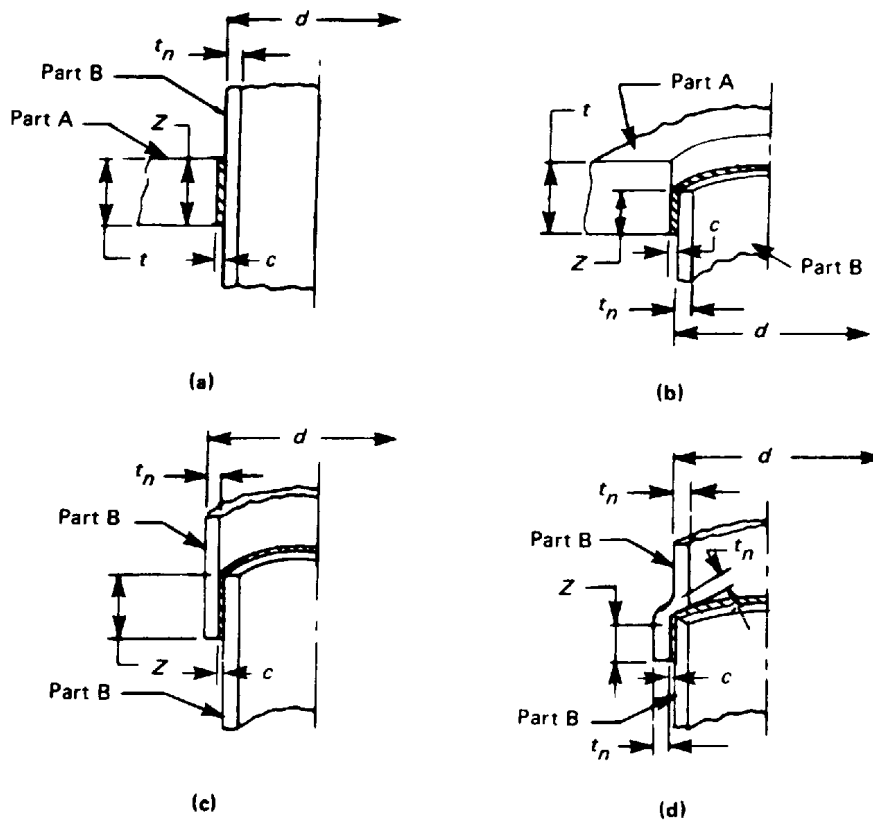
NB-4612 Preheating Methods

Preheat for welding or thermal cutting, when employed, may be applied by any method which does not harm the base material or any weld metal already

Page 211

Page 212

applied, or which does not introduce deleterious material into the welding area which is harmful to the weld.



- t = thickness of part penetrated
 t_n = nominal thickness of connecting part
 d = outside diameter of part B
 c = clearance or interference between mating parts and shall be in accordance with the brazing procedure specification
 z = depth of engagement and shall be the lesser of $3t_n$ or d , but in no case less than 1/4 in.

GENERAL NOTES:

- (1) Part A shall be attached to a component in accordance with the requirements for the component proper.
- (2) Part B shall be attached either to part A or to another part B by the joints shown above, or in accordance with the requirements of the component proper.
- (3) Grooves for preplaced filler metal are permitted, provided the reduction in cross section due to the grooves is considered in the design.

FIG. NB-4511-1 BRAZED CONNECTIONS FOR APPURTENANCES AND PIPING, 1 in. NOMINAL SIZE AND LESS ($\leq$ DN 25)

FIG. NB-4511-1 BRAZED CONNECTIONS FOR APPURTENANCES AND PIPING, 1 in. NOMINAL SIZE AND LESS ($\leq$ DN 25)

NB-4613 Interpass Temperature

Consideration shall be given to the limitations of interpass temperatures for quenched and tempered material to avoid detrimental effects on the mechanical properties.

NB-4620 POSTWELD HEAT TREATMENT

NB-4621 Heating and Cooling Methods

Postweld heat treatment (PWHT) may be accomplished by any suitable methods of heating and cooling, provided the required heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control are maintained.

NB-4622 PWHT Time and Temperature Requirements

NB-4622.1 General Requirements.³

Except as otherwise permitted in NB-4622.7, all welds, including repair welds, shall be postweld heat treated. During postweld heat treatment, the metal temperature shall be maintained within the temperature range and for the minimum holding time specified in Table NB-4622.1-1, except as otherwise permitted in NB-4622.4(c). P-Number groups in Table NB-4622.1-1 are in accordance with QW-420 of Section IX. Except as provided in NB-4624.3, PWHT shall be performed in temperature-surveyed and -calibrated furnaces, or PWHT shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. In addition, the requirements of the following subparagraphs shall apply.

NB-4622.2 Time-Temperature Recordings.

Time-temperature recordings of all postweld heat treatments shall be made available for review by the Inspector. Identification on the time-temperature recording shall be to the weld, part, or component, as applicable. A summary of the time-temperature recording may be provided for permanent records in accordance with NCA-4134.17.

3 Any postweld heat treatment time which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

NB-4622.3 Definition of Nominal Thickness Governing PWHT.

Nominal thickness in Table NB-4622.7(b)-1 is the thickness of the weld, the pressure-retaining material for structural attachment welds or the thinner of the pressure-retaining materials being joined, whichever is least. It is not intended that nominal thickness include material provided for forming allowance, thinning, or mill overrun when the excess material does not exceed $\frac{1}{8}$ in. (3.2 mm). For fillet welds the nominal thickness is the throat thickness, and for partial penetration and material repair welds the nominal thickness is the depth of the weld groove or preparation.

NB-4622.4 Holding Times at Temperature

(a) The holding time at temperature as specified in Table NB-4622.1-1 shall be based on the nominal thickness of the weld. The holding time need not be continuous. It may be an accumulation of the times of multiple postweld heat treatment cycles.

(b) Holding time at temperature in excess of the minimum requirements of Table NB-4622.1-1 may be used, provided that specimens so heat treated are tested in accordance with NB-2200, NB-2400, and NB-4300.

(c) Alternatively, when it is impractical to postweld heat treat at the temperature range specified in Table NB-4622.1-1, it is permissible to perform the postweld heat treatment of certain materials at lower temperatures for longer periods of time in accordance with Table NB-4622.4(c)-1 and (1), (2), and (3) below.

(1) Except for P-No. 1 materials, when welds in the materials listed in Table NB-4622.4(c)-1 are to be postweld heat treated at the lower minimum temperatures, the impact test specimens for the welding procedure qualification required by NB-4300 shall be made using the same minimum temperatures and increased minimum holding time. Welding procedures, qualified at the temperature range and minimum holding time specified in Table NB-4622.1-1 and at the lower temperature and increased minimum holding time permitted by Table NB-4622.4(c)-1, are also qualified for any temperature in between. When such an in-between temperature is used, the minimum holding time shall be interpolated from Table NB-4622.1-1 and the alternative requirements from Table NB-4622.4(c)-1.

(2) Except for P-No. 1 materials, when welds in the materials listed in Table NB-4622.4(c)-1 are to be postweld heat treated at these lower minimum temperatures, the welding material certification required by NB-2400 shall be made using the same minimum temperature and increased minimum holding time. Welding material certified at the temperature range and minimum holding time specified in Table NB-4622.1-1 and at the lower minimum temperatures and increased

Page 213

Page 214

TABLE NB-4622.1-1
MANDATORY REQUIREMENTS FOR POSTWELD HEAT TREATMENT OF WELDS¹

P-No. (Section IX, QW-420)	Holding Temperature Range, °F [Note (2)]	Minimum Holding Time at Temperature for Weld Thickness (Nominal)			
		½ in. or less	Over ½ in. to 2 in.	Over 2 in. to 5 in.	Over 5 in.
1, 3	1100–1250	30 min	1 hr/in.	2 hr plus 15 min each additional inch over 2 in.	2 hr plus 15 min each additional inch over 2 in.
4	1100–1250	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
5A, 5B, 5C, 6 except P-No. 6 Gr. 4	1250–1400	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
6 Gr. 4	1050–1150				
7	1300–1400	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
9A Gr. 1	1100–1250	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
9B Gr. 1	1100–1175				
10F Gr. 1	1100–1250	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
10I Gr. 1	1300–1400				
11A Gr. 4	1000–1050	30 min	1 hr/in.	1 hr/in.	1 hr/in.
P-Nos. 8, 34, 42, 43, 45, and hard surfacing on P-No. 1 base metal whose reported carbon content is not more than 0.30%	PWHT neither required nor prohibited				

NOTES:

(1) Exemptions to the mandatory requirements of this Table are defined in NB-4622.7.

(2) All temperatures are metal temperatures.

TABLE NB-4622.1-1 MANDATORY REQUIREMENTS FOR POSTWELD HEAT TREATMENT OF WELDS¹
minimum holding time permitted by Table NB-4622.4(c)-1 are also certified for any temperature in between.

**TABLE NB-4622.4(c)-1
ALTERNATIVE HOLDING TEMPERATURES AND TIMES¹**

Material P-No.	Alternative Minimum Holding Temperatures, °F	Alternative Minimum Holding Times [Note (1)]
1, 3, 9A Gr. 1, 9B Gr. 1	1050	2 hr/in. thick
1, 3, 9A Gr. 1, 9B Gr. 1	1000	4 hr/in. thick

NOTE:

(1) All other requirements of NB-4622 shall apply.

TABLE NB-4622.4(c)-1 ALTERNATIVE HOLDING TEMPERATURES AND TIMES¹

(3) Base material certified in accordance with NB-2200 may be postweld heat treated at the lower minimum temperature ranges and increased minimum holding times without recertification. Postweld heat treatment at these lower minimum temperatures and increased minimum holding times may also be the tempering operation provided a higher tempering temperature is not required by the material specification.

NB-4622.5 PWHT Requirements When Different P-Number Materials Are Joined.

When materials of two different P-Number groups are joined by welding, the applicable postweld heat treatment shall be that specified in Table NB-4622.1-1 for the material requiring the higher PWHT temperature range.

NB-4622.6 PWHT Requirements for Nonpressure-Retaining Parts.

When nonpressure-retaining material is welded to pressure-retaining material, the postweld heat treatment temperature range of the pressure-retaining material shall control.

NB-4622.7 Exemptions to Mandatory Requirements.

Postweld heat treatment in accordance with this Subarticle is not required for:

- (a) nonferrous material;
- (b) welds exempted in Table NB-4622.7(b)-1;
- (c) welds subjected to temperatures above the PWHT temperature range specified in Table NB-4622.1-1, provided the

Welding Procedure Specification is qualified in accordance with Section IX and the base material and the deposited weld filler material have been heat treated at the higher temperature;

- (d) welds connecting nozzles to components or branch to run piping provided the requirements in NB-4622.8 are met;
- (e) weld repairs to vessels provided the requirements of NB-4622.9 are met;
- (f) weld repairs to cladding after final postweld heat treatment provided the requirements of NB-4622.10 are met;
- (g) weld repairs to dissimilar metal welds after final postweld heat treatment provided the requirements of NB-4622.11 are met.

NB-4622.8 Requirements for Exempting PWHT of Nozzles to Component Welds and Branch to Run Piping Welds.

Welds connecting nozzles or branch piping of P-No. 1 materials to components or run piping of P-No. 1 or P-No. 3 materials that are not exempted from PWHT in Table NB-4622.7(b)-1 need not be given a postweld heat treatment if the requirements of (a) below are met for partial penetration and (b) below are met for full penetration welds.

- (a) The partial penetration welds are made with A-No. 8 or non-air-hardening nickel-chromium-iron weld metal after:
 - (1) the ferritic materials to be joined are buttered or built-up with A-No. 8 or non-air-hardening nickel-chromium-iron weld metal having a minimum thickness of $\frac{1}{4}$ in. (6 mm), and
 - (2) the heat affected zones of the buttered or built-up ferritic materials are postweld heat treated in accordance with NB-4620, without the PWHT exemptions being applied, prior to making the final welds.
- (b) The full penetration welds are made with A-No. 1 or A-No. 2 weld metal provided that:
 - (1) the component or run pipe is built-up or buttered in the area of the attachment with A-No. 1 or A-No. 2 metal having a minimum thickness of $\frac{1}{4}$ in. (6 mm);
 - (2) the A-No. 1 or A-No. 2 weld metal buildup or buttering is postweld heat treated in accordance with NB-4620 for P-No. 1 or P-No. 3 materials without the PWHT exemptions being applied;
 - (3) the welds do not penetrate through the component or run pipe thickness;
 - (4) weld metal with A-No. 1 or A-No. 2 analysis is used to join the nozzle or branch pipe of P-No. 1 material to the weld buildup or buttering;
 - (5) the nominal thickness of the weld joining the nozzle or branch pipe to the component or run pipe does not exceed $1\frac{1}{2}$ in. (38 mm) and the maximum reported carbon content of the nozzle or branch piping connection does not exceed 0.30%;
 - (6) a 200°F (93°C) minimum preheat is maintained during welding whenever the nominal thickness of the weld exceeds:

Page 215

Pages 216-217

**TABLE NB-4622.7(b)-1
EXEMPTIONS TO MANDATORY PWHT¹**

P-No. (Section IX, QW-420)		Type of Weld [Note (2)]	Nominal Thickness (NB-4622.3)	Max. Reported Carbon, % [Note (3)]	Min. Preheat Required, °F
1	Vessels	Circumferential butt and socket welds connecting pipe and tubes to nozzles where the materials being joined are 1½ in. and less	1¼ in. and less Over 1¼ in. to 1½ in. ¾ in. or less Over ¾ in. to 1½ in.	0.30 or less 0.30 or less Over 0.30 Over 0.30	... 200 ... 200
		Fillet welds	¾ in. or less	...	200
		All welds, except repair welds and fillet welds, provided welding procedure qualification is made using equal or greater thickness base material than the production weld	5/8 in. or less	0.25 or less	200
	Other components	All welds where the materials being joined are 1½ in. and less	1¼ in. and less Over 1¼ in. to 1½ in. ¾ in. or less Over ¾ in. to 1½ in.	0.30 or less 0.30 or less Over 0.30 Over 0.30	... 200 ... 200
		All welds in material over 1½ in.	¾ in. or less	...	200
1, 3		For repair without required PWHT, see NB-4622.9, NB-4622.10, and NB-4622.11	...	...	350
1 Gr. 1 or Gr. 2		Cladding or repair of cladding [Note (4)] with A-No. 8 or F-No. 43 filler metal on base material of: 1½ in. or less over 1½ in. to 3 in. over 3 in.		0.30 0.30 0.30	100 200 [Note (5)] 250 [Note (6)]
3 except Gr. 3		All welds, except repair welds in vessels, provided welding procedure qualification is made using equal or greater thickness base material than the production weld	5/8 in. or less	0.25 or less	200
		Attachment welds joining nonpressure-retaining material to pressure-retaining material	½ in. or less	0.25 or less	200
		Circumferential butt welds in pipe and tubes	½ in. or less	0.25 or less	200
		Socket welds in pipe and tubes with nominal O.D. 2¾ in. or less	½ in. or less	0.25 or less	200
4		Circumferential butt welds in pipe and tubes with nominal O.D. 4 in. or less and attachment welds	½ in. or less	0.15 or less	250

(continued)

TABLE NB-4622.7(b)-1 EXEMPTIONS TO MANDATORY PWHT¹

**TABLE NB-4622.7(b)-1
EXEMPTIONS TO MANDATORY PWHT¹ (CONT'D)**

P-No. (Section IX, QW-420)		Type of Weld [Note (2)]	Nominal Thickness (NB-4622.3)	Max. Reported Carbon, % [Note (3)]	Min. Preheat Required, °F
4		Socket welds in pipe and tubes with nominal O.D. $2\frac{3}{8}$ in. or less	$\frac{1}{2}$ in. or less	0.15 or less	250
5A, 5B, 5C		Circumferential butt welds in pipe and tubes with maximum reported chromium 3.00% or less and nominal O.D. 4 in. or less and attachment welds	$\frac{1}{2}$ in. or less	0.15 or less	300
		Socket welds in pipe and tubes with maximum reported chromium 3.00% or less and nominal O.D. $2\frac{3}{8}$ in. or less	$\frac{1}{2}$ in. or less	0.15 or less	300
6 (for Type 410) or 7 Gr. 1 (for Type 405)		Type 405 and 410S welded with A-No. 8, A-No. 9, or F-No. 43 filler metal	$\frac{3}{8}$ in. or less	0.08 or less	...
9A Gr. 1		All welds, provided the procedure qualification is made using equal or greater thickness base material than the production weld	$\frac{5}{8}$ in. or less	...	200
		Attachment welds joining nonpressure-retaining material to pressure-retaining material over $\frac{5}{8}$ in.	$\frac{1}{2}$ in. or less	...	200
		Circumferential butt welds in pipe and tubes with nominal O.D. 4 in. or less and attachment welds	$\frac{1}{2}$ in. or less	0.15 or less	250
		Socket welds in pipe and tubes with nominal O.D. $2\frac{3}{8}$ in. or less	$\frac{1}{2}$ in. or less	0.15 or less	250
9B Gr. 1		All welds, provided the procedure qualification is made using equal or greater thickness base material than the production weld	$\frac{5}{8}$ in. or less	...	200
		Attachment welds joining nonpressure-retaining material to pressure-retaining material over $\frac{5}{8}$ in.	$\frac{1}{2}$ in. or less	...	200
		Circumferential butt welds in pipe and tubes with nominal O.D. 4 in. or less and attachment welds	$\frac{1}{2}$ in. or less	0.15 or less	250
		Socket welds in pipe and tubes with nominal O.D. $2\frac{3}{8}$ in. or less	$\frac{1}{2}$ in. or less	0.15 or less	250
10I Gr. 1		All welds in material $\frac{1}{2}$ in. and less	$\frac{1}{2}$ in. or less	...	...
11A Gr. 4		All welds in material $\frac{1}{2}$ in. and less	$\frac{1}{2}$ in. or less	...	250

(continued)

TABLE NB-4622.7(b)-1 EXEMPTIONS TO MANDATORY PWHT¹ (CONT'D)

TABLE NB-4622.7(b)-1 (CONT'D)

NOTES:

- (1) The exemptions noted in this Table do not apply to the following:
 - (a) electron beam welds in ferritic materials over $\frac{1}{8}$ in. in thickness;
 - (b) inertia and friction welds in material of any thickness of P-No. 3, P-No. 4, P-No. 5, P-No. 7 (except for Types 405 and 410S), P-No. 10, and P-No. 11 materials.
- (2) Where the thickness of material is identified in the Type of Weld column, it is the thickness of the base material at the welded joint.
- (3) Carbon level of the pressure-retaining materials being joined.
- (4) Maximum process heat input = 150,000 J/in. The maximum resulting hardness in the procedure qualification test plate shall not exceed 35 Rc.
- (5) Intermediate postweld soak at not less than 200°F for 2 hr minimum.
- (6) Intermediate postweld soak at not less than 300°F for 2 hr minimum.

TABLE NB-4622.7(b)-1 (CONT'D)

(a) $1\frac{1}{4}$ in. (32 mm) and the maximum reported carbon content of the material of the nozzle or branch pipe is 0.30% or less, or

(b) $\frac{3}{4}$ in. (19 mm) and the maximum reported carbon content of material of the nozzle or branch pipe connection exceeds 0.30%.

NB-4622.9 Temper Bead Weld Repair.

Limited weld repairs to P-No. 1 and P-No. 3 material, and A-Nos. 1, 2, 10, or 11 weld filler metal (QW-442 of Section IX), may be made without PWHT or after the final PWHT, provided it is impossible or impractical to postweld heat treat the area after repair, and provided the requirements of the following subparagraphs are met.

(a) *Examination of Area to Be Repaired.* Before repair, the area shall be examined by either the magnetic particle or liquid penetrant method in accordance with NB-5000.

(b) *Maximum Extent of Repair.* The maximum area of an individual repair based on the finished surface shall be 100 sq in. (64,500 mm²) and the depth of repair shall not be greater than one-third of the base material thickness.

(c) *Repair Welding Procedure.* The welding procedure shall be in accordance with Section IX and this Subsection and shall include the requirements of (1) through (6) below.

(1) The area to be repaired shall be suitably prepared for welding in accordance with a written procedure.

(2) The weld metal shall be deposited by the manual shielded metal arc process using low hydrogen type electrode. The maximum bead width shall be four times the electrode core diameter.

(3) The low hydrogen covered electrodes shall be baked and otherwise cared for as required by (a) through (d) below.

(a) The Certificate Holder shall bake all covered electrodes before use at a temperature of 750°F-850°F (399°C-454°C) for 30 min to 1 hr. The temperature of the oven shall not exceed 300°F (149°C) when the electrodes are placed in the oven for baking. During the baking cycle, the temperature shall not be raised more than 300°F/hr (167°C/hr) when oven temperatures are above 500°F (260°C) and the total time above 500°F (260°C), including the holding time, shall not exceed 5 hr.

(b) After baking and before the electrodes are allowed to cool below 225°F (107°C), they shall be transferred to holding ovens operating in temperature ranges of 225°F-350°F (107°C-177°C).

(c) Suitable heated portable containers shall be used at 225°F-350°F (107°C-177°C). Electrodes turned in after exposure shall be returned to the holding ovens and held at temperatures given in (b) above for a period of not less than 8 hr before reissue.

(d) Electrodes shall not be rebaked more than once, except if tests establish that the electrodes, after multiple rebakings, meet all specification requirements.

(e) If the repair area is to be subjected to a significant fast neutron fluence (greater than 10^{19} nvt $E_0 > 1$ MeV), electrode shall be limited to Cu content of 0.10% maximum (as deposited).

(4) The weld area plus a band around the repair area of at least $1\frac{1}{2}$ times the component thickness or 5 in. (127 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 350°F (177°C) during welding. The maximum interpass temperature shall be 450°F (232°C). Thermocouples and recording instruments shall be used to monitor the process temperatures. Their removal shall be in accordance with NB-4435(b).

(5) The cavity shall be buttered, using a $\frac{3}{32}$ in. (2.4 mm) diameter electrode as shown in Fig. NB-4622.9(c)(5)-1. The weld bead crown surface shall be removed by grinding or machining before depositing the second layer [see Fig. NB-4622.9(c)(5)-1, Step 2]. The second layer shall be deposited with a $\frac{1}{8}$ in. (3.2 mm) diameter electrode. Subsequent layers shall be deposited with a welding electrode no larger than $\frac{5}{32}$ in. (4 mm) diameter. Bead deposition shall be

Page 218

performed in a manner shown in Fig. NB-4622.9(c)(5)-1, Step 3. The completed weld shall have at least one layer of weld reinforcement deposited and then this reinforcement shall be removed by mechanical means, making the finished surface of the repair substantially flush with the surface of the vessel surrounding the repair [Fig. NB-4622.9(c)(5)-2]. The technique described in this paragraph shall be performed in the procedure qualification test.

(6) The weld area shall be maintained at a temperature of 450°F-550°F (232°C-288°C) for a minimum period of 2 hr after completion of the weld repair in P-No. 1 materials. For P-No. 3 materials, the holding time shall be a minimum of 4 hr.

(d) *Examination of Repair Welds.* The second (temper bead) layer shall be examined by the magnetic particle or liquid penetrant method. The completed weld shall have the weld reinforcement, including the final layer, removed substantially flush with the surface prior to performing the required nondestructive examination. The nondestructive examination shall be performed after the completed weld has been at ambient temperature for a minimum period of 48 hr to detect the presence of possible delayed cracking of the weldment. The nondestructive examination of the repair welded and preheated region shall be in accordance with NB-4453.4. In addition, all repairs shall be ultrasonically examined. All nondestructive examination shall be in accordance with NB-5000.

(e) *Documentation of Weld Repairs.* Documentation of weld repairs shall be in accordance with NB-4130, exclusive of the size requirements.

(f) *Welding Procedure Qualification Test Plate.* The test assembly materials for the welding procedure qualification shall be of the same P-Number and Group Number, including a postweld heat treatment that is at least equivalent to the time and temperature applied to the materials being repaired. The depth of cavity in the test assembly shall be a minimum of one-half the depth of actual repair, but not less than 1 in. (25 mm). The test assembly thickness shall be a minimum of twice the depth of cavity in the test assembly. The test assembly shall be large enough to permit removal of the required test specimens. In order to simulate the restraint that the weld metal will experience in the repair section of the component, the test assembly dimensions surrounding the cavity shall be equal to the test assembly thickness, but not less than 6 in. (152 mm). The qualification test plate shall be prepared in accordance with Fig. NB-4622.9(f)-1.

(g) This test assembly may be used to qualify procedures for weld buildup repairs of pressure-retaining materials. In this case, the depth of the cavity shall not be less than the thickness of the weld buildup or 1 in. (25 mm), whichever is greater, and the area of the weld buildup to be applied or 54 sq in. (34,839 mm²), whichever is less.

(h) In all cases, the test assembly and cavity shall be of sufficient size to permit removal of the required test specimens.

(i) *Performance Qualifications.* If the repair weld is to be performed where physical obstructions impair the welder's ability to perform, the welder shall also demonstrate the ability to deposit sound weld metal in the positions required, using the same parameters and simulated physical obstructions as are involved in the repair.

NB-4622.10 Repair Welds to Cladding After Final Postweld Heat Treatment.

Nonpostweld heat treated weld repairs may be made to P-No. 8 or P-No. 43 cladding of P-No. 1 and P-No. 3 material after final PWHT, provided it is impossible or impractical to postweld heat treat the area after repair, and provided the requirements of the following subparagraphs are met.

(a) *Maximum Extent of Repair.* This procedure may be used with the base material exposed to a depth not greater than $\frac{1}{4}$ in. (6 mm) or 10% of the base material thickness, whichever is less, nor to an individual area greater than 100 sq in. (64,500 mm²). Areas with greater base material exposure depth shall be repaired in accordance with NB-4622.9 to within this limit before implementing the cladding repair.

(b) *Repair Welding Procedure.* The welding procedure shall be in accordance with Section IX and this Subsection, and shall include the requirements of (1) through (7) below.

(1) The repairs shall be made using A-No. 8 weld metal (Section IX, QW-442) for P-No. 8 cladding or F-No. 43 weld metal (Section IX, QW-432) for either P-No. 8 or P-No. 43 cladding.

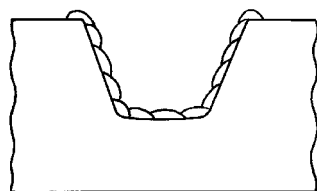
(2) The manual shielded metal arc process shall be used for welding with a bead width not to exceed four times the electrode core diameter.

(3) All covered electrodes used for qualification test and repair welding shall be from unopened, hermetically sealed packages or heated ovens maintained between 225°F (107°C) and 350°F (177°C). Electrodes withdrawn from hermetically sealed containers or ovens for longer than 8 hr shall be discarded.

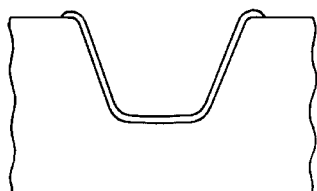
(4) During the repair, the electrodes may be maintained in heated ovens in the repair area. The oven temperature shall be maintained between 225°F (107°C) and 350°F (177°C). Electrodes exposed to the atmosphere for more than 8 hr shall be discarded.

Page 219

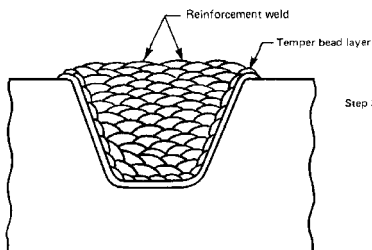
Page 220



Step 1: Butter cavity with one layer of weld metal using $\frac{3}{32}$ in. diameter coated electrode.



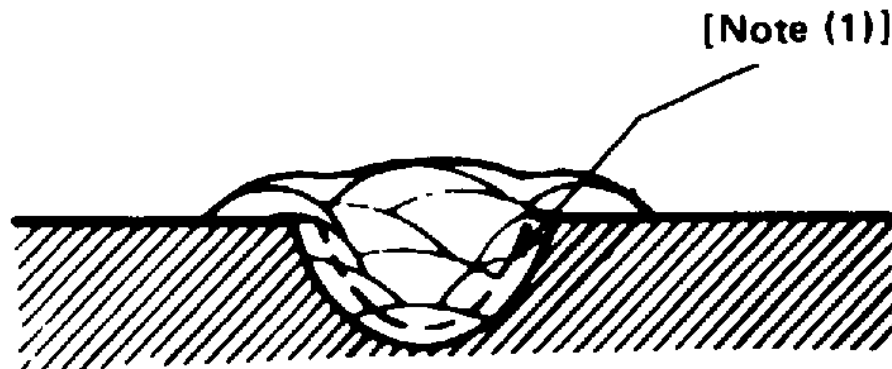
Step 2: Remove the weld bead crown of the first layer of grinding.



Step 3: The second layer shall be deposited with a $\frac{1}{8}$ in. diameter electrode. Subsequent layers shall be deposited with welding electrodes no larger than $\frac{5}{32}$ in. maximum diameter. Bead deposition shall be performed in a manner as shown. Particular care shall be taken in the application of the temper bead reinforcement weld at the tie-in points as well as its removal to ensure that the heat affected zone of the base metal and the deposited weld metal is tempered and the resulting surface is substantially flush.

FIG. NB-4622.9(c)(5)-1 TEMPER BEAD WELD REPAIR AND WELD TEMPER BEAD REINFORCEMENT

FIG. NB-4622.9(c)(5)-1 TEMPER BEAD WELD REPAIR AND WELD TEMPER BEAD REINFORCEMENT



NOTE:

- (1) Apply temper bead reinforcement weld metal to a level above the surface and then remove it substantially flush to the surface as required by NB-4622.9(c)(5).**

FIG. NB-4622.9(c)(5)-2 TEMPER BEAD REINFORCEMENT

FIG. NB-4622.9(c)(5)-2 TEMPER BEAD REINFORCEMENT

(5) The weld area plus a band around the clad repair of $1\frac{1}{2}$ times the component thickness or 5 in. (127 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 350°F (177°C) during welding. The maximum interpass temperature shall be 450°F (232°C). Thermocouples and recording instruments shall be used to monitor the process temperatures. Their removal shall be in accordance with NB-4435.

(6) All areas of the base material on which weld metal is to be deposited shall be covered with a single layer of weld deposit using $\frac{3}{32}$ in. (2.4 mm) diameter electrode, followed by a minimum of one layer of weld deposit using $\frac{1}{8}$ in. (3.2 mm) diameter electrode. Subsequent layers may be deposited with electrode no larger than $\frac{5}{32}$ in. (4 mm). The weld bead crown surface of the first layer shall be removed by grinding.

(7) After completion of welding, the weld area shall be maintained at a temperature of 450°F-550°F (232°C-288°C) for a period of 2 hr for P-No. 1 material and 4 hr for P-No. 3 material.

(c) *Examination of Repair Welds.* The weld repair as well as the preheated band shall be examined by the liquid penetrant method. All nondestructive examination shall be in accordance with NB-5000.

(d) *Documentation of Weld Repairs.* Documentation of weld repairs shall be in accordance with NB-4130, exclusive of

the size requirements.

(e) Welding Procedure Qualification Test Plate

(1) The test assembly material for the welding procedure qualification test shall be of the same P-Number and Group Number, including a postweld heat treatment that is at least equivalent to the time and temperature of that applied to the material being repaired. If the repair involves two different P-Number or Group Number materials, the test assembly shall duplicate the combination.

(2) The test assembly base material shall be at least 12 in. (305 mm) by 12 in. (305 mm), 2 in. (51 mm) min. thickness, with a clad surface area of at least 8 in. (203 mm) by 8 in. (203 mm), in the area from which the bend test specimens will be removed.

(3) The qualification test plate assembly shall be prepared and tested in accordance with the requirements of Section IX. The guided bend test acceptance standards described in Section IX for cladding shall also be applicable to the HAZ of the base material.

(f) Performance Qualifications. If the repair weld is to be performed where physical obstructions impair the welder's ability to perform, the welder shall also demonstrate the ability to deposit sound weld metal in the positions required, using the same parameters and simulated physical obstructions as are involved in the repair.

NB-4622.11 Temper Bead Weld Repair to Dissimilar Metal Welds or Buttering.

Whenever PWHT is impractical or impossible, limited weld repairs to dissimilar metal welds of P-No. 1 and P-No. 3 material or weld filler metal A-No. 8 (Section IX, QW-442) or F-No. 43 (Section IX, QW-432) may be made without PWHT or after the final PWHT provided the requirements of the following subparagraphs are met.

(a) Examination of Area to Be Repaired. Before repair, the area shall be examined by either the magnetic particle or liquid penetrant method in accordance with NB-5000.

(b) Maximum Extent of Repair. Repairs made to this paragraph are limited to those along the fusion line of a nonferritic weld to ferritic base material where $\frac{1}{8}$ in. (3.2 mm) or less of nonferritic weld deposit exists above the original fusion line after defect removal. If the defect penetrates into the ferritic base material, repair of the base material may be performed in accordance with NB-4622.11 provided the depth of repair in the base material does not exceed $\frac{3}{8}$ in. (10 mm). The repairs to a completed joint shall not exceed one-half the joint thickness. The surface of the completed repair shall not exceed 100 sq in. (64,500 mm²).

(c) Repair Welding Procedure. The welding procedure and welder qualification shall meet all of the requirements of Section IX and the additional requirements of this Article. In addition, the Welding Procedure Specification shall include the following requirements.

(1) The area to be repaired shall be suitably prepared for welding in accordance with the written procedure to be used for the repair.

(2) The weld metal shall be deposited by the shielded metal arc welding process (SMAW) using A-No. 8

Page 221

Page 222

weld metal (Section IX, QW-442) for P-No. 8 to P-No. 1 or P-No. 3 weld joints or F-No. 43 weld metal (Section IX, QW-432) for either P-No. 8 or P-No. 43 to P-No. 1 or P-No. 3 weld joints. The maximum bead width shall be four times the electrode core diameter.

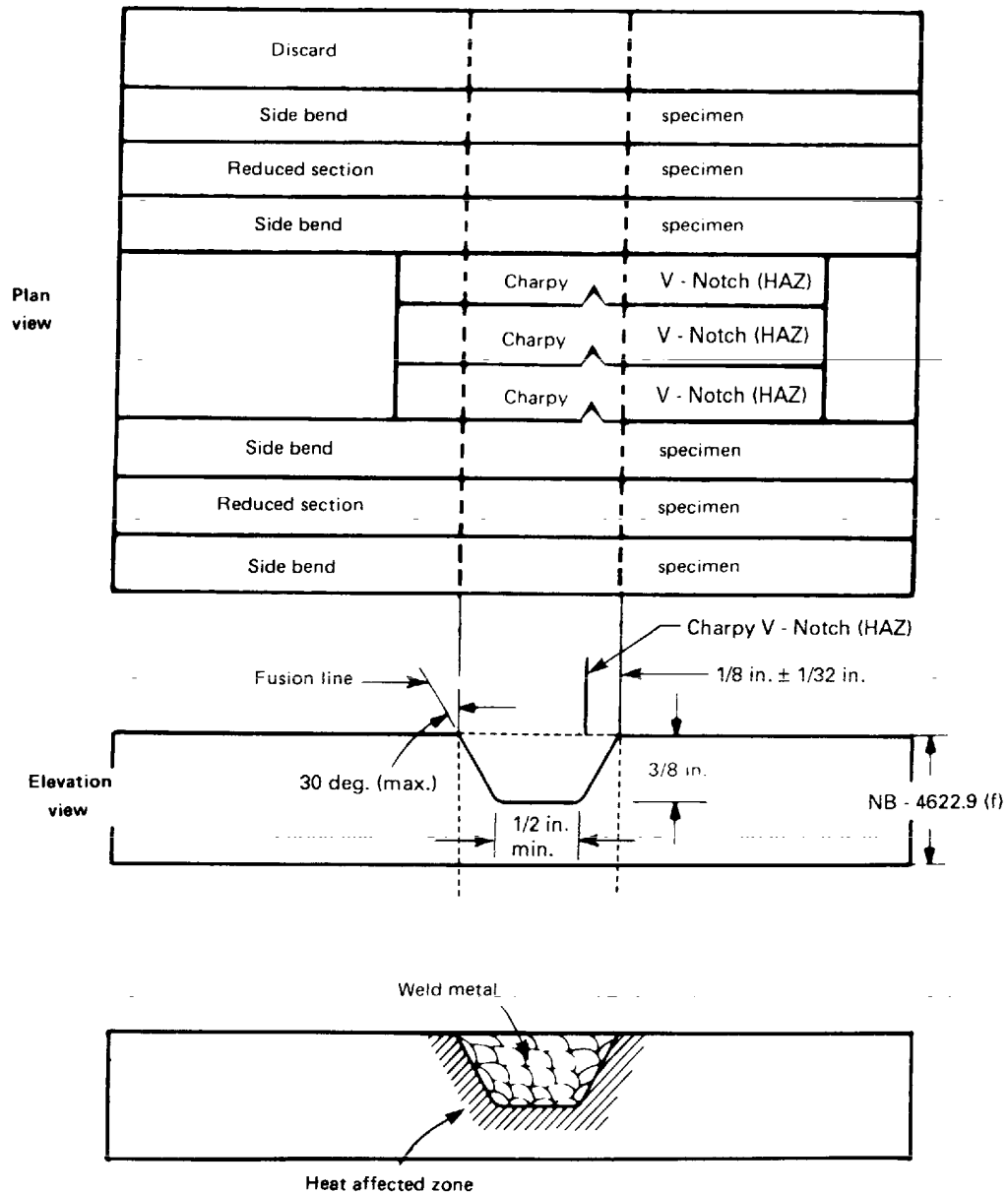


FIG. NB-4622.9(f)-1 QUALIFICATION TEST PLATE

FIG. NB-4622.9(f)-1 QUALIFICATION TEST PLATE

(3) All covered electrodes used for qualification test and repair welding shall be from unopened, hermetically sealed

packages or heated ovens maintained between 225°F (107°C) and 350°F (177°C). Electrodes withdrawn from hermetically sealed containers or ovens for longer than 8 hr shall be discarded.

(4) During the repair, the electrode may be maintained in heated ovens in the repair area. The oven temperature shall be maintained between 225°F (107°C) and 350°F (177°C). Electrodes exposed to the atmosphere for more than 8 hr shall be discarded.

(5) The weld area plus a band around the weld repair of $1\frac{1}{2}$ times the component thickness or 5 in. (127 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 350°F (177°C) during welding. The maximum interpass temperature shall be 450°F (232°C). Thermocouples and recording instruments shall be used to monitor the metal temperature during welding. Their removal shall be in accordance with NB-4435.

(6) All areas of the ferritic base material, exposed or not, on which weld metal is to be deposited, shall be covered with a single layer of weld deposit using $\frac{3}{32}$ in. (2.4 mm) diameter electrode. The weld bead crown surface shall be removed by grinding before depositing the second layer. The second layer shall be deposited with $\frac{1}{8}$ in. (3.2 mm) diameter electrode. Subsequent layers may be deposited with $\frac{5}{32}$ in. (4 mm) maximum diameter electrode. The techniques described in this paragraph shall be duplicated in the procedure qualification. [See Fig. NB-4622.11(c)(6)-1].

(7) After at least $\frac{3}{16}$ in. (4.8 mm) of weld metal has been deposited, the preheated area as defined in (c)(5) above shall be maintained in the range of 450°F-550°F (232°C-288°C) for 4 hr as a minimum.

(8) Subsequent to the above heat treatment, the balance of the welding may be performed at a minimum preheat temperature of 100°F (38°C) and at a maximum interpass temperature of 350°F (177°C).

(d) Examination of Repair Areas

(1) After the heat treatment specified in (c)(7) above has been completed, the repaired area shall be examined by the liquid penetrant method.

(2) The repaired area and the preheated band as defined in (c)(5) above shall be examined by the liquid penetrant method after the completed weld has been at ambient temperature for a minimum of 48 hr. The repaired region shall be examined by the radiographic method and, if practical, by the ultrasonic method.

(3) For repairs to partial penetration welds, the radiographic and ultrasonic examinations specified in (d)(2) above need not be performed, if meaningful results cannot be obtained. For these cases, liquid penetrant examination only shall be performed. For weld repair depths approximately $\frac{3}{16}$ in. (4.8 mm), liquid penetrant examination shall be performed at the time specified in (d)(2) above. For weld repair depths greater than $\frac{3}{16}$ in. (4.8 mm), liquid penetrant examination shall be performed after approximately $\frac{3}{16}$ in. (4.8 mm) thickness has been deposited and the post heat specified in (c)(7) above has been completed. Additional incremental deposit thicknesses shall be liquid penetrant examined in accordance with NB-5245. The final weld surface shall be liquid penetrant examined at the time specified in (d)(2) above.

(4) All nondestructive examination shall be in accordance with NB-5000.

(e) Documentation of Weld Repairs. Documentation of weld repairs shall be in accordance with NB-4130, exclusive of the size requirements.

(f) Welding Procedure Qualification Test Plate. The test assembly materials for the welding procedure qualification shall be of the same P-Number and Group Number, including a postweld heat treatment that is at least equivalent to the time and temperature applied to the materials being repaired. The depth of cavity in the test assembly shall be a minimum of one-half the depth of actual repair but not less than 1 in. (25 mm). The test assembly thickness shall be a minimum of twice the depth of cavity in the test assembly. The test assembly shall be large enough to permit removal of the required test specimens. In order to simulate the restraint that the weld metal will experience in the repaired section of the component, the test assembly dimensions surrounding the cavity shall be equal to the test assembly thickness, but not less than 6 in. (152 mm). The qualification test plate shall be prepared in accordance with Fig. NB-4622.9(f)-1.

(g) Performance Qualifications. If the repair weld is to be performed where physical constructions impair the welder's ability to perform, the welder shall also demonstrate the ability to deposit sound weld metal in the positions required, using the same parameters and simulated physical obstructions as are involved in the repair.

using the same parameters and simulated physical obstructions as are involved in the repair.

NB-4623 PWHT Heating and Cooling Rate Requirements

Above 800°F (427°C) the rate of heating and cooling in any hourly interval shall not exceed 400°F (222°C)

Page 223

Page 224

divided by the maximum thickness in inches of the material being heat treated, but shall not exceed 400°F (222°C) and need not be less than 100°F (56°C) in any hourly interval. During the heating and cooling period there shall not be a greater variation in temperature than 250°F (139°C) within any 15 ft (4.6 m) interval of weld length. The exceptions of (a) and (b) below are permitted.

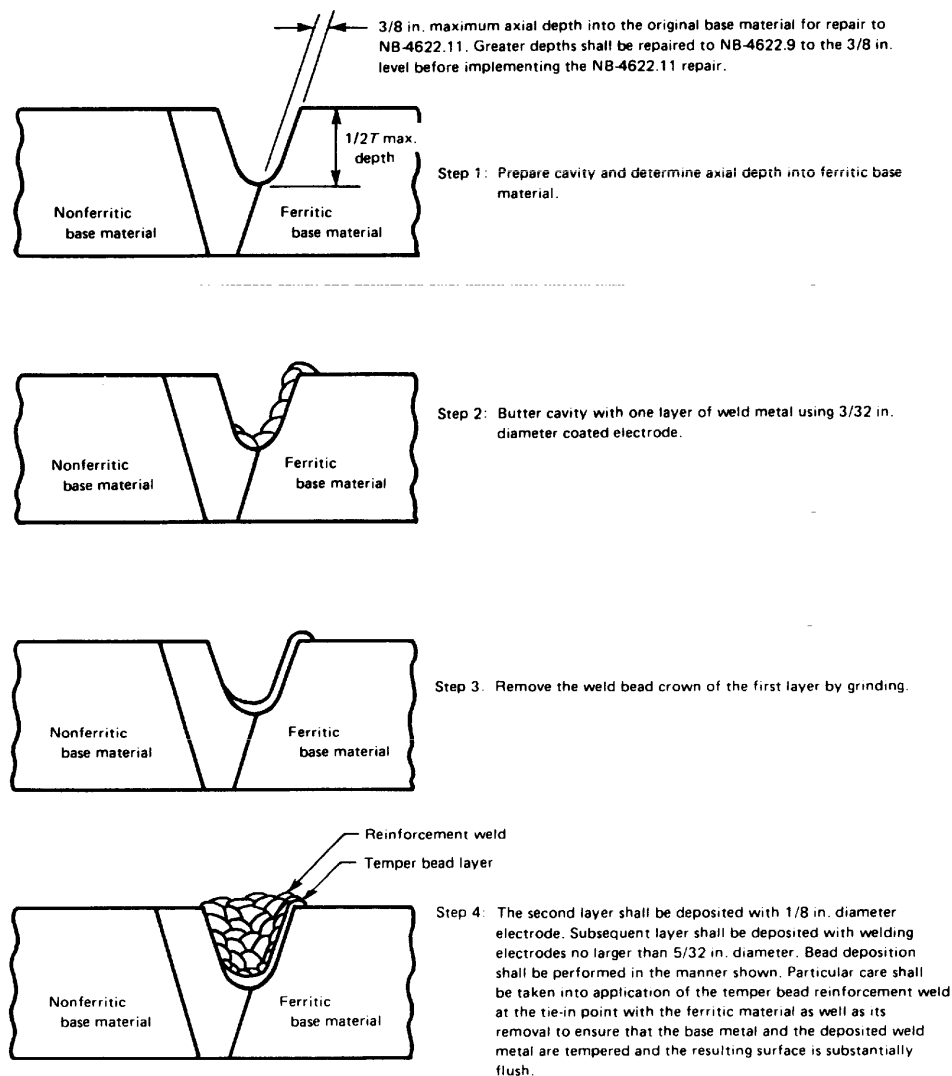


FIG. NB-4622.11(c)(6)-1 TEMPER BEAD WELD REPAIR AND WELD TEMPER BEAD REINFORCEMENT OF DISSIMILAR METAL WELDS OR BUTTERING

FIG. NB-4622.11(c)(6)-1 TEMPER BEAD WELD REPAIR AND WELD TEMPER BEAD REINFORCEMENT OF DISSIMILAR METAL WELDS OR BUTTERING

(a) P-No. 6 material may be cooled in air from the postweld heat treatment holding temperature specified in Table NB-4622.1-1.

(b) For P-No. 7 material the cooling rate at temperatures above 1200°F shall not exceed 100°F/hr (56°C/hr), after which the rate of cooling shall be sufficiently rapid to prevent embrittlement.

NB-4624 Methods of Postweld Heat Treatment

The postweld heat treatment shall be performed in accordance with the requirements of one of the following subparagraphs.

NB-4624.1 Furnace Heating - One Heat.

Heating the item in a closed furnace in one heat is the preferred procedure and should be used whenever practical. The furnace atmosphere shall be controlled so as to avoid excessive oxidation and direct impingement of flame on the component or item is prohibited.

NB-4624.2 Furnace Heating - More Than One Heat.

The item may be heated in more than one heat in a furnace, provided the furnace atmosphere control requirements of NB-4624.1 apply and overlap of the heated sections of the component or item is at least 5 ft (1.5 m). When this procedure is used, the portion of the component or item outside the furnace shall be shielded so that the temperature gradient is not harmful. The cross section where the component or item projects from the furnace shall not intersect a nozzle or other structural discontinuity.

NB-4624.3 Local Heating.

Welds may be locally postweld heat treated when it is not practical to heat treat the entire component or item. Local postweld heat treatment shall consist of heating a circumferential band around the component or item at temperature within the ranges specified in this Subarticle. The minimum width of the controlled band at each side of the weld, on the face of the greatest weld width, shall be the thickness of the weld or 2 in. (51 mm), whichever is less. The temperature of the component or item from the edge of the controlled band outward shall be gradually diminished so as to avoid harmful thermal gradients. This procedure may also be used for postweld heat treatment after repairs.

NB-4624.4 Heating Items Internally.

The component or item may be heated internally by any appropriate means and with adequate indicating and recording temperature devices to aid in the control and maintenance of a uniform distribution of temperature in the item. Previous to this operation, the item should be fully enclosed with insulating material.

NB-4630 HEAT TREATMENT OF WELDS OTHER THAN THE FINAL POSTWELD HEAT TREATMENT

The holding temperature, the time at temperature, the heating rate, and the cooling rate need not conform to the requirements of this Article for heat treatments other than the final postweld heat treatment.

NB-4650 HEAT TREATMENT AFTER BENDING OR FORMING FOR PIPES, PUMPS, AND VALVES

NB-4651 Conditions Requiring Heat Treatment After Bending or Forming

(a) Ferritic alloy steel pipe or formed portions of pumps or valves that have been heated for bending or other forming operations shall receive a heat treatment in accordance with NB-4620, a full anneal, a normalizing and tempering treatment, or a quenching and tempering treatment.

(b) Carbon steel pipe or formed portions of pumps or valves with a wall thickness greater than $\frac{3}{4}$ in. (19 mm) included in group P-No. 1 in Section IX that have been cold bent or formed shall receive heat treatment in accordance with NB-4620.

(c) Ferritic alloy pipe or formed portions of pumps or valves with an outside diameter greater than 4 in. (102 mm) and a wall thickness greater than $\frac{1}{2}$ in. (13 mm) included in groups P-No. 3 through P-No. 5 in Section IX that have been cold bent or formed shall require a heat treatment in accordance with NB-4620.

NB-4652 Exemptions From Heat Treatment After Bending or Forming

If the conditions described in (a) through (d) below are met, heat treatment after bending or forming is not required.

(a) Carbon steel pipe or portions of pumps and valves that have been bent or formed at a temperature

Page 225

of 1650°F (900°C) or higher shall require no subsequent heat treatment, provided the requirements of NB-4213 have been met.

(b) Austenitic stainless steel pipe, or portions of pumps or valves that have been heated for bending or other forming operations, may be used in the as-bent condition unless the Design Specifications require a heat treatment following bending or forming.

(c) Austenitic stainless steel pipe, or portions of pumps or valves that have been cold bent or formed, may be used in the as-bent condition unless the Design Specifications require a heat treatment following bending or forming.

(d) Carbon steel and ferritic alloy steel pipe, or portions of pumps or valves with sizes and wall thicknesses less than specified in NB-4651(b) and NB-4651(c), may be cold bent or formed without a heat treatment following bending.

NB-4660 HEAT TREATMENT OF ELECTROSLAG WELDS

Electroslag welds in ferritic materials over $1\frac{1}{2}$ in. (38 mm) in thickness at the joints shall be given a grain refining heat treatment.

NB-4700 MECHANICAL JOINTS

NB-4710 BOLTING AND THREADING

NB-4711 Thread Engagement

The threads of all bolts or studs shall be engaged in accordance with the design.

NB-4712 Thread Lubricants

Any lubricant or compound used in threaded joints shall be suitable for the service conditions and shall not react unfavorably with either the service fluid or any component material in the system.

NB-4713 Removal of Thread Lubricants

All threading lubricants or compounds shall be removed from surfaces which are to be seal welded.

NB-4720 BOLTING FLANGED JOINTS

In bolting gasketed flanged joints, the contact faces of the flanges shall bear uniformly on the gasket and the gasket shall be properly compressed in accordance with the design principles applicable to the type of gasket used. All flanged joints shall be made up with relatively uniform bolt stress.

NB-4730 ELECTRICAL AND MECHANICAL PENETRATION ASSEMBLIES

Tubes or pipes of 2 in. nominal pipe size (DN 50) and less may be joined to a penetration assembly in accordance with the rules of NB-4350.

July 1, 1998
American Society Of Mechanical Engineers
SEC III D1 NB-5000
ARTICLE NB-5000 EXAMINATION

Page 227

NB-5100 GENERAL REQUIREMENTS FOR EXAMINATION

NB-5110 METHODS, NONDESTRUCTIVE EXAMINATION PROCEDURES, AND CLEANING

NB-5111 Methods

Nondestructive examinations shall be conducted in accordance with the examination methods of Section V, except as they may be modified by the requirements of this Article.

(a) *Fabrication.* Radiographic examination shall be by film radiography or real time radioscopy in accordance with Section V, Article 2, except that fluorescent screens are not permitted for film radiography, the geometric unsharpness shall not exceed the limits of T-285, and the penetrameters of Table NB-5111-1 shall be used in lieu of those shown in Table T-276. The requirements for the retention of radioscopy images are the same as for film radiography. Ultrasonic examination shall be in accordance with Section V, Article 5; magnetic particle examination shall be in accordance with Section V, Article 7; liquid penetrant examination shall be in accordance with Section V, Article 6; and leak testing shall be in accordance with Section V, Article 10.

(b) *Preservice.* Ultrasonic examinations required for weld preservice examination shall be in accordance with Section XI, Appendix 1; eddy current examination shall be in accordance with Section V, Article 8; and surface examinations shall be in accordance with NB-5111(a).

(c) The examinations required by this Article, or by reference to this Article, shall be performed by personnel who have been qualified as required by this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards of this Article.

NB-5112 Nondestructive Examination Procedures

All nondestructive examinations required by this Article shall be performed in accordance with detailed written procedures which have been proven by actual demonstration to the satisfaction of the Inspector. The procedures shall comply with the appropriate Article of Section V for the particular examination method. The digitization of radiographic film and radioscopy images shall meet the requirements of Section V, Article 2, Mandatory Appendix III, "Digital Image Acquisition, Display, and Storage for Radiography and Radioscopy." Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Inspector on request. At least one copy of the procedure shall be readily available to all applicable nondestructive examination personnel for reference and use.

NB-5113 Post-Examination Cleaning

Following any nondestructive examination in which examination materials are applied to the piece, the piece shall be thoroughly cleaned in accordance with applicable material or procedure specifications.

NB-5120 TIME OF EXAMINATION OF WELDS AND WELD METAL CLADDING

Acceptance examinations of welds and weld metal cladding required by NB-5200 shall be performed at the times stipulated in (a) through (g) below during fabrication and installation.

(a) Radiographic examination of welds shall be performed after an intermediate¹ or final postweld heat treatment, when required, except as provided in (1) and (2) below.

1 An intermediate postweld heat treatment for this purpose is defined as a postweld heat treatment performed on a weld within a temperature range not lower than the minimum holding temperature range to which the weld shall be subjected during the final postweld heat treatment.

(1) Radiographic examination of welds in piping, pumps, and valves fabricated of P-No. 1 materials

Page 230

may be performed prior to any required postweld heat treatment.

**TABLE NB-5111-1
THICKNESS, PENETRAMETER DESIGNATIONS, ESSENTIAL HOLES, AND WIRE DIAMETERS**

Single Wall Material Thickness Range, in.	Penetrameter(s) — Hole or Wire Type [Note (1)]							
	Source Side				Film Side			
	Designation	Hole Size	Essential Hole	Required Wire Diameter-IQI	Designation	Hole Size	Essential Hole	Required Wire Diameter-IQI
Up to 0.25 incl.	5	0.040	4T	0.006	5	0.040	4T	0.006
Over $\frac{1}{4}$ – $\frac{3}{8}$	7	0.040	4T	0.006	7	0.040	4T	0.006
Over $\frac{3}{8}$ – $\frac{1}{2}$	10	0.040	4T	0.010	10	0.040	4T	0.010
Over $\frac{1}{2}$ – $\frac{5}{8}$	12	0.050	4T	0.013	12	0.050	4T	0.013
Over $\frac{5}{8}$ – $\frac{3}{4}$	15	0.060	4T	0.016	12	0.050	4T	0.013
Over $\frac{3}{4}$ –1	20	0.040	2T	0.016	17	0.035	2T	0.013
Over 1– $1\frac{1}{4}$	25	0.050	2T	0.020	17	0.035	2T	0.013
Over $1\frac{1}{4}$ – $1\frac{1}{2}$	30	0.060	2T	0.025	20	0.040	2T	0.016
Over $1\frac{1}{2}$ –2	35	0.070	2T	0.032	25	0.050	2T	0.020
Over 2– $2\frac{1}{2}$	40	0.080	2T	0.040	30	0.060	2T	0.025
Over $2\frac{1}{2}$ –3	45	0.090	2T	0.040	35	0.070	2T	0.032
Over 3–4	50	0.100	2T	0.050	40	0.080	2T	0.040
Over 4–6	60	0.120	2T	0.063	45	0.090	2T	0.040
Over 6–8	80	0.160	2T	0.100	50	0.100	2T	0.050
Over 8–10	100	0.200	2T	0.126	60	0.120	2T	0.063
Over 10–12	120	0.240	2T	0.160	80	0.160	2T	0.100
Over 12–16	160	0.320	2T	0.250	100	0.200	2T	0.126
Over 16–20	200	0.400	2T	0.320	120	0.240	2T	0.160

NOTE:

(1) Hole (plaque) type penetrameters may be used on flat plates and on objects with geometries such that the penetrameter hole image is not distorted.

TABLE NB-5111-1 THICKNESS, PENETRAMETER DESIGNATIONS, ESSENTIAL HOLES, AND WIRE DIAMETERS

(2) Radiographic examination of welds in vessels fabricated of P-No. 1 materials and all welds in components fabricated of P-No. 3 materials may be performed prior to an intermediate or final postweld heat treatment, provided the welds are ultrasonically examined [NB-5111(a)] after an intermediate or final postweld heat treatment. The ultrasonic examination and acceptance standards shall be in accordance with NB-5331.

(b) Magnetic particle or liquid penetrant examinations of welds shall be performed after any required postweld heat treatment, except that welds in P-No. 1 material may be examined either before or after postweld heat treatment. The magnetic particle or liquid penetrant examination of welds at progressive stages of welding, as required in NB-5245 and NB-5246, may be performed before PWHT.

(c) All dissimilar metal weld joints, such as in austenitic or high nickel to ferritic material, or using austenitic or high nickel alloy filler metal to join ferritic materials which penetrate the wall, shall be examined after final postweld heat treatment.

(d) The magnetic particle or liquid penetrant examination of weld surfaces that are to be covered with weld metal cladding shall be performed before the weld metal cladding is deposited. The magnetic particle or liquid penetrant examination of weld surfaces that are not accessible after a postweld heat treatment shall be performed prior to the operation which caused this inaccessibility. These examinations may be performed before PWHT.

(e) Weld metal cladding shall be examined after either an intermediate¹ or final postweld heat treatment, except the examination of weld metal cladding on P-Nos. 1, 3, and 11 materials may be performed before or after the intermediate¹ or final postweld heat treatment.

(f) All of the joints in austenitic stainless steel and nonferrous material shall be examined by the liquid penetrant method after an intermediate or final postweld heat treatment, if any, is performed. This requirement does not apply to tube-to-tubesheet joints.

(g) Ultrasonic examination of electroslog welds in ferritic materials shall be performed after a grain refining heat treatment, when performed, or after final postweld heat treatment.

Page 231

NB-5130 EXAMINATION OF WELD EDGE PREPARATION SURFACES

All full penetration weld edge preparation surfaces for joint Categories A, B, C, D, and similar joints in material 2 in. (51 mm) or more in thickness shall be examined by the magnetic particle or liquid penetrant method. Indications shall be evaluated in accordance with the acceptance standards of (a), (b), and (c) below.

(a) Only indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Laminar-type imperfections are acceptable without repair if they do not exceed 1 in. (25 mm) in length. The extent of all laminar-type imperfections exceeding 1 in. (25 mm) in length shall be determined by ultrasonic examination. Imperfections exceeding 1 in. (25 mm) in length shall be repaired by welding to a depth of $\frac{3}{8}$ in. (10 mm) or the depth of the imperfection, whichever is less, unless the ultrasonic examination reveals that additional depth of repair is required to meet the ultrasonic examination requirement for the product form.

(c) Indications of nonlaminar imperfections of (1) through (3) below are unacceptable:

(1) any linear indications greater than $\frac{3}{16}$ in. (4.8 mm) long;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);

(3) four or more indications, in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less, edge to edge.

(d) Weld repairs made to weld edge preparations for Category A, B, C, D, or similar type welds shall be examined by the magnetic particle or liquid penetrant method before the surfaces become inaccessible. The examination may be performed before or after postweld heat treatment.

NB-5140 EXAMINATION OF WELDS AND ADJACENT BASE MATERIAL

When performing the surface examinations of weld joint Categories A, B, C, and D and the equivalent welded joints in piping, pumps, and valves as required by NB-5200, the external and accessible internal weld surfaces and adjacent base material for at least $\frac{1}{2}$ in. on each side of the weld shall be included in the examination. Acceptance standards for the weld shall be as stated in this Article while the acceptance standards for base material shall be as stated in NB-2500.

NB-5200 REQUIRED EXAMINATION OF WELDS FOR FABRICATION AND PRESERVICE BASELINE

NB-5210 CATEGORY A VESSEL WELDED JOINTS AND LONGITUDINAL WELDED JOINTS IN OTHER COMPONENTS

Category A welded joints in vessels and longitudinal welded joints in other components shall be examined by a volumetric² and either the liquid penetrant or magnetic particle method.

NB-5220 CATEGORY B VESSEL WELDED JOINTS AND CIRCUMFERENTIAL WELDED JOINTS IN PIPING, PUMPS, AND VALVES

NB-5221 Vessel Welded Joints

Category B welded joints in vessels shall be examined by a volumetric² and either the liquid penetrant or magnetic particle method.

NB-5222 Piping, Pump, and Valve Circumferential Welded Joints

(a) Butt welded joints shall be examined by a volumetric² and either the liquid penetrant or magnetic particle method.

(b) Fillet and partial penetration welded joints shall be examined by either the liquid penetrant or magnetic particle method.

NB-5230 CATEGORY C VESSEL WELDED JOINTS AND SIMILAR WELDED JOINTS IN OTHER COMPONENTS

NB-5231 General Requirements

(a) Category C full penetration butt welded joints in vessels and similar welded joints in other components shall be examined by a volumetric² and either the liquid penetrant or magnetic particle method.

(b) Category C full penetration corner welded joints and similar welded joints in other components shall be ultrasonically or radiographically examined and either liquid penetrant or magnetic particle examined.

2 A radiographic examination [NB-5111(a)] is required; a preservice examination [NB-5111(b)] may or may not be required for compliance to the Design Specification [NCA-3252(c)].

Page 232

(c) Type 2 Category C full penetration corner welded joints similar to Fig. NB-4243-1 sketches (d), (e), and (f) also require the fusion zone and the parent metal beneath the attachment surface to be ultrasonically examined after welding to verify freedom from lack of fusion and laminar defects.

(d) Category C partial penetration and fillet welded joints, and similar welded joints in other components shall be examined by either the magnetic particle or liquid penetrant method on all accessible surfaces.

NB-5240 CATEGORY D VESSEL WELDED JOINTS AND BRANCH AND PIPING CONNECTIONS IN OTHER COMPONENTS

NB-5241 General Requirements

All Category D welded joints in vessels and similar welded joints in other components shall be examined as stated in the following paragraphs.

NB-5242 Full Penetration Butt Welded Nozzles, Branch, and Piping Connections

Nozzles, branch, and piping connections attached by full penetration butt welded joints as shown in Fig. NB-4244(a)-1 shall be examined by the radiographic and either the liquid penetrant or magnetic particle method.

NB-5243 Corner Welded Nozzles, Branch, and Piping Connections

(a) Full penetration corner welded nozzles in vessels as shown in Fig. NB-4244(b)-1 shall be examined by either the ultrasonic or the radiographic method, and either the liquid penetrant or magnetic particle method. If radiographed, the weld fusion zone and the parent metal beneath the attachment surface for details shown in Fig. NB-4244(b)-1 sketches (a), (b), (c), (d), (e), and (g) shall be ultrasonically examined after welding to assure freedom from lack of fusion and laminar defects.

(b) Full penetration corner welded branch and piping connections exceeding 4 in. nominal pipe size (DN 100) in piping, pumps, and valves, as shown in Fig. NB-4244(b)-1, shall be examined by either the ultrasonic or the radiographic method, and either the liquid penetrant or magnetic particle method.

(c) Full penetration corner welded branch and piping connections with 4 in. and less nominal pipe size ($\leq$ DN 100) in piping, pumps, and valves shall be examined by either the magnetic particle or liquid penetrant method.

NB-5244 Weld Metal Buildup at Openings for Nozzles, Branch, and Piping Connections

(a) When weld metal buildup is made to a surface as shown in Step 1 of Fig. NB-4244(c)-1, the weld metal buildup, the fusion zone, and the parent metal beneath the weld metal buildup shall be ultrasonically examined to ensure freedom from lack of fusion and laminar defects. Nozzles, branch, and piping connections may then be attached by a full penetration weld as shown in Step 2 of Fig. NB-4244(c)-1. The full penetration butt welded joint shall be examined by either the ultrasonic or radiographic method, and either the liquid penetrant or magnetic particle method.

(b) For branch and piping connections with 4 in. and less nominal pipe size ($\leq$ DN 100) in piping, pumps, and valves, full penetration welds shown in sketch (c) of Fig. NB-4244(c)-1 shall be examined in accordance with NB-5243(c).

NB-5245 Partial Penetration Welded Joints

Partial penetration welded joints, as permitted in NB-3352.4(d), and as shown in Figs. NB-4244(d)-1 and NB-4244(d)-2, shall be examined progressively using either the magnetic particle or liquid penetrant methods. The increments of examination shall be the lesser of one-half of the maximum welded joint dimension measured parallel to the center line of the connection or $\frac{1}{2}$ in. (13 mm). The surface of the finished welded joint shall also be examined by either method.

NB-5246 Oblique Full Penetration Nozzles, Branch, and Piping Connections

(a) Full penetration oblique nozzles in vessels as shown in Fig. NB-4244(e)-1 shall be examined by either the ultrasonic or radiographic method, and either the liquid penetrant or magnetic particle method. In addition, the weld, the fusion zone, and the parent metal beneath the attachment surface for details shown in Fig. NB-4244(e)-1, sketches (a), (b), and (c) shall be ultrasonically examined after welding to assure freedom from lack of fusion and laminar defects.

(b) Full penetration oblique welded joint branch and piping connections in piping, pumps, and valves, as shown in Fig. NB-4244(e)-1, shall be examined in accordance with the requirements for corner welded

Page 233

branch and piping connections specified in NB-5243(b) and (c), as applicable.

NB-5260 FILLET, PARTIAL PENETRATION, SOCKET, AND ATTACHMENT WELDED JOINTS

NB-5261 Fillet, Partial Penetration, and Socket Welded Joints

Fillet and partial penetration welded joints, except for nonstructural attachments (NB-1132.1), and socket welds shall be examined by the magnetic particle or liquid penetrant method.

NB-5262 Structural Attachment Welded Joints

Structural attachment welded joints made to pressure-retaining material shall be examined by either the magnetic particle or liquid penetrant method.

NB-5270 SPECIAL WELDED JOINTS

NB-5271 Welded Joints of Specially Designed Seals

Welded joints of this type shall be examined by either the magnetic particle or liquid penetrant method.

NB-5272 Weld Metal Cladding

Weld metal cladding shall be examined by the liquid penetrant method.

NB-5273 Hard Surfacing

Hard surfacing weld metal shall be examined by the liquid penetrant method in accordance with NB-2546, and the acceptance standards applicable to materials less than $\frac{5}{8}$ in. (16 mm) thick shall apply. Penetrant examination is not

required for hard surfacing on valves with inlet connections 4 in. nominal pipe size (DN 100) or less.

NB-5274 Tube-to-Tubesheet Welded Joints

Tube-to-tubesheet welded joints shall be examined by the liquid penetrant method.

NB-5275 Brazed Joints

Flux and flux residue shall be removed from all surfaces prior to examination. Joints shall be visually examined on all accessible surfaces to determine whether there has been adequate flow of brazing metal through the joint. Optical aids may be employed for indirect visual examination of joints which cannot be directly examined.

NB-5276 Inertia and Continuous Drive Friction Welds

(a) When radiographic examination is required by this Article, inertia and continuous drive friction welds shall also be examined by the ultrasonic method to verify bonding over the entire area.

(b) The materials used shall be those assigned a P-Number by Section IX, but shall not include rimmed or semikilled steel.

(c) One of the two parts to be joined must be held in a fixed position and the other part rotated. The two faces to be joined must be symmetrical with respect to the axis of rotation.

(d) The weld between the two members shall be a full penetration weld.

NB-5277 Electron Beam Welds

In addition to the requirements for the type of weld being examined, all complete penetration welds made by the electron beam welding process shall be ultrasonically examined.

NB-5278 Electroslag Welds

In addition to the requirements for the type of weld being examined, all complete penetration welds made by the electroslag welding process in ferritic materials shall be ultrasonically examined.

NB-5279 Special Exceptions

When the joint detail does not permit radiographic examination to be performed in accordance with procedures of this Subsection for joints attaching penetration assemblies, which are fabricated as appurtenances or of the closing seam within an electrical penetration assembly, not necessarily fabricated as an appurtenance, ultrasonic examination plus liquid penetrant or magnetic particle examination of the completed weld may be substituted for the radiographic examination. The absence of suitable radiographic equipment shall not be justification for such substitution. The substitution of ultrasonic examination can be made provided the examination is performed using a detailed written procedure which has been proven by actual demonstration to the

Page 234

satisfaction of the Inspector as capable of detecting and locating defects described in this Subsection. The nondestructive examination shall be in accordance with Section V and meet the acceptance standards of NB-5300.

NB-5280 PRESERVICE EXAMINATION

NB-5281 General Requirements

(a) Examinations required by NCA-3252(c) shall be completed prior to completion of the N-5 Data Report.

(b) All volumetric and surface examinations shall be documented with results and identified in a form consistent with those required in NCA-4134.17 for transfer to the Owner.

NB-5282 Examination Requirements

(a) Components shall be examined as specified in Section XI, Table IWB-2500-1. The method of examination for the components and parts of the pressure-retaining boundaries shall comply with those tabulated in Table IWB-2500-1. Only the volumetric and surface examinations are required to be performed.

(b) For Control Rod housings, Examination Category B-O, the examination shall be extended to include essentially 100% of the welds in the installed peripheral control rod drive housing only.

NB-5283 Components Exempt From Preservice Examination

The following components or parts of components are exempted from the volumetric and surface examination requirements of this subarticle:

(a) piping of NPS 1 (DN 25) and smaller, except for steam generator tubing;

(b) reactor vessel head connections and associated piping, NPS 2 (DN 50) and smaller, made inaccessible by control rod drive penetrations; and

(c) integral attachments of supports and restraints that are inaccessible due to being encased in concrete, buried underground, or encapsulated by guard pipe.

NB-5300 ACCEPTANCE STANDARDS

NB-5320 RADIOGRAPHIC ACCEPTANCE STANDARDS

Indications shown on the radiographs of welds and characterized as imperfections are unacceptable under the following conditions:

(a) any indication characterized as a crack or zone of incomplete fusion or penetration;

(b) any other elongated indication which has a length greater than:

(1) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive

(2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (57 mm), inclusive

(3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm) where t is the thickness of the thinner portion of the weld;

(c) internal root weld conditions are acceptable when the density change as indicated in the radiograph is not abrupt; elongated indications on the radiograph at either edge of such conditions shall be unacceptable, as provided in (b) above;

(d) any group of aligned indications having an aggregate length greater than t in a length of $12t$, unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication;

(e) rounded indications in excess of that shown as acceptable in Appendix VI.

NB-5330 ULTRASONIC ACCEPTANCE STANDARDS

NB-5331 Fabrication

All imperfections which produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and evaluate them in terms of the acceptance standards given in (a) and (b) below.

(a) Imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths exceeding:

(1) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive

(2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (57 mm), inclusive

(3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm)

where t is the thickness of the weld being examined; if a weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses.

(b) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

NB-5332 Preservice Examination

(a) Components whose volumetric examination reveals flaws that meet the acceptance standards of Section XI, IWB-3000 shall be acceptable. The flaws will be dimensioned and recorded in accordance with Section V, Article 4 and this Subsection.

(b) Components whose volumetric examination reveals flaws that exceed the standards of IWB-3000 are not acceptable for service and shall be repaired.

NB-5340 MAGNETIC PARTICLE ACCEPTANCE STANDARDS

NB-5341 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication that is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. After an indication has been verified to be nonrelevant, it is not necessary to reinvestigate repetitive nonrelevant indications of the same type. Nonrelevant indications that would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NB-5342 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks and linear indications;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);

(3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) with the area taken in the most unfavorable location relative to the indications being evaluated.

NB-5343 Preservice Examination

Components whose surface examination reveals flaws that meet the acceptance standards of NB-2500 and NB-5300 shall be acceptable and recorded as required by NB-5281(b).

NB-5350 LIQUID PENETRANT ACCEPTANCE STANDARDS

NB-5351 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities, such as may occur from machining marks, surface conditions, or an incomplete bond between base metal and cladding, may produce similar indications which are nonrelevant.

(b) Any indication which is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NB-5352 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks or linear indications;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);

(3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

Page 236

(4) ten or more rounded indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) with the area taken in the most unfavorable location relative to the indications being evaluated.

NB-5353 Preservice Examination

Components whose surface examination reveals flaws that meet the acceptance standards of NB-2500 and NB-5300 shall be acceptable and recorded as required by NB-5281(b).

NB-5360 EDDY CURRENT PRESERVICE EXAMINATION OF INSTALLED NONFERROMAGNETIC STEAM GENERATOR HEAT EXCHANGER TUBING

Flaws revealed during preservice examination of installed nonferromagnetic heat exchanger tubing shall be evaluated using the criteria in the Design Specification [NCA-3252(c)].

NB-5370 VISUAL ACCEPTANCE STANDARDS FOR BRAZED JOINTS

Braze metal shall give evidence of having flowed uniformly through a joint by the appearance of an uninterrupted, narrow visible line of brazing alloy at the end of the joint.

NB-5380 BUBBLE FORMATION TESTING

Bubble formation testing shall be in accordance with Section V, Article 10. When vacuum box testing is used, the soak time shall be a minimum of 10 sec. Any indication of leaking, by the formation of bubbles or by the breaking of the continuous soap film by leaks, shall be evidence of an unacceptable condition.

NB-5400 FINAL EXAMINATION OF VESSELS

NB-5410 EXAMINATION AFTER HYDROSTATIC TEST

After the pressure test of a vessel:

(a) All weld joints and heat affected zones of Categories A, B, C, and D, used to join ferritic material and repair welds in ferritic material that exceed in depth either $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness, whichever is less, shall be examined when physically accessible by the magnetic particle or liquid penetrant method.

(b) All required volumetric preservice examinations shall be performed.

NB-5500

NB-5500 QUALIFICATIONS AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

NB-5510 GENERAL REQUIREMENTS

Organizations performing Code required nondestructive examinations shall use personnel competent and knowledgeable to the degree specified by NB-5520. When these services are subcontracted by the Certificate Holder or Quality System Certificate Holder, he shall verify the qualification of personnel to the requirements of NB-5520. All nondestructive examinations required by this Subsection shall be performed by and the results evaluated by qualified nondestructive examination personnel.

NB-5520 PERSONNEL QUALIFICATION, CERTIFICATION, AND VERIFICATION

3 SNT-TC-1A is a Recommended Practice for Nondestructive Testing Personnel Qualification and Certification published by the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, OH 43228-0518. SNT-TC-1A-1992 is the applicable edition.

4 Personnel qualified by examination and certified to the previous editions of SNT-TC-1A are considered to be qualified to the 1992 edition when the recertification is based on continuing satisfactory performance. All reexaminations and new examinations shall be in accordance with the 1992 edition.

5 Employer as used in this Article shall include: N Certificate Holders; Quality System Certificate Holders; Material Organizations who are qualified in accordance with NCA-3862(a)(1); and organizations who provide subcontracted nondestructive examination services to organizations described above.

NB-5521 Qualification Procedure

(a) Personnel performing nondestructive examinations shall be qualified in accordance with the recommended guidelines of SNT-TC-1A.³⁴ The Employer's⁵ written practice, required by paragraph 5 of SNT-TC-1A, shall identify the requirements relative to the recommended guidelines. The recommended guidelines

Page 237

of SNT-TC-1A shall be considered as minimum requirements, except as modified in (1) through (5) below.

(1) Qualification of Level III nondestructive examination personnel shall be by examination.

(a) The basic and method examinations, paragraphs 8.8(1) and 8.8(2) of SNT-TC-1A, may be prepared and administered by Employer,⁵ ASNT, or an outside agency.

(b) The specific examination, paragraph 8.8(3) of SNT-TC-1A, shall be prepared and administered by the Employer or an outside agency. The Employer or outside agency administering the specific examination shall identify the minimum grade requirement in the written program when the basic and method examinations have been administered by ASNT, which issues grades on a pass/fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(2) The written practice identified in paragraph 5 of SNT-TC-1A and the procedures used for examination of personnel shall be referenced in the Employer's Quality Program.

(3) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform nondestructive examination of limited scope, may be less than that recommended in Table 6.3.1 of SNT-TC-1A. The time of training and experience shall be described in the written practice, and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate.

The minimum classroom training times identified in Table 6.3.1 of SNT-TC-1A may be reduced from 8 and 16 hours to 4 and 8 hours, respectively, for visual examination personnel.

(4) For visual examination, the Jaeger Number 1 letters shall be used in lieu of the Jaeger Number 2 letters specified in paragraph 8.2(1) of SNT-TC-1A. The use of equivalent type and size letters is permitted.

(5) A Level I individual shall be qualified to perform specific setups, calibrations, and tests, and to record and evaluate data by comparison with specific acceptance criteria defined in written instructions. The Level I individual shall implement these written NDE instructions under the guidance of a Level II or Level III individual. A Level I individual may independently accept the results of nondestructive examinations when the specific acceptance criteria are defined in

the written instructions.

(6) Personnel performing the volumetric preservice examination using the ultrasonic method shall meet the requirements of Section XI, Appendix VII, and Appendix VIII when required by Appendix I.

(b) For nondestructive examination methods not covered by SNT-TC-1A documents, personnel shall be qualified to comparable levels of competency by subjection to comparable examinations on the particular method involved.

(c) The emphasis shall be on the individual's ability to perform the nondestructive examination in accordance with the applicable procedure for the intended application.

(d) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use personnel qualified to perform one or more operations. As an example, one person may be used who is qualified to conduct radiographic examination and another may be used who is qualified to interpret and evaluate the radiographic film.

NB-5522 Certification of Personnel

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of Levels I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations [NB-5521(a)(1)(a)], the Employer may use a letter from ASNT as evidence on which to base the certification.

(c) When an outside agency is the examining agent for Level III qualification of the Employer's personnel, the examination results shall be included with the Employer's record.

NB-5523 Verification of Nondestructive Examination Personnel Certification

The Certificate Holder has the responsibility to verify the qualification and certification of nondestructive examination personnel employed by Material Organizations and qualified by them in accordance with NCA-3820 and subcontractors who provide nondestructive examination services to them.

NB-5530 RECORDS

Personnel qualification records identified in paragraph 9.4 of SNT-TC-1A shall be retained by the Employer.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NB-6000

ARTICLE NB-6000 TESTING

Page 239

NB-6100 GENERAL REQUIREMENTS

NB-6110 PRESSURE TESTING OF COMPONENTS, APPURTENANCES, AND SYSTEMS

NB-6111 Scope of Pressure Testing

All pressure-retaining components, appurtenances, and completed systems shall be pressure tested. The preferred method shall be a hydrostatic test using water as the test medium. Bolts, studs, nuts, washers, and gaskets are exempted from the pressure test.

NB-6112 Pneumatic Testing

A pneumatic test in accordance with NB-6300 may be substituted for the hydrostatic test when permitted by NB-6112.1 (a).

NB-6112.1 Pneumatic Test Limitations

(a) A pneumatic test may be used in lieu of a hydrostatic test only when any of the following conditions exists:

(1) when components, appurtenances, or systems are so designed or supported that they cannot safely be filled with liquid;¹

(2) when components, appurtenances, or systems which are not readily dried are to be used in services where traces of the testing medium cannot be tolerated.

(b) A pneumatic test at a pressure not to exceed 25% of the Design Pressure may be applied, prior to either a hydrostatic or a pneumatic test, as a means of locating leaks.

1 These tests may be made with the item being tested partially filled with liquid, if desired.

NB-6112.2 Precautions to Be Employed in Pneumatic Testing.

Compressed gaseous fluid is hazardous when used as a testing medium. Therefore, it is recommended that special precautions for protection of personnel be taken when a gaseous fluid under pressure is used as a test medium.

NB-6113 Witnessing of Pressure Tests

Pressure testing required by this Article shall be performed in the presence of the Inspector, except that testing of each line valve and each pump having piping connections of 4 in. nominal pipe size (DN 100) and less need not be witnessed by the Inspector. For line valves and pumps 4 in. nominal pipe size (DN 100) and less, the Inspector's review and acceptance of the Certificate Holder's test records will be authorization to sign the Data Report Form and take precedence over NCA-5280.

NB-6114 Time of Pressure Testing

NB-6114.1 System Pressure Test.

The installed system shall be pressure tested prior to initial operation.

(a) The pressure test may be performed progressively on erected portions of the system.

(b) Systems which are open ended, such as spray systems, may be pressure tested with the nozzle attachment opening plugged. The spray nozzles and their attachment weld joints or mechanical joints need not be pressure tested.

NB-6114.2 Component and Appurtenance Pressure Test

(a) Components and appurtenances shall be pressure tested prior to installation in a system, except as permitted in (b) below.

(b) The system pressure test may be substituted for a component or appurtenance pressure test, provided:

(1) the component can be repaired by welding in accordance with the rules of NB-4130 and NB-4450, if required, as a result of the system pressure test;

(2) the component repair weld can be postweld heat treated in accordance with NB-4620, if required,

Page 242

and nondestructively examined in accordance with the rules of NB-4130 and NB-4450, as applicable;

(3) the component is resubjected to the required system pressure test following the completion of repair and examination if the repair is required to be radiographed by NB-4453.4.

(c) Valves require pressure testing prior to installation in a system in accordance with NB-3500.

(d) Items which, when assembled, form a completed pump or valve may be tested in the form of subassemblies, provided:

- (1) the test pressure is in accordance with the requirements of NB-6221;
- (2) the pressure test is performed in a manner which, in the subassembly under test, will simulate the loadings present when the completed pump or valve is assembled and pressurized;
- (3) the component Certificate Holder approves any pressure test of component subassemblies;
- (4) the component Certificate Holder specifies the pressure test requirements and test pressure to be used;
- (5) each subassembly pressure test is performed by a Certificate Holder and is performed in the presence of the Authorized Inspector;
- (6) each subassembly pressure tested by other than the component Certificate Holder is stamped with the NPT symbol, except as provided in NCA-8330. The test pressure shall be identified on the Partial Data Report Form.
- (7) each subassembly pressure tested by other than the component Certificate Holder is listed on the Code Data Report Form;
- (8) the pressure tested subassemblies of pumps or valves are subsequently assembled by mechanical methods only;
- (9) welds examined during the subassembly pressure test need not be reexamined during the system pressure test.

NB-6114.3 Material Pressure Test.

The component or appurtenance pressure test may be used in lieu of any such test required by the material specification for a part or material used in the component or appurtenance, provided:

- (a) nondestructive examinations, if required by the material specification, can be performed subsequent to the component or appurtenance pressure test;
- (b) the material can be repaired by welding in accordance with the rules of NB-4130, if required, as a result of the pressure test;
- (c) postweld heat treatment, when required after repairs, can be performed in accordance with NB-4620.

NB-6115 Machining After Pressure Test

An additional amount of material, not to exceed 10% of the wall thickness or $\frac{3}{8}$ in. (10 mm), whichever is less, is permitted on the completed component during pressure testing where machining to critical dimensions and tolerances is required.

NB-6120 PREPARATION FOR TESTING

NB-6121 Exposure of Joints

All joints, including welded joints, shall be left uninsulated and exposed for examination during the test.

NB-6122 Addition of Temporary Supports

Components designed to contain vapor or gas may be provided with additional temporary supports, if necessary, to support the weight of the test liquid.

NB-6123 Restraint or Isolation of Expansion Joints

Expansion joints shall be provided with temporary restraints, if required, for the additional pressure load under test.

NB-6124 Isolation of Equipment Not Subjected to Pressure Test

Equipment that is not to be subjected to the pressure test shall be either disconnected from the component or system or

isolated during the test by a blind flange or similar means. Valves may be used if the valves with their closures are suitable for the proposed test pressure.

NB-6125 Treatment of Flanged Joints Containing Blanks

Flanged joints at which blanks are inserted to isolate other equipment during the test need not be retested.

NB-6126 Precautions Against Test Medium Expansion

If a pressure test is to be maintained for a period of time and the test medium in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure.

Page 243

NB-6127 Check of Test Equipment Before Applying Pressure

The test equipment shall be examined before pressure is applied to ensure that it is tight and that all low pressure filling lines and other items that should not be subjected to the test have been disconnected or isolated.

NB-6200 HYDROSTATIC TESTS

NB-6210 HYDROSTATIC TEST PROCEDURE

NB-6211 Venting During Fill Operation

The component or system in which the test is to be conducted shall be vented during the filling operation to minimize air pocketing.

NB-6212 Test Medium and Test Temperature

(a) Water or an alternative liquid, as permitted by the Design Specification, shall be used for the hydrostatic test.

(b) It is recommended that the test be made at a temperature that will minimize the possibility of brittle fracture (Appendix G). The test pressure shall not be applied until the component, appurtenance, or system and the pressurizing fluid are at approximately the same temperature.

NB-6220 HYDROSTATIC TEST PRESSURE REQUIREMENTS

NB-6221 Minimum Hydrostatic Test Pressure

(a) The installed system shall be hydrostatically tested at not less than 1.25 times the lowest Design Pressure of any component within the boundary protected by the overpressure protection devices which satisfy the requirements of NB-7000.

(b) Valves shall be hydrostatically tested in accordance with the rules of NB-3500.

(c) Components shall be hydrostatically tested at not less than 1.25 times their Design Pressure.

NB-6222 Maximum Permissible Test Pressure

The stress limits specified in NB-3226 shall be used in determining the maximum permissible test pressure. In multichamber components, pressure may be simultaneously applied to the appropriate adjacent chamber to satisfy these stress limits.

NB-6223 Hydrostatic Test Pressure Holding Time

The hydrostatic test pressure shall be maintained a minimum of 10 min prior to initiation of the examination for leakage required by NB-6224.

NB-6224 Examination for Leakage After Application of Pressure

Following the application of the hydrostatic test pressure for the required time (NB-6223), all joints, connections, and regions of high stress, such as regions around openings and thickness transition sections, shall be examined for leakage. Except in the case of pumps and valves which shall be examined while at test pressure, this examination shall be made at a pressure equal to the greater of the Design Pressure or three-fourths of the test pressure and it shall be witnessed by the Inspector. Leakage of temporary gaskets and seals, installed for the purpose of conducting the hydrostatic test and which will be replaced later, may be permitted unless the leakage exceeds the capacity to maintain system test pressure for the required amount of time. Other leaks, such as those from permanent seals, seats, and gasketed joints in components, may be permitted when specifically allowed by the Design Specification. Leakage from temporary seals or leakage permitted by the Design Specification shall be directed away from the surface of the component to avoid masking leaks from other joints.

NB-6300 PNEUMATIC TESTS

NB-6310 PNEUMATIC TESTING PROCEDURES

NB-6311 General Requirements

When a pneumatic test is performed, it shall be conducted in accordance with the requirements of NB-6100 and this Subarticle.

NB-6312 Test Medium and Test Temperature

(a) The gas used as the test medium shall be nonflammable.

(b) Testing temperature shall be in accordance with NB-6212(b).

Page 244

NB-6313 Procedure for Applying Pressure

The pressure in the system shall gradually be increased to not more than one-half of the test pressure, after which the pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached.

NB-6320 PNEUMATIC TEST PRESSURE REQUIREMENTS

NB-6321 Minimum Required Pneumatic Test Pressure

(a) The installed system shall be pneumatically tested at not less than 1.2 times the lowest Design Pressure of any component within the boundary protected by the overpressure protection devices which satisfy the requirements of NB-7000.

(b) Valves shall be pneumatically tested in accordance with the rules of NB-3500.

(c) Components shall be pneumatically tested at not less than 1.2 times their Design Pressure.

NB-6322 Maximum Permissible Test Pressure

The maximum test pressure shall be limited as defined in NB-6222.

NB-6323 Test Pressure Holding Time

The test pressure of NB-6321 shall be maintained for a minimum total time of 10 min.

NB-6324 Examination for Leakage After Application of Pressure

Following the application of pressure for the time specified in NB-6323, the test pressure shall be reduced to a value

equal to the greater of the Design Pressure or three-fourths of the test pressure and held for a sufficient time to permit examination as defined in accordance with NB-6224.

NB-6400 PRESSURE TEST GAGES

NB-6411 Types of Gages to Be Used and Their Location

Pressure test gages used in pressure testing shall be indicating pressure gages and shall be connected directly to the component. If the indicating gage is not readily visible to the operator controlling the pressure applied, an additional indicating gage shall be provided where it will be visible to the operator for the duration of the test. For systems with a large volumetric content, it is recommended that a recording gage be used in addition to the indicating gages.

NB-6412 Range of Indicating Pressure Gages

(a) Analog type indicating pressure gages used in testing shall be graduated over a range not less than $1\frac{1}{2}$ times nor more than 4 times the test pressure.

(b) Digital type pressure gages may be used without range restriction provided the combined error due to calibration and readability does not exceed 1% of the test pressure.

NB-6413 Calibration of Pressure Test Gages

All test gages shall be calibrated against a standard dead weight tester or a calibrated master gage. The test gages shall be calibrated before each test or series of tests. A series of tests is that group of tests using the same pressure test gage or gages which is conducted at the same site within a period not exceeding 2 weeks.

NB-6600 SPECIAL TEST PRESSURE SITUATIONS

NB-6610 COMPONENTS DESIGNED FOR EXTERNAL PRESSURE

Components designed for external pressure only shall be subjected to an internal test pressure at 1.25 times the design external pressure. The pressure shall be under proper control so that the required test pressure is never exceeded by more than 6%.

NB-6620 PRESSURE TESTING OF COMBINATION UNITS

NB-6621 Pressure Chambers Designed to Operate Independently

Pressure chambers of combination units that have been designed to operate independently shall be hydrostatically tested as separate vessels; that is, each chamber shall be tested without pressure in the adjacent chamber.

Page 245

NB-6622 Common Elements Designed for a Maximum Differential Pressure

(a) When pressure chambers of combination units have their common elements designed for the maximum differential pressure that can occur during startup, operation, and shutdown, and the differential pressure is less than the higher of the Design Pressures of the adjacent chambers, the common elements shall be subjected to a hydrostatic test pressure of at least $1\frac{1}{4}$ times the maximum differential pressure.

(b) Following the test of the common elements, as required by (a) above and their inspection, the adjacent chambers shall be hydrostatically tested (NB-6221). Care must be taken to limit the differential pressure between the chambers to the pressure used when testing the common elements.

July 1, 1998

American Society Of Mechanical Engineers

NB-7100 GENERAL REQUIREMENTS

NB-7110 SCOPE

(a) A system¹ shall be protected from the consequences arising from the application of conditions of pressure and coincident temperature that would cause either the Design Pressure or the Service Limits specified in the Design Specification to be exceeded.

(b) Pressure relief devices² are required when the operating conditions considered in the Overpressure Protection Report would cause the Service Limits specified in the Design Specification to be exceeded.

(c) Protection of the system from the effects of pressure increases of extremely short duration, such as water hammer resulting from the rapid closing of a valve, is beyond the scope of this Article. These effects shall be included in the Design Specification.

(d) Rules covering the design of reactor shutdown systems and their application as an integrated part of system overpressure protection are beyond the scope of this Article. Appropriate guidance is found in engineering standards and in requirements of the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

1 Wherever the word system appears in this Article, it refers to the component or group of components for which overpressure protection is provided as described in the Overpressure Protection Report.

2 A pressure relief device is designed to open to prevent a rise of internal fluid pressure, greater than a specified value, resulting from exposure to pressure transient conditions. It may be a pressure relief valve or a nonreclosing pressure relief device.

NB-7111 Definitions

(a) *Overpressure* is that pressure which exceeds the Design Pressure and is caused by increases in system fluid pressure resulting from thermal imbalances, excess pump flow, and other similar phenomena capable of causing a system pressure increase of a sufficient duration to be compatible with the dynamic response characteristics of the pressure relief devices listed in this Article.

(b) The basic definitions of pressure relief devices as specified in this Article are given in ASME PTC 25-1994, Pressure Relief Devices.

(c) *Primary pressure* is the pressure of the fluid at the inlet of the pressure relief device.

(d) *Secondary pressure* is that value of pressure existing in the passage between the actual discharge area and the outlet for which the discharge system of the pressure relief devices shall be designed.

NB-7120 INTEGRATED OVERPRESSURE PROTECTION

Overpressure protection of the components shall be provided by any of the following as an integrated overpressure protection:

(a) the use of pressure relief devices and associated pressure sensing elements;

(b) the use of the reactor shutdown system;

(c) a design without pressure relief devices that does not exceed the Service Limits specified in the Design Specifications [NB-7110(b)].

NB-7130 VERIFICATION OF THE OPERATION OF RECLOSING PRESSURE RELIEF DEVICES

NB-7131

(a) Reclosing pressure relief devices shall be constructed so that potential impairment of the overpressure protection function from service exposure to fluids can be determined by test or examination.

(b) Means shall be provided for remote monitoring of valve position (fully open and fully closed). These means may be incorporated in the valve design or its system installation.

Page 252

(c) Reclosing pressure relief devices and their associated pressure sensing elements shall be so constructed that their correct operation can be demonstrated under service or test conditions, as may be required by regulatory or enforcement authorities having jurisdiction at the nuclear power plant site.

NB-7140 INSTALLATION

NB-7141 Pressure Relief Devices

(a) Pressure relief devices shall be as close as practicable to the major source of overpressure anticipated to arise within the system under the conditions summarized in the Overpressure Protection Report (NB-7200).

(b) The connection between a system and its pressure relief device shall have a minimum inside diameter equal to or greater than the nominal inside diameter of the pressure relief device inlet. The opening in the connection shall be designed to provide direct and unobstructed flow between the system and the pressure relief device.

(c) The connection between a system and its safety valve shall be not longer than the face-to-face dimension of the corresponding tee fitting of the same dimension and pressure rating listed in ANSI B16.5, ANSI B16.9, or ANSI B16.11. Alternatively the connection shall not result in accumulative line losses greater than 2% of the relieving pressure.

(d) The connection between a system and its safety relief valve or relief valve shall not result in accumulated line losses greater than 3% of the relieving pressure.

(e) Safety, safety relief, and relief valves shall be installed in an upright position.

(f) The flow area of the discharge piping connected to a pressure relief device shall not be less than the flow area of the device outlet. Back pressure that may exist or develop shall not reduce the relieving capacity of the relieving device(s) below that required to protect the system; potential for flashing shall be considered.

(g) Valve installation not in accordance with (c), (d), (e), and (f) above may be used provided:

(1) the NV Certificate Holder confirms that the valve design is satisfactory for the intended installation and satisfies the requirements of the valve Design Specification;

(2) the valves are adjusted for acceptable performance in conformance with the requirements of the valve Design Specification;

(3) technical justification for the adequacy of the installation is provided in the Overpressure Protection Report, including verification that the requirements of (1) and (2) have been met.

(h) A pressure relief valve certified for steam service may be installed on an inlet water loop seal³ if the following conditions are met:

(1) the loop seal water purge time is considered and included in the Overpressure Protection Report;

(2) the requirements of NB-7510, NB-7520, and NB-7732.2 as applicable are met and the pressure relief valve set pressure is established on steam.

NB-7142 Stop Valves

(a) No stop valve or other device shall be placed in such a location relative to a pressure relief device, that it could reduce the overpressure protection below that required by the rules of this Article, unless such stop valves are constructed and installed with controls and interlocks so that the relieving capacity requirements of NB-7300 are met under all conditions of operation of both the system and the stop valves.

of operation of both the system and the stop valves.

(b) Simple administrative control of stop valve position is not acceptable.

(c) Stop valves shall have independent and diverse interlocks to prevent valves from being closed during all conditions of system operation when the pressure relief device is needed to meet the requirements of NB-7300.

(d) Stop valves shall have independent and diverse interlocks to assure that the valves will automatically open and remain open during all conditions of system operation when the pressure relief device is needed to meet the requirements of NB-7300.

(e) Means shall be provided to permit verification of the operation of controls and interlocks.

NB-7143 Draining of Pressure Relief Devices

(a) A pressure relief device installation shall be fitted with a drain at its lowest point where liquid or residue can collect, if such liquid or residue could interfere with proper relieving operation.

(b) If the design of a pressure relief device permits liquid or residue to collect on the discharge side of the disk and could interfere with the proper relieving operation, the device shall be fitted with a drain to minimize the collection of liquid or residue.

(c) Drains shall discharge to a controlled thermal dissipation or discharge storage system.

3 An inlet water loop seal consists of valve inlet piping that is configured to from a water seal below the pressure relief valve seat which separates the normal system relieving fluid (steam) from the valve seat.

Page 253

NB-7150 ACCEPTABLE PRESSURE RELIEF DEVICES

NB-7151 Pressure Relief Valves⁴

Pressure relief valves may be used in accordance with NB-7170 and NB-7500.

NB-7152 Nonreclosing Pressure Relief Devices⁵

Nonreclosing pressure relief devices may be used in accordance with NB-7170 and NB-7600.

NB-7160 UNACCEPTABLE PRESSURE RELIEF DEVICES

NB-7161 Deadweight Pressure Relief Valves

Dead weight valves shall not be used.

NB-7170 PERMITTED USE OF PRESSURE RELIEF DEVICES

NB-7171 Safety Valves⁶

Safety valves, meeting the requirements of NB-7510, may be:

(a) steam service;

(b) air and gas service.

NB-7172 Safety Relief Valves⁷

Safety relief valves, meeting the requirements of NB-7510, may be used for:

(a) steam service;

(b) air and gas service;

(c) liquid service.

NB-7173 Relief Valves⁸

Relief valves, meeting the requirements of NB-7510, may be used for liquid service.

4 A pressure relief valve is a pressure relief device which is designed to reclose and prevent the further flow of fluid after normal conditions have been restored.

5 A nonreclosing pressure relief device is a pressure relief device designed to remain open after operation.

6 A safety valve is a pressure relief valve actuated by inlet static pressure and characterized by rapid opening or pop action.

7 A safety relief valve is a pressure relief valve characterized by rapid opening pop action, or by opening generally proportional to the increase in pressure over the opening pressure.

8 A relief valve is a pressure relief valve actuated by inlet static pressure and having a gradual lift generally proportional to the increase in pressure over the opening pressure.

NB-7174 Pilot Operated Pressure Relief Valves⁹

Pilot operated pressure relief valves, meeting the requirements of NB-7520, may be used for:

- (a) steam service;
- (b) air and gas service;
- (c) liquid service.

NB-7175 Power Actuated Pressure Relief Valves¹⁰

Power actuated pressure relief valves, meeting the requirements of NB-7530, may be used for:

- (a) steam service;
- (b) air and gas service;
- (c) liquid service.

NB-7176 Safety Valves With Auxiliary Actuating Devices

Safety valves with auxiliary actuating devices, meeting the requirements of NB-7540, may be used for steam service.

NB-7177 Pilot Operated Pressure Relief Valves With Auxiliary Actuating Devices

Pilot operated pressure relief valves with auxiliary actuating devices, meeting the requirements of NB-7540, may be used for:

- (a) steam service;
- (b) air and gas service;
- (c) liquid service.

NB-7178 Nonreclosing Devices

Rupture disk devices¹¹ may be used on air or gas service in accordance with NB-7600.

9 A pilot operated pressure relief valve is a pressure relief valve in which the major relieving device is combined with and is controlled by a self-actuated auxiliary pressure relief valve.

10 A power actuated pressure relief valve is a pressure relief valve in which the major relieving device is combined with and controlled by a device requiring an external source of energy.

11 A rupture disk device is a nonreclosing pressure relief device actuated by inlet static pressure and designed to function by the bursting of a pressure-containing disk.

NB-7200 OVERPRESSURE PROTECTION REPORT

NB-7210 RESPONSIBILITY FOR REPORT

The provisions intended to meet the requirements of this Article shall be the subject of an Overpressure Protection Report prepared by the Owner or his designee.

[98]

NB-7220 CONTENT OF REPORT

The Overpressure Protection Report shall define the protected systems and the integrated overpressure protection provided. As a minimum, the Report shall include the following:

- (a) identification of specific ASME Section III, Article NB-7000, Edition and Addenda and applicable Code Cases used in the design of the overpressure protection system;
 - (b) drawings showing arrangement of protected systems, including the pressure relief devices;
 - (c) the range of operating conditions, including the effect of discharge piping back pressure;
 - (d) an analysis of the conditions that give rise to the maximum pressure relieving requirements, except when the basis for establishing relieving capacity is the loss of the heat sink of the protected system when the thermal output of the reactor is at its rated power;
 - (e) the relief capacity required to prevent a pressure rise in any component from exceeding the limitations of NB-7300;
 - (f) the operating controls or safety controls of the protected system upon which the anticipated required relief capacity and the maximum pressure and temperature are predicted;
 - (g) the redundancy and independence of the pressure relief devices and their associated pressure sensors and controls employed to preclude a loss of overpressure protection in the event of a failure of any pressure relief device, sensing elements, associated controls, or external power sources;
 - (h) the extent that an individual component can be isolated from the overall system overpressure protection and the analysis of the conditions under which additional individual overpressure protection is necessary;
 - (i) the design secondary pressure, including a justification of the value identified in the Design Specification for pressure relief devices;
 - (j) the analysis of pressure transient conditions, including those associated with the response time of pressure relief valves, taking into account the effect of liquid and two-phase flow;
 - (k) consideration of set pressure and blowdown limitations, taking into account opening pressure tolerances and overpressure of the pressure relief device;
 - (l) consideration of burst pressure tolerance and manufacturing design range of the rupture disk device; and
 - (m) verification that pressure relief devices are not required, if applicable. Verification shall include reference to each component's Design Report and applicable requirements in NB-3000 that demonstrate that the calculated stress intensity levels do not exceed the Service Limits specified in the component Design Specification for all system service loadings.
- [98]**

NB-7230 CERTIFICATION OF REPORT

The Report, after it has been reconciled with the requirements of this Article, shall be certified by one or more Registered Professional Engineers competent in the applicable field of design and qualified in accordance with the requirements of Appendix XXIII of Section III Appendices.

NB-7240 REVIEW OF REPORT AFTER INSTALLATION

(a) Any modification of the installation from that used for the preparation of the Overpressure Protection Report shall be reconciled with the Overpressure Protection Report.

(b) Modifications shall be documented in an addendum to the Overpressure Protection Report. The addendum shall contain a copy of the as-built drawing and shall include either:

- (1) a statement that the as-built system meets the requirements of the Overpressure Protection Report; or
- (2) a revision to the Overpressure Protection Report to make it agree with the as-built system; or
- (3) a description of the changes made to the asbuilt system to make it comply with the Overpressure Protection Report.

(c) The addendum shall be certified by one or more Registered Professional Engineers competent in the applicable field of design and qualified in accordance with the requirements of Appendix XXIII of Section III Appendices.

NB-7250 FILING OF REPORT

A copy of the Overpressure Protection Report shall be filed at the nuclear power plant site prior to the

Page 255

Inspector signing the Owner's Data Report. The report shall be made available to the Authorized Inspector and regulatory and enforcement authorities having jurisdiction at the nuclear plant site.

NB-7300 RELIEVING CAPACITY

NB-7310 EXPECTED SYSTEM PRESSURE TRANSIENT CONDITIONS¹²

NB-7311 Relieving Capacity of Pressure Relief Devices

(a) The total relieving capacity of the pressure relief devices (certified in accordance with NB-7700 intended for overpressure protection within the scope of this Subsection and credited in conformance with NB-7500 or NB-7600) shall take into account any losses due to flow through piping and other components.

(b) The total relieving capacity shall be sufficient to prevent a rise in pressure of more than 10% above the Design Pressure of any component within the pressure-retaining boundary of the protected system under any expected system pressure transient conditions as summarized in the Overpressure Protection Report (NB-7200).

NB-7312 Relieving Capacity of Pressure Relief Devices Used With Pressure-Reducing Devices

When using pressure-reducing devices, the combined relieving capacity of the pressure relief devices shall be sufficient to meet the requirements of NB-7311, when:

- (a) pressure-reducing devices and their bypass valves are fully open; and
- (b) all discharge paths are blocked on the low pressure side of the pressure-reducing device.

NB-7313 Required Number and Capacity of Pressure Relief Devices

The required relieving capacity for overpressure protection of a system shall be provided by the use of at least two pressure relief devices. In each such group of pressure relief devices when more than one device is used, no device shall have a capacity less than 50% of the device with the largest capacity.

¹² Expected system pressure transient conditions are those associated with normal system transient operation, such as loss of feedwater or loss of load.

NB-7314 Required Number and Capacity of Pressure Relief Devices for Isolatable Components

The required relieving capacity of an isolatable component shall be provided by at least one pressure relief device meeting the requirements of NB-7500 or NB-7600.

NB-7320 UNEXPECTED SYSTEM EXCESS PRESSURE TRANSIENT CONDITIONS¹³

NB-7321 Relieving Capacity of Pressure Relief Devices

- (a) The total relieving capacity of the pressure relief devices (certified in accordance with NB-7700 intended for

overpressure protection within the scope of this Subsection and credited in conformance with NB-7500 or NB-7600) shall take into account any losses due to flow through piping and other components.

(b) The total relieving capacity shall be sufficient to limit the maximum system pressure such that the requirements of (c) are satisfied for each of the components of the system for which overpressure protection is provided, under each of the unexpected system excess pressure transient conditions specified in the Overpressure Protection Report.

(c) The system overpressure established for setting the required total relieving capacity of (b) shall be such that the calculated stress intensity and other design limitations for Service Limit C specified in NB-3000 are not exceeded for each of the components in the protected system.

NB-7400 SET PRESSURES OF PRESSURE RELIEF DEVICES

NB-7410 SET PRESSURE LIMITATIONS FOR EXPECTED SYSTEM PRESSURE TRANSIENT CONDITIONS

13 Unexpected system excess pressure transient conditions are those associated with unusual or abnormal system transients, but still considered to be within the design basis, such as loss of load with failure of reactor scram.

The stamped set pressure of at least one of the pressure relief devices connected to the system shall not be greater than the Design Pressure of any component within the pressure-retaining boundary of the protected system. Additional pressure relief devices may

Page 256

have higher stamped set pressures, but in no case shall these set pressures be such that the total system pressure exceeds the system limitations specified in NB-7310.

NB-7420 SET PRESSURE LIMITATION FOR UNEXPECTED SYSTEM EXCESS PRESSURE TRANSIENT CONDITIONS

The establishment of the stamped set pressure shall take into account the requirements of NB-7320.

NB-7500 OPERATING AND DESIGN REQUIREMENTS FOR PRESSURE RELIEF VALVES

NB-7510 SAFETY, SAFETY RELIEF, AND RELIEF VALVES

NB-7511 General Requirements

NB-7511.1 Spring-Loaded Valves.

Valves shall open automatically by direct action of the fluid pressure as a result of forces acting against a spring.

NB-7511.2 Balanced Valves

(a) Balanced valves, whose operation is independent of back pressure, may be used if means are provided to verify the operability of the balancing device.

(b) Balanced safety valves for steam service shall additionally have a redundant back pressure balancing device.

NB-7511.3 Antisimmer Type Valves.

Valves which are fitted with antisimmer devices that serve to raise the set pressure of the valve during normal operation of the system may be used, provided:

(a) the design is such that the valve opens automatically and discharges its certified capacity at 110% of the system design pressure in the event any item of the auxiliary loading device should fail;

(b) the operating signal and energy source provisions are such that the valve reverts to its normal set pressure in the event of any failure of signal or loss of energy source;

- (c) the auxiliary loading force imposed on such valves does not raise the set pressure of the valve by more than 10%;
- (d) the auxiliary loading force which augments the force exerted by the valve spring is automatically unloaded at a pressure not greater than the set pressure of the valve.

NB-7512 Safety Valve Operating Requirements

NB-7512.1 Antichattering and Lift Requirements.

Safety valves shall be constructed to operate without chattering and to attain rated lift at a pressure which does not exceed the set pressure by more than 3% or 2 psi (13.8 kPa), whichever is greater.

NB-7512.2 Set Pressure Tolerance

(a) The set pressure tolerance plus or minus shall not exceed the following: 2 psi (13.8 kPa) for pressures up to and including 70 psi (483 kPa), 3% for pressures from 70 psi (483 kPa) to 300 psi (2070 kPa), 10 psi (69 kPa) for pressures over 300 psi (2070 kPa) to 1000 psi (6900 kPa), and 1% for pressures over 1000 psi (6900 kPa). The set pressure tolerance shall apply unless a greater tolerance is established as permissible in the Overpressure Protection Report (NB-7200) and in the safety valve Design Specification (NCA-3250).

(b) Conformance with the requirements of (a) shall be established for each production valve by test. Steam valves shall be tested on steam.

NB-7512.3 Blowdown.

Safety valves shall be adjusted to close after blowing down to a pressure not lower than 95% of the set pressure unless a different percentage is specified in the safety valve Design Specification (NCA-3250) and the basis for the setting is covered in the Overpressure Protection Report (NB-7200). The adjustment shall be determined by test or by proration from the Certificate Holder's blowdown test data.

NB-7513 Safety Relief and Relief Valve Operating Requirements

Safety relief and relief valves shall be constructed to attain rated lift at a pressure which does not exceed the set pressure by more than 10% or 3 psi (20.6 kPa), whichever is greater.

NB-7513.1 Set Pressure Tolerance

(a) The set pressure tolerance plus or minus from the set pressure of safety relief and relief valves shall not exceed 2 psi (13.8 kPa) for pressures up to and including 70 psi (483 kPa) and 3% for pressure above 70 psi (483 kPa). The set pressure tolerance shall apply unless a greater tolerance is established as permissible in the Overpressure Protection Report (NB-7200) and in the valve Design Specification (NCA-3250).

(b) Conformance with the requirements of (a) shall be established for each production valve by test. Steam valves shall be tested on steam, air or gas valves on air or gas, and liquid valves on liquid.

Page 257

NB-7513.2 Blowdown.

Safety relief and relief valves shall be adjusted to close after blowing down to a pressure not lower than that specified in the valve Design Specification (NCA-3250), and the basis for the setting shall be covered in the Overpressure Protection Report (NB-7200). The adjustment shall be determined by test or by proration from the Certificate Holder's blowdown test data.

NB-7514 Credited Relieving Capacity

The credited relieving capacity of safety, safety relief, and relief valves shall be based on the certified relieving capacity. In addition, the capacity can be prorated as in NB-7700.

NB-7515 Sealing of Adjustments

Means shall be provided in the design of all valves for sealing all adjustments or access to adjustments which can be made without disassembly of the valve. For a pilot operated pressure relief valve, an additional seal shall be provided to seal the pilot and main valve together. Seals shall be installed by the Certificate Holder at the time of initial adjustment. Seals shall be installed in a manner to prevent changing the adjustment or disassembly of the valve without breaking the seal. The seal shall serve as a means of identifying the Certificate Holder making the initial adjustment.

NB-7520 PILOT OPERATED PRESSURE RELIEF VALVES

NB-7521 General Requirements

Pilot operated pressure relief valves shall operate independently of any external energy source.

NB-7522 Operating Requirements

NB-7522.1 Actuation.

The pilot control device shall be actuated directly by the fluid pressure of the protected system.

NB-7522.2 Response Time.

The Overpressure Protection Report (NB-7200) shall include the effects of divergence between opening (set) and closing (blow down) pressures of the pilot valve and the pressures at which the main valve attains rated lift and closes. These divergences are caused by the inherent time delay (e.g., response time) between the operation of the pilot and the main valve, and the rate of the system pressure change. The limits for response time shall be specified in the valve Design Specification (NCA-3250).

NB-7522.3 Main Valve Operation.

The main valve shall operate in direct response to the pilot control device. The valve shall be constructed to attain rated lift under stable conditions at pressures which do not exceed the set pressure by more than 3% or 2 psi (13.8 kPa), whichever is greater, for steam, and 10% or 3 psi (20.6 kPa), whichever is greater, for air, gas, or liquid service.

NB-7522.4 Sensing Mechanism Integrity.

For other than spring loaded direct acting pilot control devices, means shall be provided to detect failure of the pressure sensing element, such as bellows, when operation of the pilot control device is dependent upon the integrity of a pressure sensing element.

NB-7522.5 Set Pressure Tolerance

(a) The set pressure tolerance shall apply only to the pilot valve.

(b) The set pressure tolerance plus or minus shall not exceed the following: 2 psi (13.8 kPa) for pressures up to and including 70 psi (483 kPa), 3% for pressures over 70 psi (483 kPa) for liquid valves and 3% for pressures over 70 psi (483 kPa) up to and including 300 psi (2070 kPa), 10 psi (69 kPa) for pressures over 300 psi (2070 kPa) up to and including 1000 psi (6900 kPa), and 1% for pressures over 1000 psi (6900 kPa) for steam, air, and gas valves. The set pressure tolerance as stated shall apply unless a greater tolerance is established as permissible in the Overpressure Protection Report (NB-7200) and in the valve Design Specification (NCA-3250).

(c) Conformance with the requirements of (b) above shall be established for each production valve by test. Steam valves shall be tested on steam, air or gas valves on air or gas, and liquid valves on liquid.

NB-7522.6 Blowdown

(a) The blowdown requirements shall only apply to the pilot valve.

(b) Pilot operated valves shall be adjusted to close after blowing down to a pressure not lower than 95% of the set pressure for steam, unless a different percent age is specified in the valve Design Specification (NCA-3250) and the basis for the setting is covered in the Overpressure Protection Report (NB-7200). For all other fluids, pilot operated valves shall be adjusted to close after blowing down to a pressure not lower than that specified in the valve Design Specification (NCA-3250), and the basis for the setting shall be covered in the Overpressure Protection Report (NB-7200).

Page 258

(c) Conformance with the requirements of (b) above shall be established for each production valve by test or by proration from the Certificate Holder's blowdown test data.

NB-7523 Credited Relieving Capacity

The credited relieving capacity of pilot operated pressure relief valves shall be based on the certified relieving capacity. In addition, the capacity may be prorated as permitted in NB-7700.

NB-7524 Sealing of Adjustments

The sealing requirements of NB-7515 shall apply.

NB-7530 POWER ACTUATED PRESSURE RELIEF VALVES

NB-7531 General Requirements

Power actuated pressure relief valves which depend upon an external energy source, such as electrical, pneumatic, or hydraulic systems, may be used provided the requirements of NB-7530 are met.

NB-7532 Operating Requirements

NB-7532.1 Actuation.

Power actuated pressure relief valves shall be actuated in response to signals from protected system fluid pressure sensing devices.

NB-7532.2 Response Times

(a) The *opening response time* is the time delay between the time the pressure sensor recognizes a predetermined system pressure and the time the power actuated pressure relief valve attains its certified capacity.

(b) The *closing response time* is the time delay between the time the pressure sensor recognizes a predetermined system pressure and the time the power actuated pressure relief valve is fully closed.

(c) The Overpressure Protection Report (NB-7200) shall include an analysis of the effect that opening and closing time responses have on the overpressure protection for the system.

(d) Each production valve shall be tested to verify that the stipulated response time in the Design Specification (NCA-3250) for the valve has been met.

NB-7532.3 Main Valve Operation.

The main valve shall provide rated flow under stable system conditions at pressures which do not exceed the opening actuation pressure by more than 3% or 2 psi (13.8 kPa) whichever is greater for steam, and 10% or 3 psi (20.6 kPa) whichever is greater for air, or gas, or liquid service.

NB-7532.4 Sensors, Controls, and External Energy Sources

(a) The sensors, controls, and external energy sources for valve operation shall have redundancy and independence at least equal to that required for the control and safety protection systems associated with the system being protected.

(b) The pressure sensors shall be capable of controlling the opening actuation pressure to within a tolerance of $\pm 1\%$ when the automatic control is in use.

(c) When automatic control is in use, the valve closing actuation pressure shall be controlled to a pressure not lower than 95% of the opening actuation pressure unless a different percentage is specified in the Design Specification (NCA-3250) and the basis for the closing actuation pressure is covered in the Overpressure Protection Report (NB-7200).

(d) Conformance with requirements of (b) and (c) above shall be established through test by the owner or his designee. Steam valves shall be tested on steam, gas or air valves on gas or air, and liquid valves on liquid.

NB-7533 Certified Relieving Capacity

The power actuated pressure relief valve certified relieving capacity and the proration of capacity shall be as determined by NB-7700.

NB-7534 Credited Relieving Capacity

NB-7534.1 Expected System Pressure Transient Conditions.

For expected system pressure transient conditions, the relieving capacity with which these valves are credited shall be not more than:

(a) the certified relieving capacity of the smaller one when two valves are installed;

(b) one-half of total certified relieving capacity when three or more valves are installed.

NB-7534.2 Unexpected System Excess Pressure Transient Conditions.

For unexpected system excess pressure transient conditions, the credited relieving capacity with which these valves are credited shall be not more than:

(a) the certified relieving capacity of the valve with the smaller certified capacity when two valves are installed;

(b) the certified relieving capacity of all except the valve with the largest certified capacity when three through ten valves are installed;

Page 259

(c) the certified relieving capacity of all except two valves of the largest certified capacity when more than ten valves are installed.

NB-7535 Sealing of Adjustments

Means shall be provided for the sealing of all adjustments which affect valve operation. Seals shall be installed by the owner or his designee at the time of setting. Seals shall be installed in such a manner as to prevent changing the adjustment without breaking the seal and shall serve as a means of identifying the organization responsible for making the adjustment.

NB-7540 SAFETY VALVES AND PILOT OPERATED PRESSURE RELIEF VALVES WITH AUXILIARY ACTUATING DEVICES

Safety valves and pilot operated pressure relief valves with auxiliary actuating devices which operate independently of the self-actuating mechanism of the valve may be used provided the requirements of NB-7510 or NB-7520, as applicable, are met, except as modified below.

NB-7541 Construction

(a) The construction shall be such that the valve opens automatically by direct action of the fluid at a pressure not higher than the valve set pressure and relieves at the certified relieving capacity in the event of failure of any essential part of the valve's auxiliary devices.

(b) The construction of the auxiliary actuating device shall be such that loss of electrical power or loss of auxiliary actuating pressure to the device will not prevent the valve from closing.

NB-7542 Expected System Pressure Transient Conditions

For expected system pressure transient conditions, credit for capacity (NB-7545) can be taken for valves opening at the setpoint of the auxiliary actuating device in accordance with (a) and (b) below.

(a) When two valves are installed, the valve of the smaller certified capacity is credited with opening at the setpoint of the auxiliary actuating device. The valve with the larger certified capacity is credited with opening at the valve set pressure.

(b) For groups of more than two valves (all of the same certified capacity), half the valves in a group containing an even number of valves or the number of valves in the group minus one divided by two in a group containing an odd number of valves are credited with opening at the setpoint of the auxiliary actuating device. The remainder of the valves in the group are credited with opening at the valve set pressure.

NB-7543 Unexpected System Excess Pressure Transient Conditions

For unexpected system excess pressure transient conditions, credit for capacity may be taken for valves opening at the setpoint of the auxiliary actuating device in accordance with the following.

(a) When two valves are installed, the valve with the smaller certified capacity may be credited with opening at the setpoint of the auxiliary actuating device. The valve with the larger certified capacity shall be credited with opening at the valve set pressure.

(b) When three through ten valves are installed, credit may be given for opening at the setpoint of the auxiliary actuating device for all valves except one with the largest certified capacity. The valve assumed not to open at the setpoint of the auxiliary actuating device shall be credited with opening at the valve set pressure.

(c) When more than ten valves are installed, credit may be given for opening at the setpoint of the auxiliary actuating device for all valves except for two of the largest certified capacity. The two valves assumed not to open at the setpoint of the auxiliary actuating device shall be credited with opening at the valve set pressure.

NB-7544 Auxiliary Device Sensors and Controls

The sensors, controls, and external energy sources for the auxiliary actuating device shall comply with the requirements of NB-7532.

NB-7545 Credited Relieving Capacity

The relieving capacities with which these valves are credited shall be:

(a) for valves credited with opening at auxiliary actuating device setpoint, the capacity at the lower relieving pressure as determined by the rules of NB-7700 (this shall specifically include the 90% of average tested capacity inherent in the Code certification procedure);

(b) for valves credited with opening at the valve set pressure, the certified capacity as determined by the rules of NB-7700.

Page 260

NB-7546 Response Time

For valves credited with opening at the auxiliary actuating device setpoint, consideration shall be given to the time delay between the signal to open and achieving the fully opened position and the time delay between the signal to close and achieving the fully closed position.

NB-7600 NONRECLOSING PRESSURE RELIEF DEVICES

NB-7610 RUPTURE DISK DEVICES

Rupture disk devices certified in accordance with NB-7720 are subject to the following:

- (a) rupture disk devices shall not be used as the sole pressure relief devices;
- (b) rupture disk devices used in conjunction with pressure relief valves shall be located only on the outlet side of the valve (NB-7623).

NB-7611 Burst Pressure Tolerance

The burst pressure tolerance at the specified disk temperature¹⁴ shall not exceed ± 2 psi (± 13.8 kPa) for stamped burst pressure up to and including 40 psi (276 kPa) and $\pm 5\%$ for stamped burst pressure above 40 psi (276 kPa) as established by the rules of NB-7613, unless other values have been established in the Design Specification and are covered in the Overpressure Protection Report.

NB-7612 Tests to Establish Stamped Burst Pressure

(a) Every rupture disk shall have a stamped burst pressure established by rules of NB-7611 within a manufacturing design range¹⁵ at a specified disk temperature, and shall be stamped with a lot number.

(b) Each lot of rupture disks shall be tested in accordance with one of the following methods. All tests of disks for a given lot shall be made in a holder of the same form and pressure area dimensions as that being used in service.

14 The specified disk temperature supplied to the rupture disk manufacturer shall be the expected temperature of the disk when the disk is expected to burst.

15 The manufacturing design range is a range of pressure within which the stamped burst pressure must fall. This range is included in the Design Specification and the Overpressure Protection Report.

(1) At least two sample rupture disks from each lot of rupture disks¹⁶ shall be burst at the specified disk temperature. The stamped burst pressure shall be determined so that the sample rupture disk burst pressures are within the tolerance specified by NB-7611.

(2) At least four sample rupture disks, but not less than 5%, from each lot of rupture disks shall be burst at four different temperatures distributed over the applicable temperature range for which the disks will be used. This data shall be used to establish a smooth curve of burst pressure versus temperature for the lot of disks. The burst pressure for each data point shall not deviate from the curve more than the burst pressure tolerance specified in NB-7611.

The value for the stamped burst pressure shall be established from the curve for a specified disk temperature.

(3) For prebulged solid metal disks or graphite disks only, at least four sample rupture disks using one size of disk from each lot of material shall be burst at four different temperatures, distributed over the applicable temperature range for which this material will be used. This data shall be used to establish a smooth curve of burst pressure versus temperature for the lot of material. The burst pressure for each data point shall not deviate from the curve more than the burst pressure tolerance specified in NB-7611.

At least two disks from each lot of disks, made from this lot of material and of the same size as those to be used, shall be burst at the ambient temperature to establish the room rating of the lot of disks. The curve shall be used to establish the stamped rating at the specified disk temperature for the lot of disks.

NB-7620 INSTALLATION

NB-7621 Provisions for Venting or Draining

When a rupture disk is used in conjunction with a pressure relief valve, the space between the rupture disk and the pressure relief valve shall be vented and/or drained to controlled thermal dissipation or discharge storage systems.

NB-7622 System Obstructions

Piping and other components downstream of the rupture disk shall be constructed so that bursting of the rupture disk will not impair the function of the pressure relief valve by the release of rupture disk material.

NB-7623 Rupture Disk Devices at the Outlet Side of Pressure Relief Valves

A rupture disk device may be installed at the outlet side of pressure relief valves if the following provisions are met:

- (a) the set pressure of the valve is independent of back pressure, or the set pressure of the valve plus the stamped burst pressure of the rupture disk plus any pressure in the outlet piping does not exceed the limits of NB-7400;
- (b) the relieving capacity meets the requirements of NB-7300;
- (c) the stamped burst pressure of the rupture disk at the specified disk temperature plus any pressure in the outlet piping from the rupture disk device shall not exceed the secondary Design Pressure of the pressure relief valve and the Design Pressure of any pipe or fittings between the valve and the rupture disk device. However, in no case shall the stamped burst pressure of the rupture disk at the operating temperature plus any pressure in the outlet piping from the rupture disk device exceed the limits of NB-7400;
- (d) the opening provided through the rupture disk device after burst is sufficient for the pressure relief valve to flow at its certified capacity.

NB-7700 CERTIFICATION

NB-7710 RESPONSIBILITY FOR CERTIFICATION OF PRESSURE RELIEF VALVES

The Certificate Holder shall be responsible for having the relieving capacity of its valves certified as prescribed in this Subarticle.

NB-7720 RESPONSIBILITY FOR CERTIFICATION OF NONRECLOSING PRESSURE RELIEF DEVICES

The rupture disk Manufacturer shall certify the stamped burst pressure of the disk.

NB-7730 CAPACITY CERTIFICATION PRESSURE RELIEF VALVES - COMPRESSIBLE FLUIDS

NB-7731 General Requirements

NB-7731.1 Capacity Certification

- (a) Capacity certification procedures shall be as required in NB-7732 through NB-7737.
- (b) For steam at pressures over 1500 psig and up to 3200 psig, the value of K used to determine the certified relieving capacity shall be multiplied by:

$$(0.1906P - 1000)/(0.2292P - 1061)$$

where

$$P = \text{set pressure, psig}$$

This correction is also applicable to the certified relieving capacity as determined by the curve method.

NB-7731.2 Test Media

- (a) Capacity certification tests of pressure relief valves for steam service shall be conducted with dry saturated steam. For test purposes, the limits of 98% minimum quality and 20°F (11°C) maximum superheat shall apply. Capacity shall be corrected to the dry saturated condition from within these limits.

(b) Capacity certification tests for pressure relief valves for air and gas service shall be conducted with air, gas, or dry saturated steam.

(c) Demonstration of function tests shall be performed using the same fluid media to which the pressure relief valve is expected to be exposed in service.

NB-7731.3 Test Pressure

(a) Capacity certification tests of pressure relief valves (except safety relief valves) for steam service shall be conducted at a pressure which does not exceed the set pressure by more than 3% or 2 psi (13.8 kPa), whichever is greater, except as permitted in (b).

(b) Capacity certification tests of safety relief valves (NB-7513) for steam service shall be conducted at a pressure which does not exceed the set pressure by more than 10% or 3 psi (20.6 kPa), whichever is greater.

(c) Capacity certification tests of pressure relief valves for air or gas shall be conducted at a pressure which does not exceed the set pressure by more than 10% or 3 psi (20.6 kPa), whichever is greater.

NB-7731.4 Blowdown.

Valves having an adjustable blowdown construction shall be adjusted prior to capacity certification testing so that the blowdown does not exceed 5% of the set pressure.

NB-7731.5 Drawings.

Prior to capacity certification and demonstration of function tests, the Certificate Holder shall submit drawings showing the valve construction to the Authorized Observer. The Authorized Observer shall submit the drawings and all test results to the ASME designee for review and acceptance.

NB-7731.6 Design Changes.

When changes are made in the design of a pressure relief valve which affect the

Page 262

flow path, lift, or performance characteristics, new tests shall be performed in accordance with this Subarticle.

NB-7732 Flow Model Test Method

NB-7732.1 Flow Capacity.

When test facility limitations make it impossible to perform tests of the full-scale pressure relief valves, flow models of three different sizes may be utilized as a basis for capacity certification. Such flow models shall be sized consistent with the capabilities of the accepted test laboratory where the tests will be conducted and shall accurately model those features which affect flow capacity, such as orifice size, valve lift, and internal flow configuration. The test models need not be functional pressure relief valves, provided that other tests are conducted to demonstrate proper function of the valve design as prescribed in NB-7732.2. The relieving capacity of valve designs certified by the use of flow models shall be established by the coefficient of discharge method similar to that outlined in NB-7734.1 and NB-7734.2. The certified relieving capacity of all sizes and pressures of a given design for which the value of K has been established, based on flow model tests in accordance with the method of NB-7734, shall not exceed the value calculated by the appropriate formula in NB-7734.2 multiplied by the coefficient K .

NB-7732.2 Demonstration of Function

(a) The function of three valves of the design to be certified shall be demonstrated by test. The three valves selected shall envelop the largest and smallest combination of inlet size and orifice size of the specific design. Such tests may be performed in conjunction with the capacity certification tests outlined above or as separate tests using production valves.

(b) These tests shall be conducted at a place meeting the requirements of NB-7739 to demonstrate to the satisfaction of an ASME designee that the valves will meet the operating requirements specified in NB-7500 and achieve full lift under

the conditions established in (c).

(c) The NV Certificate Holder shall specify the range of pressures, temperatures, and other fluid conditions for which the valves are to be tested. The range shall be sufficient to cover all expected operating fluid conditions. Additionally, tests shall include the range of inlet pressure losses and discharge back pressure conditions for which the valves are expected to be used.

(d) The NV Certificate Holder shall document in the remarks section on the Data Report Form NV-1 that the requirements of this subparagraph have been met.

NB-7733 Slope Method

(a) For pressure relief valves of a specific design, four valves of each combination inlet size and orifice size shall be tested. These four valves shall be set at pressures that will cover the appropriate range of pressures for which the valves are to be used or within the range of the authorized test facility.

(b) The instantaneous slope of each test point shall be calculated and averaged, where slope is defined as the measured capacity divided by the absolute inlet pressure. If any of the experimentally determined slopes fall outside of a range of $\pm 5\%$ of the average slope, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following a test of these valves, a new average slope shall be determined, excluding the replaced valve test results. If any individual slope is now outside of the $\pm 5\%$ range, then the tests shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design. The certified capacity shall be 90% of the average slope multiplied by the flow rating pressure, psia.

(c) In addition, demonstration of function tests shall be conducted as prescribed in NB-7732.2.

NB-7734 Coefficient of Discharge Method

A coefficient K may be established for a specific pressure relief valve design according to the procedure given in the following subparagraphs.

NB-7734.1 Number of Valves to Be Tested.

For each design, at least three valves for each of three different sizes shall be submitted for test. Each valve of a given size shall be set at a different pressure.

NB-7734.2 Establishment of Coefficient of Discharge

(a) Tests shall be made on each pressure relief valve to determine its lift, opening, blowdown pressures, and capacity in terms of the fluid used in the test. A coefficient of discharge K_D shall be established for each test run as follows:

$$K_D = \frac{\text{Actual Flow}}{\text{Theoretical Flow}} = \text{Coefficient of Discharge}$$

where Actual Flow is determined quantitatively by test, and Theoretical Flow is calculated by the following formula:

For test with dry saturated steam:

$$W_T = 51.5AP$$

Pressures over 1500 psig and up to 3200 psig the value of W_T , calculated by the above equation, shall be corrected by being multiplied by the following factor:

$$\frac{(0.1906P - 1000)}{(0.2292P - 1061)}$$

For test with air:

$$W_T = 356AP \sqrt{\frac{M}{T}}$$

For test with gas:

$$W_T = CAP \sqrt{\frac{M}{ZT}}$$

where

A	= actual discharge area through the valve at developed lift, sq in.
C	= constant for gas or vapor which is a function of the ratio of specific heats, k
k	= c_p/c_v (see Fig. XVIII-1110-1)
M	= molecular weight
P	= (set pressure $\times$ 1.03) plus atmospheric pressure, psia, or set pressure plus 2 psi plus atmospheric pressure, whichever is greater, for test pressures determined by NB-7731.3(a) = (set pressure $\times$ 1.10) plus atmospheric pressure, psia, or set pressure plus 3 psi plus atmospheric pressure, whichever is greater, for test pressures determined by NB-7731.1(b) or (c)
T	= absolute temperature at inlet, $^{\circ}\text{F} + 460$
W_T	= theoretical flow, lb/hr
Z	= compressibility factor corresponding to P and T

The average of the coefficients of discharge K_D of the tests required shall be multiplied by 0.90, and their product shall be taken as the coefficient K of that design. The coefficient of the design shall not be greater than 0.876 (the product of 0.9×0.975).

(b) If any of the experimentally determined coefficients fall outside of a range of $\pm 5\%$ of the average coefficient, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average coefficient shall be determined, excluding the replaced valve test results. If any individual coefficient is now outside of the $\pm 5\%$ range, then the test shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design.

NB-7734.3 Calculation of Certified Capacity

(a) The certified capacity of all sizes and pressures of a given design, for which the value of K has been established

under the provisions of NB-7734.2 and which are manufactured subsequently, shall not exceed the value calculated by the appropriate formula multiplied by the coefficient K .

(b) The coefficient shall not be applied to valves whose beta ratio (the ratio of valve throat and inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that individual coefficients of discharge, K_D , for valves of the extreme ends of a larger range is within $\pm 5\%$ of the average coefficient, K . For designs where lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio (L/D).

NB-7734.4 Demonstration of Function.

Tests shall be conducted as prescribed in NB-7732.2.

NB-7735 Single Valve Method

NB-7735.1 Valve Capacity Within Test Facility Limits

(a) When a single valve is to be capacity tested, the certified capacity may be based on three separate tests associated with each set pressure for which capacity certification is required.

(b) The certified capacity associated with each set pressure shall not exceed 90% of the average capacity established by the tests. Failure of the individual test capacities to fall within $\pm 5\%$ of the average capacity associated with each set pressure shall be cause for rejection of the test. The reason for the failure shall be determined, and the test repeated.

(c) Should additional valves of the same design be constructed at a later date, the results of the tests on the original valve may be included as applicable to the particular test method selected.

NB-7735.2 Valve Capacity in Excess of Test Facility Limits.

For valves whose capacity exceeds that of the test facility, the certified capacity may be based on a flow coefficient K (NB-7734.2) determined from either blocked open flow tests or flow model tests, provided the orifice area is such that choked flow conditions are obtained. The certified capacity shall be calculated as directed in NB-7734.3.

NB-7735.3 Valve Demonstration of Function.

Tests shall be conducted as prescribed in NB-7732.2, except that one valve of the specific inlet size, orifice size,

Page 264

and specific design shall be tested. Should additional valves of the same design be constructed at a later date, the results of the tests on the original valve may be included as applicable to meet the three valve requirement of NB-7732.2.

NB-7736 Proration of Capacity

(a) The capacity of a pressure relief valve applied to a system may be prorated to an overpressure greater than the overpressure for which the valve design is certified. This overpressure shall be within the allowable limits of the system.

(b) Depending on the method used for the initial capacity certification:

(1) the prorated capacity shall be 90% of the average slope determined in NB-7733 multiplied by the prorated relieving pressure (psia); or

(2) the prorated capacity shall be calculated using the appropriate formula from NB-7734.2 [where P is the prorated relieving pressure (psia) multiplied by the coefficient K].

NB-7737 Capacity Conversions

The relieving capacity of pressure relief valves for fluids other than the fluid used for certification shall be determined by the method of conversion given in Appendix XVIII-1000, except that valves for steam service shall be tested on steam.

NB-7738 Laboratory Acceptance of Pressure Relieving Capacity Tests

Tests shall be conducted at a place where the testing facilities, methods, procedures, and Authorized Observer (person supervising the tests) meet the applicable requirements of ASME PTC 25-1994, Pressure Relief Devices. The tests shall be made under the supervision of, and certified by, an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation of an ASME designee. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designee for review and acceptance.¹⁷

17 Valve capacities published in "Pressure Relief Device Certification." This publication may be obtained from the National Board of Boiler and Pressure and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, OH 43229.

NB-7739 Laboratory Acceptance of Demonstration of Function Tests

The NV Certificate Holder shall assure that the tests are conducted at a place where the testing facilities, methods, and procedures provide for sufficient testing capacity and range of fluid properties so that the testing requirements of NB-7732.2 are met.

NB-7740 CAPACITY CERTIFICATION OF PRESSURE RELIEF VALVES - INCOMPRESSIBLE FLUIDS

NB-7741 General Requirements

NB-7741.1 Capacity Certification.

Capacity certification procedures shall be as required in NB-7742 through NB-7745.

NB-7741.2 Test Medium.

The test medium to be used for capacity certification shall be water at a temperature between 40°F (4°C) and 125°F (52°C). Demonstration of function tests shall be performed on water at temperatures representative of those to which the pressure relief valve is expected to be exposed in service.

NB-7741.3 Test Pressure.

The capacity certification tests shall be conducted at pressures which do not exceed the set pressure by more than 10% or 3 psi (20.6 kPa), whichever is greater. Demonstration of function tests shall be performed at pressures representative of those to which the pressure relief valve is expected to be exposed in service.

NB-7741.4 Blowdown.

Blowdown shall be recorded at the time of the capacity certification and demonstration of function tests.

NB-7741.5 Drawings.

Prior to capacity certification and demonstration of function tests, the Certificate Holder shall submit drawings showing the valve construction to the Authorized Observer. The Authorized Observer shall submit the drawings and all test results to the ASME designee for review and acceptance.

NB-7741.6 Design Changes.

When changes are made in the design of a pressure relief valve in such a manner as to affect the flow path, lift, or performance characteristics of the valve, new tests in accordance with this Subarticle shall be performed.

NB-7742 Slope Method

(a) Four valves of each combination of pipe size and orifice size shall be tested. These four valves shall

be set at pressures which cover the appropriate range of pressures for which the valves are to be used, or within the range

of the test facility. The instantaneous slope of each test point shall be calculated and averaged, where slope is defined as the measured capacity divided by the square root of the difference between the flow rating pressure and the valve discharge pressure. If any of the experimentally determined slopes fall outside of a range of $\pm 5\%$ of the average slope, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following a test of these valves, a new average slope shall be determined, excluding the replaced valve test results. If any individual slope is now outside of the $\pm 5\%$ range, then the tests shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design. The certified capacity shall be 90% of the average slope multiplied by the square root of the difference between the flow rating pressure and the valve discharge pressure.

(b) Demonstration of function tests shall be conducted as specified in NB-7732.2.

NB-7743 Coefficient of Discharge Method

Instead of individual capacity tests or the capacity curve method, a coefficient K may be established for a specific pressure relief valve design in accordance with the following subparagraphs.

NB-7743.1 Number of Valves to Be Tested.

For each design, three valves for each of three different sizes shall be tested, for a total of nine valves. Each valve of a given size shall be set at a different pressure.

NB-7743.2 Establishment of Coefficient of Discharge

(a) Tests shall be made on each relief valve to determine its lift, opening and closing pressures, and actual capacity, in terms of pounds of water per hour. A coefficient of discharge K_D shall be established for each test run as follows:

$$K_D = \frac{\text{Actual Flow}}{\text{Theoretical Flow}} = \text{Coefficient of Discharge}$$

where Actual Flow is determined quantitatively by test, and Theoretical Flow is calculated by the following formula:

For tests with water:

$$W_t = 2407A \sqrt{(P - P_d)W}$$

where

A	= actual minimum discharge area through the valve at developed lift, sq in.
P	= (set pressure $\times 1.10$) plus atmospheric pressure, psia, or set pressure plus 3 psi plus atmospheric pressure, whichever is greater, flow rating pressure, psia
P_d	= pressure at discharge from valve, psia
W	= density of water at valve inlet conditions, lb/cu ft
W_t	= Theoretical Flow, lb/hr

The average of the coefficients of discharge K_D of the tests shall be multiplied by 0.90, and the product shall be taken as the coefficient K of the design. The coefficient of the design shall not be greater than 0.896 (the product of 0.9×0.975).

(b) If any of the experimentally determined coefficients fall outside of a range of $\pm 5\%$ of the average coefficient, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average coefficient shall be determined, excluding the replaced valve test results. If any individual coefficient is now outside of the $\pm 5\%$ range, then the test shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design.

NB-7743.3 Calculation of Certified Capacity

(a) The certified capacity of all sizes and pressures of a given design for which the value of K has been established under the provisions of NB-7743.2 shall not exceed the value calculated by the theoretical formula above multiplied by the coefficient K .

(b) The coefficient shall not be applied to valves whose beta ratio (the ratio of valve throat and inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that individual coefficients of discharge, K_D , for valves of the extreme ends of a larger range is within $\pm 5\%$ of the average coefficient, K . For designs where lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio (L/D).

NB-7743.4 Demonstration of Function.

Tests shall be conducted as specified in NB-7732.2.

NB-7744 Single Valve Method

(a) When a single valve at a single pressure is to be capacity tested, the capacity rating may be based

Page 266

on three separate tests of the single valve at the specified set pressure.

(b) The certified capacity rating of the valve shall not exceed 90% of the average established by the tests. Failure of the individual test capacities to fall within 5% of the average capacity shall be cause for rejection of the test. The reason for the failure shall be determined and the tests repeated.

(c) Should additional valves of the same design be constructed at a later date, the results of the tests on the original valve may be included as applicable to the particular test method selected.

(d) Demonstration of function tests shall be conducted as specified in NB-7732.2 except one valve of the specific inlet size, orifice size, and that specific design shall be tested. Should additional valves of the same design be constructed at a later date, the results of the tests on the original valve may be included as applicable, to meet the three valve requirement of NB-7732.2.

NB-7745 Laboratory Acceptance of Pressure Relieving Capacity Tests

Tests shall be conducted at a place where the testing facilities, methods, procedures, and Authorized Observer (person supervising the tests) meet the applicable requirements of ASME PTC 25-1994, Pressure Relief Devices. The tests shall be made under the supervision of, and certified by, an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to acceptance of the ASME Boiler and Pressure Vessel Committee upon recommendation of an ASME designee. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designee for review and acceptance.

NB-7746 Proration of Capacity

(a) The capacity of a pressure relief valve applied to a system may be prorated to an overpressure greater than the overpressure for which the valve design is certified. This overpressure shall be within the allowable limits of the system.

(b) Depending on the method used for the initial capacity certification:

(1) the prorated capacity shall be 90% of the average slope determined in NB-7742 multiplied by the prorated relieving pressure (psia); or

(2) the prorated capacity shall be calculated using the appropriate formula from NB-7743.2 [where P is the prorated relieving pressure (psia) multiplied by the coefficient K].

NB-7747 Capacity Conversions

The rated pressure relieving capacity of pressure relief valves for liquids other than the liquids used for certification shall be determined by the method of conversion given in Appendix XVIII-1000. This conversion is not valid for liquid flashing valve operating conditions.

NB-7748 Laboratory Acceptance of Demonstration of Function Tests

The NV Certificate Holder shall assure that the tests are conducted at a place where the testing facilities, methods, and procedures provide for sufficient testing capacity and range of fluid properties so that the requirements of NB-7732.2 are met.

NB-7800 MARKING, STAMPING, AND DATA REPORTS

NB-7810 PRESSURE RELIEF VALVES

NB-7811 Marking and Stamping

Each pressure relief valve shall be plainly marked by the Certificate Holder with the required data below in such a way that the marking will not be obliterated in service. The data shall be in characters not less than $\frac{3}{32}$ in. (2.4 mm) high. The marking shall be placed on the valve or on a nameplate securely fastened to the valve. The Code Symbol shall be stamped on the valve or nameplate, but the other required data may be stamped, etched, impressed, or cast. The marking shall include the following:

(a) the name, or an acceptable abbreviation, of the Certificate Holder;

(b) Certificate Holder's design or type number;

(c) size ____ (NPS, the nominal pipe size) of the valve inlet;

(d) set pressure ____ psi;

(e) certified capacity and overpressure in percent or psi:

(1) lb/hr of saturated steam for valves certified on steam; or

(2) scfm (standard cubic feet per minute) at 60°F and 14.7 psia of air for valves certified on air or gas; or

(3) gal/min of water at 70°F for valves certified on water.

Page 267

(f) applicable official Code Symbol Stamp, as shown in Table NCA-8100-1. In addition to the above, each pressure relief valve shall have a separate nameplate attached to the component that includes the marking requirements of NCA-8220 and NB-3593.2.

NB-7812 Report Form for Pressure Relief Valves

A Data Report Form NV-1 shall be filled out and signed by the Certificate Holder, and signed by the Inspector for each safety and safety relief valve stamped with the Code NV Symbol.

NB-7820 RUPTURE DISK DEVICES

18 In lieu of marking all of the listed items on the flange or tab of each rupture disk, the marking may consist of a Manufacturer's coding number sufficient to identify each rupture disk with a certificate or tab which includes the required information and is supplied with each lot of rupture disks.

NB-7821 Rupture Disks

Every rupture disk shall be plainly marked by the manufacturer in such a way that the marking will not be obliterated in service. The rupture disk marking may be placed on the flange of the rupture disk or on a metal tab permanently attached thereto.¹⁸ The marking shall include the following:

- (a) the name or identifying trademark of the manufacturer
- (b) manufacturer's design or type number
- (c) lot number
- (d) size ____ in.
- (e) stamped bursting pressure ____ psi
- (f) specified disk temperature ____ °F
- (g) capacity ____ lb/hr of saturated steam or ____ standard cu ft of air (60°F and 14.7 psia)/min
- (h) year built

NB-7822 Disk Holders (If Used)

Rupture disk holders shall be marked with the following:

- (a) the name or identifying trademark of the manufacturer
- (b) manufacturer's design or type number
- (c) size ____ in.
- (d) year built
- (e) serial number

NB-7830 CERTIFICATE OF AUTHORIZATION TO USE CODE SYMBOL STAMP

Each pressure relief valve within the scope of this Article shall be constructed by a Manufacturer possessing a Code NV Symbol Stamp and valid Certificate of Authorization. Pressure relief valves shall have the Code NV Symbol applied in accordance with the rules of NB-8100.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NB-8000

ARTICLE NB-8000 NAMEPLATES, STAMPING, AND REPORTS

Page 269

NB-8100 GENERAL REQUIREMENTS

The requirements for nameplates, stamping, and reports shall be as given in NCA-8000.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NB SI UNITS

The 1998 Edition of the Boiler and Pressure Vessel Code is based on U.S. Customary (ft-lb) units of measurement which are to be regarded as the standard. This supplement is provided as a convenience to the Code user and contains SI conversion factors for units contained in the Code.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

Quantity	Unit	Symbol	Other Units or Limitations
Space and Time			
plane angle	radian	rad	degree (decimalized)
length	meter	m	
area	square meter	m ²	
volume	cubic meter	m ³	liter (L) for liquid only (use without prefix other than in milliliter, mL)
time	second	s	minute (min), hour (h), day (d), week, and year
Periodic and Related Phenomena			
frequency	hertz	Hz	revolutions per second (r/s)
rotational frequency	revolutions per second	s ⁻¹	revolutions per minute (r/m)
Mechanics			
mass	kilogram	kg	
density	kilogram per cubic meter	kg/m ³	
moment of inertia	kilogram · meter ²	kg · m ²	
force	newton	N	
moment of force (torque)	newton-meter	N · m	
pressure and stress	pascal	Pa	(pascal = newton per square meter)
energy, work	joule	J	kilowatt-hour (kW · h)
power	watt	W	
impact strength	joule	J	
section modulus	meter ³	m ³	
moment of section (second moment of area)	meter ⁴	m ⁴	
fracture toughness	Pa · $\sqrt{m}$		
Heat			
temperature — thermodynamic [Note (2)]	kelvin	K	degree Celsius (°C)
temperature — other than thermodynamic	degree Celsius	°C	kelvin (K)
linear expansion coefficient	meter per meter-kelvin	K ⁻¹	°C ⁻¹
quantity of heat	joule	J	
heat flow rate	watt	W	
thermal conductivity	watt per meter-kelvin	W/(m · K)	W/(m · °C)
thermal diffusivity	square meter per second	m ² /s	
specific heat capacity	joule per kilogram-kelvin	J/(kg · K)	J/(kg · °C)
Electricity and Magnetism			
electric current	ampere	A	
electric potential	volt	V	
current density	ampere per meter ²	A/m ²	
magnetic field strength	ampere per meter	A/m	

NOTES:

- (1) Conversion factors between SI units and U.S. customary are given in SI-1, "ASME Orientation and Guide for Use of SI (Metric) Units," and ASTM E 380.
- (2) Preferred use for temperature and temperature interval is degrees Celsius (°C), except for thermodynamic and cryogenic work where kelvins may be more suitable. For temperature interval, 1 K = 1°C exactly.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

COMMONLY USED CONVERSION FACTORS¹ (For Others See ASTM E 380)

Quantity	To Convert From	To	Multiply by [Note (2)]	
plane angle	degree	rad	1.745 329	E-02
length	in	m	2.54*	E-02
	ft	m	3.048*	E-01
	yd	m	9.144*	E-01
area	in ²	m ²	6.451 6*	E-04
	ft ²	m ²	9.290 304*	E-02
	yd ²	m ²	8.361 274	E-01
volume	in ³	m ³	1.638 706	E-05
	ft ³	m ³	2.831 685	E-02
	US gallon	m ³	3.785 412	E-03
	Imperial gallon	m ³	4.546 09	E-03
	liter	m ³	1.0*	E-03
mass	lbm	kg	4.535 924	E-01
	ton (metric) (mass)	kg	1.000 00*	E+03
	ton (short 2000 lbm)	kg	9.071 847	E+02
force	kgf	N	9.806 65*	E+00
	lbf	N	4.448 222	E+00
bending, torque	kgf · m	N · m	9.806 65*	E+00
	lbf · in	N · m	1.129 848	E-01
	lbf · ft	N · m	1.355 818	E+00
pressure, stress	kgf/m ²	Pa	9.806 65*	E+00
	lbf/ft ²	Pa	4.788 026	E+01
	lbf/in ² (psi)	Pa	6.894 757	E+03
	kips/in ²	Pa	6.894 757	E+06
	bar	Pa	1.0*	E+05
energy, work	Btu (IT) [Note (3)]	J	1.055 056	E+03
	ft · lbf	J	1.355 818	E+00
power	hp (550 ft · lbf/s)	W	7.456 999	E+02
fracture toughness	ksi $\sqrt{\text{in}}$	Pa · $\sqrt{\text{m}}$	1.098 843	E+06
temperature	°C	K	$t_K = t_C + 273.15$	
	°F	K	$t_K = (t_F + 459.67)/1.8$	
	°F	°C	$t_C = (t_F - 32)/1.8$	
temperature interval	°C	K	1.0*	E+00
	°F	K or °C	5.555 555	E-01

NOTES:

- (1) Care should be taken when converting formulas or equations that contain constant terms or factors. The value of these terms must be understood and may also require conversion.
- (2)(a) Relationships that are exact in terms of the base units are followed by a single asterisk.
 (b) The factors are written as a number greater than 1 and less than 10 with 6 or less decimal places. The number is followed by the letter E (for exponent), a plus or minus symbol, and two digits that indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example: 3.523 907 E-02 is $3.523\ 907 \times 10^{-2}$ or 0.035 239 07.
- (3) International Table.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NC A98

1998 ADDENDA SUMMARY OF CHANGES

Page xxv

Changes given below are identified on the pages by a margin note, **98**, placed next to the affected area.

Page	Location	Change
13	NC-2110	In subpara. (a), second line corrected by Errata
23	NC-2360	In subpara. (b), fourth line corrected by Errata
41	NC-2600	Title corrected by Errata
	NC-2610	(1) In subpara. (a), first and second lines corrected by Errata (2) In subpara. (b), third and fourth lines corrected by Errata
75	Fig. NC-3224.6-1	Placement of 0.005 value corrected by Errata
89	NC-3239.1	In subpara. (f), in-text table corrected by Errata
131	NC-3411.2	Subparagraph (a) revised
162	NC-3641.1	In definition of S , second and third lines corrected by Errata
164	NC-3643.1	(1) In subpara. (c)(5), second line corrected by Errata (2) In subpara. (c)(5)(a), third line corrected by Errata (3) In subpara. (c)(5)(b), third and fourth lines corrected by Errata
165	NC-3643.2	In subpara. (b), seventh and eighth lines corrected by Errata
166	Fig. NC-3643.2(b)-2	Sketch (a) and nomenclature for sketches (a) through (d) corrected by Errata
167	Fig. NC-3643.3(c)(1)-1	(1) In Examples A and B, "Excell wall in header" corrected to read "Excess wall in header" by Errata (2) Second line in General Note (a) corrected by Errata
172	NC-3647.2	In definition of S , first and second lines corrected by Errata
	NC-3647.3	Penultimate and ultimate lines corrected by Errata
175, 176	NC-3649.4	In subpara. (d), definitions of S_c and S_{hp} second and third lines corrected by Errata

Page	Location	Change
179 - 180	NC-3655	(1) In subpara. (a)(2), ultimate line corrected by Errata (2) In subpara. (b), third line corrected by Errata
184, 185	NC-3673.2	(1) Subparagraph (b) revised (2) New subparas. (c) through (k) added (3) Existing subparas. (c) through (f) redesignated as (l) through (o), respectively
191	Fig. NC-3673.2(b)-2	(1) In sketch (b), $T_l/2$ corrected to read $T_b/2$ by Errata (2) General Note (2) corrected by Errata
325	NC-7311	Subparagraph (b) revised
	NC-7321	Subparagraph (b) revised
326	NC-7511.3	Subparagraphs (a) and (c) revised
333 - 335	NC-7731.3	(1) Subparagraph (b) revised (2) Subparagraph (c) added
	NC-7731.4	Revised in its entirety
	NC-7733	(1) Subparagraph (b) revised in its entirety (2) Subparagraph (c) deleted (3) New subparas. (c) through (f) added
	NC-7734.2	Subparagraph (a) revised in its entirety
	Fig. NC-7734.2(a)-1	Added

NOTE: Volume 42 of the Interpretations to Section III, Divisions 1 and 2, of the ASME Boiler and Pressure Vessel Code follows the last page of the Edition of Subsection NCA.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NC INTRO

INTRODUCTION

1998 ASME

BOILER &

PRESSURE VESSEL CODE

AN INTERNATIONAL CODE

III

Division 1 -

Subsection NC

Class 2

Components

**RULES FOR
CONSTRUCTION
OF NUCLEAR
POWER PLANT
COMPONENTS**

[ASME logo] The American Society of
Mechanical Engineers

**IMPORTANT INFORMATION ON THE 1998 BOILER AND PRESSURE VESSEL CODE
ADDENDA DISTRIBUTION SCHEDULE**

There is a change in the way the Addenda to the 1998 Edition of the ASME Boiler and Pressure Vessel Code are distributed. The 1998 Edition, published July 1, 1998, incorporates the 1998 Addenda revisions, additions, or deletions. There will be no separate 1998 Addenda issued in a replacement page format. Two additional Addenda to the 1998 Edition, in the form of replacement pages, will be issued on July 1, 1999 and July 1, 2000.

The Summary of Changes published with the 1998 Edition lists and describes the revisions that are part of the 1998 Addenda. These changes are identified with a margin note, **98**, denoting the affected area.

The Addenda for 1999 and 2000 will also have a Summary of Changes and identifiers printed on the replacement pages. The revisions, additions, or deletions will be incorporated directly into the affected pages. It is advisable to retain the title sheets and all replaced pages for reference.

The effective dates for Code Editions and Addenda are described in the Foreword.

**ASME BOILER AND PRESSURE VESSEL CODE
AN INTERNATIONAL CODE**

**RULES FOR
CONSTRUCTION OF
NUCLEAR POWER
PLANT COMPONENTS**

III

**Division 1 -
Subsection NC**

Class 2

Components

1998 Edition

July 1, 1998

**ASME BOILER AND
PRESSURE VESSEL
COMMITTEE
SUBCOMMITTEE ON
NUCLEAR POWER**

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

NEW YORK, NEW YORK

Date of Issue - July 1, 1998

(Includes all Addenda dated December 1997 and earlier)

This code or standard was developed under procedures accredited as meeting the criteria for American National Standards. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment which provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not "approve," "rate," or "endorse" any item, construction, proprietary device, or activity.

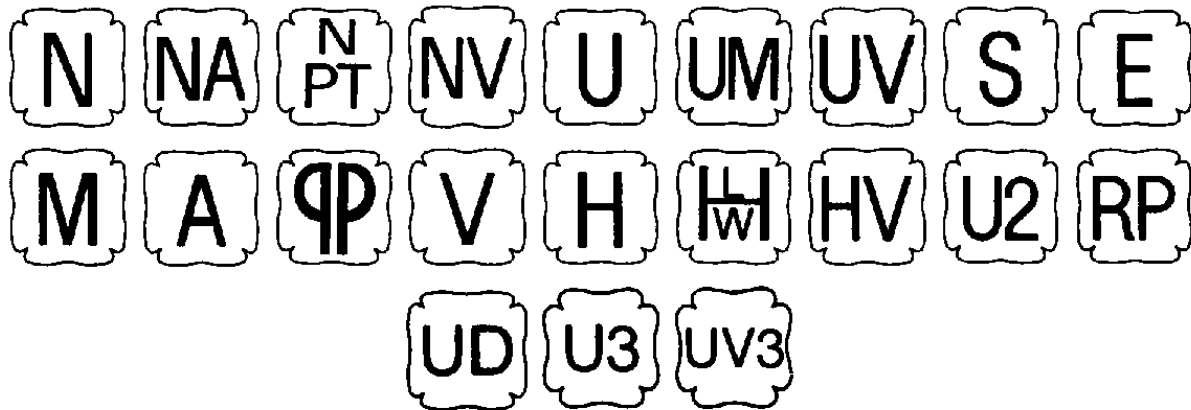
ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of any applicable Letters Patent, nor assume any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations issued in accordance with governing ASME procedures and policies which preclude the issuance of interpretations by individual volunteers.

The footnotes in this document are part of this American National Standard.

[ASME logo] ASME collective membership mark



LOGOS

The above ASME symbols are registered in the U.S. Patent Office.

"ASME" is the trademark of the American Society of Mechanical Engineers.

No part of this document may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Library of Congress Catalog Card Number: 56-3934

Printed in the United States of America

Printed in the United States of America

Adopted by the Council of the American Society of Mechanical Engineers, 1914.

Revised 1940, 1941, 1943, 1946, 1949, 1952, 1953, 1956, 1959, 1962, 1965, 1968, 1971, 1974, 1977, 1980, 1983, 1986, 1989, 1992, 1995, 1998

The American Society of Mechanical Engineers
Three Park Avenue, New York, NY 10016-5990

Copyright © 1998 by
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
All Rights Reserved

1998 ASME
BOILER AND PRESSURE VESSEL CODE

SECTIONS

I Rules for Construction of Power Boilers

II Materials

Part A - Ferrous Material Specifications

Part B - Nonferrous Material Specifications

Part C - Specifications for Welding Rods, Electrodes, and Filler Metals

Part D - Properties

III Subsection NCA - General Requirements for Division 1 and Division 2

III Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

III Division 2 - Code for Concrete Reactor Vessels and Containments

III Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

IV Rules for Construction of Heating Boilers

V Nondestructive Examination

VI Recommended Rules for the Care and Operation of Heating Boilers

VII Recommended Guidelines for the Care of Power Boilers

VIII Rules for Construction of Pressure Vessels

Division 1

Division 2 - Alternative Rules

Division 3 - Alternative Rules for Construction of High Pressure Vessels

IX Welding and Brazing Qualifications

X Fiber-Reinforced Plastic Pressure Vessels

XI Rules for Inservice Inspection of Nuclear Power Plant Components

ADDENDA

Colored-sheet Addenda, which include additions and revisions to individual Sections of the Code, are published annually and will be sent automatically to purchasers of the applicable Sections up to the publication of the 2001 Code. The 1998 Code is available only in the loose-leaf format; accordingly, the Addenda will be issued in the loose-leaf, replacement-page format.

INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code. The Interpretations for each individual Section will be published separately and will be included as part of the update service to that Section. They will be issued semiannually (July and December) up to the publication of the 2001 Code. Interpretations of Section III, Divisions 1 and 2, will be included with the update service to Subsection NCA.

CODE CASES

The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 1998 Code Cases book: (1) Boilers and Pressure Vessels and (2) Nuclear Components. Supplements will be sent automatically to the purchasers of the Code Cases books up to the publication of the 2001 Code.

Page v

FOREWORD

The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety governing the design, fabrication, and inspection during construction of boilers and pressure vessels, and to interpret these rules when questions arise regarding their intent. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property and to provide a margin for deterioration in service so as to give a reasonably long, safe period of usefulness. Advancements in design and material and the evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction,¹ and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

¹ Construction, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor

prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are responsible for the application of these programs to their design.

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practice as determined by the engineer.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Boiler and Pressure Vessel Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Mandatory Appendix covering preparation of technical inquiries). Proposed revisions to the Code resulting from inquiries will be presented to the Main Committee for appropriate action. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by ASME.

Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute and published in *Mechanical Engineering*

Page viii

to invite comments from all interested persons. After the allotted time for public review and final approval by ASME, revisions are published annually in Addenda to the Code.

Code Cases may be used in the construction of components to be stamped with the ASME Code symbol beginning with the date of their approval by ASME.

Code Editions may be used on or after the date of issue shown in the Edition. After Code revisions are approved by ASME, they may be used beginning with the date of issue shown on the Addenda. Revisions to material specifications are originated by the American Society for Testing and Materials (ASTM) and other recognized national or international organizations, and are usually adopted by ASME. However, those revisions may or may not have any effect on the suitability of material, produced to earlier editions of specifications, for use in ASME construction. ASME material specifications approved for use in each construction Code are listed in the Appendices of Section II, Parts A and B. These Appendices list, for each specification, the latest edition adopted by ASME, and earlier and later editions considered by ASME to be identical for ASME construction.

Owners of nuclear power plants are cautioned that Code Editions, Addenda, and Cases to be used in construction shall be acceptable to the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

Each state and municipality in the United States and each province in Canada that adopts or accepts one or more Sections of the Boiler and Pressure Vessel Code is invited to appoint a representative to act on the Conference Committee to the Boiler and Pressure Vessel Committee. Since the members of the Conference Committee are in active contact with the administration and enforcement of the rules, the requirements for inspection in this Code correspond with those in effect in their respective jurisdictions. The required qualifications for an Authorized Inspector under these rules may be obtained from the administrative authority of any state, municipality, or province which has adopted these rules.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, method of fabrication, inspection, and safety devices. Permission may be granted to regulatory bodies and organizations publishing safety standards to use a complete Section of the Code by reference. If usage of a Section, such as Section IX, involves exceptions, omissions, or changes in provisions, the intent of the Code might not be attained.

Where a state or other regulatory body, in the printing of any Section of the Boiler and Pressure Vessel Code, makes additions or omissions, it is recommended that such changes be clearly indicated.

The National Board of Boiler and Pressure Vessel Inspectors is composed of chief inspectors of states and municipalities in the United States and of provinces in Canada that have adopted the Boiler and Pressure Vessel Code. This Board, since its organization in 1919, has functioned to uniformly administer and enforce the rules of the Boiler and Pressure Vessel Code. The cooperation of that organization with the Boiler and Pressure Vessel Committee has been extremely helpful.

The Code Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The Scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Code for vessels or components not considered to be within its Scope or may establish additions or deletions in that Scope. Accordingly, inquiries regarding such laws or regulations are to be directed to the issuing enforcement or regulatory body.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the ASME Boiler and Pressure Vessel Committee. ASME is to be notified should questions arise concerning improper use of an ASME Code symbol.

The specifications for materials given in Section II are identical with or similar to those of specifications published by ASTM, AWS, and other recognized national or international organizations. When reference is made in an ASME material specification to a non-ASME specification for which a companion ASME specification exists, the reference shall be interpreted as applying to the ASME material specification. Not all materials included in the material specifications in Section II have been adopted for use in this Section. Usage is limited to those materials and grades listed in at least one of the tables of Section II, Part D, Subpart 1, identified as applicable to this Section. All materials allowed by this Section and used for construction within the scope of these rules shall be furnished in accordance with material specifications

Page ix

contained in Section II or referenced in Appendices A of Section II, Parts A and B except where otherwise provided in Code Cases or in this Section of the Code. Materials covered by these specifications are acceptable for use in items covered by the Code Sections only to the degree indicated in the applicable Section. Materials for Code use should preferably be ordered, produced, and documented on this basis. Material produced to an acceptable specification with requirements different from the requirements of the corresponding specification listed in Appendix A of Part A or Part B may also be used in accordance with the above, provided the material manufacturer or vessel manufacturer certifies with evidence acceptable to the Authorized Inspector that the corresponding ASME specification requirements of specifications listed in Appendix A of Part A or Part B have been met. Material produced to an acceptable material specification is not limited as to country of origin.

When required by context in this Section, the singular shall be interpreted as the plural, and vice-versa; and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

Publication of the SI (Metric) Edition of the ASME Boiler and Pressure Vessel Code was discontinued with the 1986 Edition. Effective October 1, 1986, the SI Edition was withdrawn as an ASME Boiler and Pressure Vessel Code document.

Page xi

STATEMENT OF POLICY ON THE USE OF CODE SYMBOLS AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use Code Symbols for marking items or constructions which have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the symbols, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications which might so indicate. An organization holding a Code Symbol and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code."

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified items will carry the symbol. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

The ASME logo, which is the cloverleaf with the letters ASME within, shall not be used by any organization other than ASME.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Code Symbol Stamp described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the various Code Symbols shall not be used on any item which is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME which tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

Page xiii

PERSONNEL ASME Boiler and Pressure Vessel Committee Subcommittees, Subgroups, and Working Groups

As of December 31, 1997

MAIN COMMITTEE

D. A. Canonico, *Chair*

G. G. Karcher, *Vice Chair*

J. S. Brzuszkiewicz, *Secretary*

R. W. Barnes

F. P. Barton

D. L. Berger

M. D. Bernstein

M. N. Bressler

W. J. Carter

T. M. Cullen

J. R. Farr

R. E. Feigel

J. G. Feldstein

M. Gold

O. F. Hedden

A. J. Justin
D. F. Landers
W. M. Lundy
J. R. MacKay
T. J. Mawson
T. G. McCarty
G. C. Millman
R. A. Moen
C. C. Neely
C. J. Pieper
R. F. Reedy
B. W. Roberts
F. J. Schaaf, Jr.
A. Selz
K. K. Tam
D. E. Tanner

EXECUTIVE COMMITTEE (MAIN COMMITTEE)

G. G. Karcher, *Chair*
D. A. Canonico, *Vice Chair*
J. S. Brzuszkiewicz, *Secretary*
F. P. Barton
J. R. Farr
J. G. Feldstein
M. Gold
O. F. Hedden
A. J. Justin
J. R. MacKay
T. G. McCarty
T. P. Pastor
T. E. Quaka
R. F. Reedy
A. J. Spencer

HONORARY MEMBERS (MAIN COMMITTEE)

R. D. Bonner
R. J. Bosnak
H. M. Canavan
L. J. Chockie
J. S. Clarke
W. E. Cooper
W. D. Doty
R. C. Griffin
E. J. Hemzy
E. C. Kistner, Jr.
J. E. Lattan
J. LeCoff

F. N. Moschini
C. E. Rawlins
W. E. Somers
L. P. Zick, Jr.

HONORS AND AWARDS COMMITTEE

J. R. MacKay, *Chair*
A. J. Spencer, *Vice Chair*
F. R. Lyons, *Secretary*
F. P. Barton
W. J. Carter
J. G. Feldstein
M. Gold
F. E. Gregor
E. C. Kistner, Jr.
T. P. Pastor
R. F. Reedy

MARINE CONFERENCE GROUP

J. Tiratto, *Chair*
C. F. Banks
L. W. Douthwaite
J. L. Jones
G. F. Wright

CONFERENCE COMMITTEE

D. E. Tanner - Tennessee (*Chair*)
R. D. Reetz - North Dakota (*Vice Chair*)
A. J. Justin - National Board of Boiler and Pressure Vessel Inspectors (*Secretary*)
R. J. Aben, Jr. - Michigan
J. S. Aclaro - Los Angeles, California
E. A. Anderson - Chicago, Illinois
J. Anderson - South Dakota
R. Barkdoll - Washington
F. P. Barton - Virginia
C. Castle - Nova Scotia, Canada
R. R. Cate - Louisiana
L. Chase - Northwest Territories, Canada
R. A. Coomes - Kentucky
J. Corcoran - Connecticut
M. H. Diehl, Jr. - Maryland
D. A. Douin - Illinois
D. Eastman - Newfoundland and Labrador, Canada
G. L. Ebeyer - New Orleans, Louisiana
F. Ellis - New Hampshire
E. Everett - Georgia
P. C. Hackford - Utah
D. Hanrath - North Carolina

J. B. Harlan - Delaware
K. Hynes - Prince Edward Island, Canada
D. T. Jagger - Ohio
D. J. Jenkins - Kansas
M. Kotb - Quebec, Canada
J. P. Larson - Minnesota
K. T. Lau - Alberta, Canada
J. Lemire - California
G. A. Lundberg - Florida
W. C. Lundine - Oregon
M. A. Malek - Maine
I. W. Mault - Manitoba, Canada
H. T. McEwen - Mississippi
A. W. Meiring - Indiana
R. Mile - Ontario, Canada
T. J. Monroe - Oklahoma
Y. Nagpaul - Hawaii
J. D. Payton - Pennsylvania
D. K. Peetz - Missouri
D. C. Price - Yukon Territory, Canada
R. S. Pucek - Wisconsin
T. E. Rennie - Arizona
L. Roussinos - British Columbia, Canada
M. Shuff - West Virginia
R. Snyder - New Jersey
N. Surtees - Saskatchewan, Canada
M. J. Verhagen - Wisconsin
R. B. West - Iowa
M. J. Wheel - Vermont
K. A. White - Nevada
R. K. White - New York
T. F. Wickham - Rhode Island
C. S. Withers - Colorado

SUBCOMMITTEE ON POWER BOILERS (SC I)

J. R. MacKay, *Chair*
M. D. Bernstein, *Vice Chair*
P. D. Stumpf, *Secretary*
D. L. Berger
E. Everett
D. N. French
F. R. Gerety
J. Hainsworth
T. E. Hansen
J. S. Hunter
W. L. Lowry
T. C. McGough

P. A. Molvie
D. K. Parrish
J. T. Pillow
R. G. Presnak
B. W. Roberts
R. D. Schueler, Jr.
R. V. Wielgoszinski
R. L. Williams

Page xiv

Subgroup on Design (SC I)

M. D. Bernstein, *Chair*
R. D. Schueler, Jr., *Vice Chair*
P. A. Molvie, *Secretary*
M. A. Farrugia
J. D. Fishburn
C. F. Jeerings
K. C. Morrison
A. Nassif
N. Surtees
R. V. Wielgoszinski

Subgroup on Fabrication and Examination (SC I)

D. L. Berger, *Chair*
R. E. McLaughlin, *Secretary*
R. W. Boyce
D. N. French
J. Hainsworth
T. E. Hansen
M. H. Iken
J. M. Lyons
J. T. Pillow
M. E. Reese
R. D. Schueler, Jr.
R. F. Slack, Sr.
R. V. Wielgoszinski

Subgroup on General Requirements (SC I)

T. C. McGough, *Chair*
M. D. Bernstein, *Vice Chair*
W. L. Lowry, *Secretary*
D. L. Berger
E. Everett
F. R. Gerety
J. Hainsworth
C. F. Jeerings
J. M. Lyons
R. E. McLaughlin
D. K. Parrish

J. T. Pillow
W. E. Somers
R. L. Williams

Subgroup on Materials (SC I)

B. W. Roberts, *Chair*
C. E. Spaeder, Jr., *Chair*
J. S. Hunter, *Secretary*
T. M. Cullen
D. N. French
J. F. Henry
J. P. Libbrecht
F. Masuyama
J. M. Tanzosh

Subgroup on Piping (SC I)

T. E. Hansen, *Chair*
D. L. Berger
M. D. Bernstein
P. D. Edwards
W. L. Lowry
T. C. McGough
R. G. Presnak
E. Whittle
P. L. Ziegler

SUBCOMMITTEE ON MATERIALS (SC II)

M. Gold, *Chair*
T. M. Cullen, *Vice Chair*
F. R. Lyons, *Secretary*
A. P. Ahrendt
M. N. Bressler
A. Cohen
R. Dirscherl
W. D. Doty
W. D. Edsall
D. Gandy
M. H. Gilkey
J. J. Heger
J. F. Henry
G. C. Hsu
F. Masuyama
E. Michalopoulos
R. A. Moen
R. K. Nanstad
E. G. Nisbett
J. T. Parsons
D. W. Rahoi

B. W. Roberts
E. Shapiro
C. E. Spaeder, Jr.
R. W. Swindeman
J. M. Tanzosh
B. E. Thurgood
A. W. Zeuthen

Subgroup on External Pressure (SC II)

R. W. Mikitka, *Chair*
D. J. Green
D. S. Griffin
E. Michalopoulos
B. R. Morelock
D. Nadel
C. E. Spaeder, Jr.
C. H. Sturgeon

Subgroup on Ferrous Specifications (SC II)

E. G. Nisbett, *Chair*
B. M. Dingman
W. D. Edsall
T. Graham
W. N. Holliday
E. A. Jonas
D. C. Krouse
J. F. Longenecker
W. C. Mack
A. S. Melilli
J. T. Parsons
E. J. Rozic, Jr.
E. Upitis
A. W. Zeuthen
R. H. Zong

Subgroup on International Material Specifications (SC II)

J. T. Parsons, *Chair*
D. C. Agarwal
J. Cameron
R. Dirscherl
W. D. Doty
D. M. Fryer
M. Gold
M. H. Iken
W. M. Lundy
H. Masahisa
T. F. Miskell
F. Osweiller

A. P. Povilonis
R. D. Schueler, Jr.
R. R. Seeley
E. A. Steen
E. Uptis
E. O. Woolridge

Subgroup on Nonferrous Alloys (SC II)

D. W. Rahoi, *Chair*
D. C. Agarwal, *Secretary*
W. R. Apblett
L. G. Coffee
A. Cohen
R. Dirscherl
M. H. Gilkey
G. C. Hsu
M. Katcher
E. Shapiro
L. E. Shoemaker
R. C. Sutherlin

Subgroup on Strength, Ferrous Alloys (SC II)

B. W. Roberts, *Chair*
J. M. Tanzosh, *Secretary*
A. P. Ahrendt
W. R. Apblett
T. M. Cullen
M. Gold
J. J. Heger
C. L. Hoffmann
A. Iseda
F. Masuyama
R. A. Moen
D. W. Rahoi
C. E. Spaeder, Jr.
R. W. Swindeman
B. E. Thurgood

Subgroup on Strength of Weldments (SC II & SC IX)

C. E. Spaeder, Jr., *Chair*
W. D. Doty
D. W. Rahoi
B. W. Roberts
C. Robino
W. J. Sperko
J. M. Tanzosh
B. E. Thurgood

Subgroup on Toughness (SC II)

J. M. Barsom
D. A. Hansen
A. Selz
R. S. Vecchio
S. Yukawa
R. Zawierucha

Page xv

SUBCOMMITTEE ON NUCLEAR POWER (SC III)

C. J. Pieper, *Chair*
R. M. Jessee, *Vice Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
Y. Asada
R. W. Barnes
J. N. Baysden
W. H. Borter
E. B. Branch
M. N. Bressler
F. C. Cherny
G. D. Cooper
R. P. Deubler
W. D. Doty
F. R. Drahos
K. Ennis
B. A. Erler
D. Hanrath
C. L. Hoffmann
K.-H. Hsu
D. F. Landers
W. C. LaRochelle
T. J. Mawson
W. N. McLean
R. A. Moen
D. B. Nickerson
R. F. Perrin
R. F. Reedy
M. W. Smith
J. D. Stevenson
R. E. Tome
K. R. Wichman

Subgroup on Containment Systems for Spent Fuel and High-Level Waste Transport Packagings (SC III)

J. D. Stevenson, *Chair*
H. H. Chung
R. R. Doggart
E. L. Farrow

K. Goldmann
R. H. Jones
W. H. Lake
R. W. Lambert
H. W. Lee
P. McConnell
R. E. Nickell
D. J. Nolan
D. T. Raske
T. Saegusa
R. H. Smith
K. B. Sorenson
P. Turula
N. Urabe
C. R. Witt
S. Yukawa

Subgroup on Design (SC III)

R. W. Barnes, *Chair*
E. B. Branch, *Vice Chair*
R. S. Hill III, *Secretary*
Y. Asada
M. N. Bressler
C. W. Bruny
J. R. Cole
G. D. Cooper
R. P. Deubler
N. W. Edwards
R. E. Gimple
D. Hanrath
R. W. Haupt
T. Iida
B. Jarman
D. F. Landers
W. N. McLean
D. B. Nickerson
E. C. Rodabaugh
J. R. Santangelo
G. C. Slagis
J. D. Stevenson
J. H. Wawrzeniak
K. R. Wichman
R. Wray

Working Group on Administration (SG-D) (SC III)

E. B. Branch, *Chair*
R. W. Barnes, *Vice Chair*
R. S. Hill III, *Secretary*

C. W. Bruny
G. D. Cooper
R. P. Deubler
J. T. Land
D. F. Landers
W. N. McLean
D. B. Nickerson
J. R. Santangelo
R. Wray

Working Group on Core Support Structures (SG-D) (SC III)

J. T. Land, *Chair*
R. H. Hansen
K. B. Larsen
J. F. Mullooly
B. L. Silverblatt

Working Group on Dynamic and Extreme Load Conditions (SG-D) (SC III)

R. Wray, *Chair*
A. E. Meligi, *Secretary*
P. L. Anderson
M. K. Au-Yang
R. D. Blevins
G. J. Bohm
D. L. Caldwell
P.-Y. Chen
A. Hadjian
M. Hartzman
W. S. LaPay
H. Lockert
P. R. Olson
R. F. Perry
J. Wallach

Working Group on Piping (SG-D) (SC III)

D. F. Landers, *Chair*
R. S. Hill III, *Vice Chair*
P. Hirschberg, *Secretary*
T. M. Adams
G. A. Antaki
J. R. Cole
A. B. Glickstein
R. W. Haupt
J. C. Hennart
R. D. Hookway
R. B. Jenkins
K. A. Manoly
J. C. Minichiello

S. E. Moore
A. N. Nguyen
D. B. Nickerson
O. O. Oyamada
R. D. Patel
E. C. Rodabaugh
J. R. Santangelo
M. S. Sills
G. C. Slagis
E. A. Wais

Working Group on Pumps (SG-D) (SC III)

D. B. Nickerson, *Chair*
H. L. Brammer
P. Burchett
R. E. Cornman, Jr.
A. A. Fraser
M. Higuchi
G. R. Jones
J. W. Leavitt
J. E. Livingston
R. A. Schussler
H. Tafarrodi
G. K. Vaghasia

Working Group on Supports (SG-D) (SC III)

R. P. Deubler, *Chair*
R. M. Dulin, Jr., *Secretary*
U. S. Bandyopadhyay
F. J. Birch
M. N. Bressler
J. R. Cole
J. C. Finneran, Jr.
R. W. Haupt
J. C. Hennart
A. S. Laurenson
A. Lee
R. J. Masterson
A. E. Meligi
A. N. Nguyen
J. R. Stinson

Working Group on Valves (SG-D) (SC III)

W. N. McLean, *Chair*
E. A. Bake
R. R. Brodin
W. G. Knecht
R. Koester

J. J. McGavin
S. N. Shields
H. R. Sonderegger
J. C. Tsacoyeanes
R. G. Visalli
J. R. Zahorsky

Working Group on Vessels (SG-D) (SC III)

C. W. Bruny, *Chair*
T. K. Burr, Sr.
G. D. Cooper
G. A. Deaver
N. W. Edwards
D. Hanrath
W. J. Heilker
B. Jarman
T. M. Khan
O. Maekawa
K. A. Manoly
A. Merend
G. K. Miller
W. Z. Novak
E. Pelling
H. S. Thornton

Page xvi

Special Working Group on Environmental Effects (SG-D) (SC III)

R. S. Hill III, *Chair*
Y. Asada
W. J. Heilker
C. L. Hoffmann
R. A. Moen
W. Z. Novak
S. Yukawa

Special Working Group on Seismic Piping Rules (SG-D) (SC III)

E. B. Branch, *Chair*
T. M. Adams
G. A. Antaki
R. D. Hookway
J. C. Minichiello
M. S. Sills
E. A. Wais

Subgroup on General Requirements (SC III & SC 3C)

W. C. LaRochelle, *Chair*
K. Ennis, *Secretary*
A. Appleton
J. R. Barbee

J. N. Baysden
L. M. Beason
B. H. Berg
R. E. Kelley
G. S. Korin
A. S. Laurenson
C. Lizotte
M. J. Meyer
M. R. Minick
L. C. Oakes
R. F. Perrin
U. Potapovs
B. B. Scott
D. E. Tanner
D. V. Walshe

Subgroup on Materials, Fabrication, and Examination (SC III)

C. L. Hoffmann, *Chair*
G. P. Milley, *Secretary*
C. W. Allison
D. Doyle
F. R. Drahos
G. M. Foster
G. B. Georgiev
J. E. Harris
R. W. Jackson
R. M. Jessee
C. C. Kim
R. A. Moen
C. J. Pieper
R. R. Seeley
N. M. Simpson
R. C. Soin
W. J. Sperko
K. B. Stuckey
S. Yukawa

Subgroup on Pressure Relief (SC III)

F. C. Cherny, *Chair*
S. F. Harrison, Jr.
E. M. Petrosky
M. W. Smith
A. L. Szeglin
B. S. York
J. R. Zahorsky

Special Working Group on Editing and Review (SC III)

R. F. Reedy, *Chair*
W. H. Borter

W. H. Borter
M. N. Bressler
R. P. Deubler
B. A. Erler
W. C. LaRochelle
M. W. Smith
J. D. Stevenson
E. O. Woolridge

JOINT ACI-ASME COMMITTEE ON CONCRETE COMPONENTS FOR NUCLEAR SERVICE (SC 3C)

B. A. Erler, *Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
R. M. Attar
A. C. Eberhardt
J. Gutierrez
D. J. Haavik
M. F. Hessheimer
T. E. Johnson
G. R. Murphy
S. F. Putman
B. B. Scott
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Design (SC 3C)

D. G. Adams
A. C. Eberhardt
T. E. Johnson
S. F. Putman
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Materials, Construction, and Examination (SC 3C)

D. J. Haavik, *Chair*
J. F. Artuso
R. M. Attar
B. A. Erler
J. Gutierrez

SUBCOMMITTEE ON HEATING BOILERS (SC IV)

F. P. Barton, *Chair*
P. A. Molvie, *Vice Chair*
B. P. Feder, *Secretary*
R. B. Duggan
W. L. Haag, Jr.
W. M. Hiddleston

J. D. Hoh
K. M. McTague
R. I. Mullican
E. A. Nordstrom
J. L. Seigle
D. E. Tanner
S. V. Voorhees
R. H. Weigel
R. V. Wielgoszinski
J. I. Woodworth
T. L. Bedeaux, Alternate

Subgroup on Care and Operation of Heating Boilers (SC IV)

J. I. Woodworth, *Chair*
B. P. Feder, *Secretary*
K. J. Hoey
J. D. Hoh
F. M. Lucas
K. M. McTague
P. A. Molvie
R. I. Mullican
R. H. Weigel
T. F. Wickham
T. L. Bedeaux, Alternate

Subgroup on Cast Iron Boilers (SC IV)

K. M. McTague, *Chair*
R. B. Duggan
R. H. Weigel
T. F. Wickham
J. I. Woodworth
T. L. Bedeaux, Alternate

Subgroup on Water Heaters (SC IV)

W. L. Haag, Jr., *Chair*
T. D. Gantt
W. M. Hiddleston
F. M. Lucas
K. M. McTague
R. I. Mullican
D. Smith
D. E. Tanner
M. A. Taylor

Subgroup on Welded Boilers (SC IV)

P. A. Molvie, *Chair*
T. L. Bedeaux
D. H. Mapes
E. A. Nordstrom

J. L. Seigle
R. F. Slack, Sr.
R. P. Sullivan
D. E. Tanner
R. V. Wielgoszinski

SUBCOMMITTEE ON NONDESTRUCTIVE EXAMINATION (SC V)

T. G. McCarty, *Chair*
J. E. Batey, *Vice Chair*
F. S. Fitzgerald, *Secretary*
A. S. Birks
B. H. Clark, Jr.
W. T. Clayton
R. A. Coomes
N. Y. Faransso
H. C. Graber
O. F. Hedden
G. W. Hembree
F. B. Kovacs
J. F. Manning
W. C. McGaughey
R. D. McGuire

Page xvii

Subgroup on General Requirements/Personnel Qualifications and Inquiries (SC V)

R. D. McGuire, *Chair*
J. E. Batey
W. T. Clayton
N. Y. Faransso
H. C. Graber
G. W. Hembree
J. R. MacKay
J. P. Swezy

Subgroup on Surface Examination Methods (SC V)

H. C. Graber, *Chair*
S. J. Akrin
T. Alexander
A. S. Birks
B. H. Clark
R. A. Coomes
G. W. Hembree

Subgroup on Volumetric Methods (SC V)

J. E. Batey, *Chair*
S. J. Akrin
W. T. Clayton
N. Y. Faransso
H. C. Graber

G. W. Hembree
B. Kellerhall
E. K. Kietzman
F. B. Kovacs
R. W. Kruzic
J. F. Manning
W. C. McGaughey
J. R. Mitchell

Working Group on Acoustic Emissions (SG-VM) (SC V)

B. H. Clark, Jr.
P. M. Horrigan
J. F. Manning
J. R. Mitchell

Working Group on Radiography (SG-VM) (SC V)

G. W. Hembree, *Chair*
S. J. Akrin
T. Alexander
J. E. Batey
N. Y. Faransso
H. C. Graber
F. B. Kovacs

Working Group on Ultrasonics (SG-VM) (SC V)

W. T. Clayton, *Chair*
O. F. Hedden
B. Kellerhall
E. K. Kietzman
J. F. Manning
W. C. McGaughey
R. Paillaman
F. J. Sattler
M. L. Shakinovsky

SUBCOMMITTEE ON PRESSURE VESSELS (SC VIII)

T. P. Pastor, *Chair*
K. Mokhtarian, *Vice Chair*
A. J. Roby, *Secretary*
A. P. Ahrendt
V. Bogosian
S. M. Caldwell
W. J. Carter
S. C. Cyr
R. Dirscherl
R. M. Elliott
J. R. Farr
R. E. Feigel
J. G. Feldstein

G. L. Hollinger
M. J. Houle
W. S. Jacobs
G. G. Karcher
G. B. Komora
K. T. Lau
R. W. Mikitka
U. R. Miller
C. C. Neely
K. J. Schneider
A. Selz
J. R. Sims, Jr.
A. J. Spencer
E. A. Steen
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Design (SC VIII)

U. R. Miller, *Chair*
R. E. Knoblock, *Secretary*
M. R. Bauman
M. R. Breach
S. M. Caldwell
N. W. Edwards
J. R. Farr
J. A. Hayward
G. L. Hollinger
W. S. Jacobs
G. G. Karcher
G. B. Komora
R. W. Mikitka
K. Mokhtarian
T. P. Pastor
M. D. Rana
A. Selz
S. C. Shah
J. W. Stokes
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Fabrication and Inspection (SC VIII)

E. A. Steen, *Chair*
K. Mokhtarian, *Vice Chair*
W. J. Bees
R. W. Boyce
S. C. Cyr
R. E. Feigel
H. E. Gordon

H. E. Gordon
M. J. Houle
W. S. Jacobs
R. A. Johnson
A. S. Lester III
F. C. Ouyang
M. J. Rice
W. P. Webb

Subgroup on General Requirements (SC VIII)

R. M. Elliott, *Chair*
A. P. Ahrendt
V. Bogosian
W. J. Carter
W. P. Crow
J. P. Glaspie
C. R. Good
D. B. Kadakia
J. C. Keenan
W. E. Laveck, Jr.
A. S. Mann
C. C. Neely
A. S. Olivares
K. J. Schneider
A. J. Spencer

Subgroup on Materials (SC VIII)

R. Dirscherl, *Chair*
D. C. Agarwal
A. P. Ahrendt
J. Cameron
W. D. Doty
W. D. Edsall
M. Katcher
W. M. Lundy
E. E. Morgenegg
E. G. Nisbett
J. T. Parsons
D. W. Raho
K. K. Tam
B. K. Thakur

Special Working Group on Heat Transfer Equipment (SC VIII)

G. B. Komora, *Chair*
R. P. Zoldak, *Secretary*
C. F. Andreone
D. E. Bolt
S. M. Caldwell
T. K. Haldas

M. J. Holtz
W. G. Jandrasits
R. Mahadeen
U. R. Miller
F. Osweiler
J. E. Soehrens
A. I. Soler
W. A. Treff
S. Yokell

Page xviii

Special Working Group on High-Pressure Vessels (SC VIII)

J. R. Sims, Jr., *Chair*
P. A. Reddington, *Secretary*
L. P. Antalffy
J. E. Baxter
R. C. Biel
T. B. Boyd
D. J. Burns
P. N. Chaku
E. L. Danfelt
R. E. Feigel
D. M. Fryer
J. L. Heck, Jr.
A. H. Honza
V. T. Hwang
M. M. James
P. Jansson
J. A. Kapp
D. P. Kendall
A. K. Khare
S. C. Mordre
G. J. Mraz
E. H. Perez
L. M. Picqueur
E. D. Roll
W. L. Stewart
J. F. Sullivan
F. W. Tatar

Special Working Group on Toughness (SC VIII)

W. S. Jacobs, *Chair*
J. Cameron
W. D. Doty
D. A. Hansen
G. G. Karcher
G. B. Komora

K. Mokhtarian
J. L. Mooney
C. C. Neely
M. D. Rana
J. W. Stokes

SUBCOMMITTEE ON WELDING (SC IX)

J. G. Feldstein, *Chair*
W. J. Sperko, *Vice Chair*
J. Labrador, *Secretary*
R. Barkdoll
D. A. Bowers
M. L. Carpenter
W. D. Doty
P. D. Flenner
M. J. Houle
R. A. Johnson
W. M. Lundy
R. D. McGuire
J. J. Meyer
A. H. Miller
B. R. Newmark
P. P. Norris
S. D. Reynolds, Jr.
W. K. Scattergood
G. W. Spohn III
M. J. Stanko
J. M. Tanzosh
R. R. Young

Subgroup on Brazing (SC IX)

M. J. Houle, *Chair*
A. S. Artayet
M. L. Carpenter
C. F. Jeerings
A. H. Miller
C. Robino

Subgroup on General Requirements (SC IX)

B. R. Newmark, *Chair*
R. Barkdoll
P. R. Evans
P. C. Filean
R. M. Jessee
D. W. Mann
A. S. Olivares
C. E. Wainwright
R. A. Weiss
K. R. Willens

K. R. Willens

Subgroup on Materials (SC IX)

M. L. Carpenter, *Chair*

L. P. Connor

P. D. Flenner

R. M. Jessee

A. H. Miller

H. A. Sadler

C. E. Sainz

C. E. Spaeder, Jr.

W. J. Sperko

M. J. Stanko

R. R. Young

Subgroup on Performance Qualification (SC IX)

J. J. Meyer, *Chair*

V. A. Bell

D. A. Bowers

L. P. Connor

R. A. Coomes

P. D. Flenner

G. Herrmann

M. J. Houle

W. M. Lundy

R. D. McGuire

S. R. Nordman

P. P. Norris

W. K. Scattergood

G. W. Spohn III

Subgroup on Procedure Qualification (SC IX)

J. J. Meyer, *Chair*

R. K. Brown, Jr.

R. A. Johnson

A. H. Miller

P. P. Norris

A. S. Olivares

F. C. Ouyang

S. D. Reynolds, Jr.

M. J. Rice

W. K. Scattergood

W. J. Sperko

T. C. Wiesner

SUBCOMMITTEE ON FIBER-REINFORCED PLASTIC PRESSURE VESSELS (SC X)

P. J. Conlisk, *Chair*

D. Eisberg, *Vice Chair*

A. J. Roby, *Secretary*

K. M. Agrawal
F. L. Brown
J. L. Bustillos
T. W. Cowley
T. J. Fowler
S. V. Hoa
L. E. Hunt
J. C. Murphy
A. L. Newberry
D. J. Painter
J. A. Rolston
B. F. Shelley
P. R. Wilt

SUBCOMMITTEE ON NUCLEAR INSERVICE INSPECTION (SC XI)

O. F. Hedden, *Chair*
T. J. Mawson, *Vice Chair*
G. L. Fechter, *Secretary*
C. W. Allison
W. H. Bamford, Jr.
R. L. Beverly
J. M. Bloom
R. W. Boyce
C. D. Cowfer
D. D. Davis
R. L. Dyle
T. N. Epps III
R. E. Gimple
F. E. Gregor
L. B. Gross
K. Iida
C. A. Ireland
R. D. Kerr
D. F. Landers
T. F. Lentz
J. T. Lindberg
G. C. Millman
C. R. Osman
P. C. Riccardella
L. Sage
F. J. Schaaf, Jr.
J. E. Staffiera
R. P. Sullivan
R. W. Swayne
R. J. Tamminga
J. C. Tobin
R. A. Yonekawa

Honorary Members (SC XI)

S. H. Bush
L. J. Chockie
J. P. Houstrup
L. R. Katz
R. R. MacCary

Page xix

Subgroup on Evaluation Standards (SC XI)

W. H. Bamford, Jr., *Chair*
M. Kupinski, *Secretary*
J. M. Bloom
R. C. Cipolla
R. M. Gamble
T. J. Griesbach
P. J. Hijeck
K. Iida
Y. Imamura
J. G. Merkle
S. Ranganath
P. C. Riccardella
D. A. Scarth
W. L. Server
C. A. Tomes
W. A. Van Der Sluys
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa

Working Group on Flaw Evaluation (SG-ES) (SC XI)

R. C. Cipolla, *Chair*
W. H. Bamford, Jr.
M. Basol
J. M. Bloom
E. Friedman
T. J. Griesbach
F. D. Hayes
D. N. Hopkins
K. Iida
Y. Imamura
M. Kupinski
H. S. Mehta
J. G. Merkle
J. S. Panesar
R. K. Qashu
S. Ranganath
D. A. Scarth

D. A. Scarth
T. S. Schurman
W. L. Server
F. A. Simonen
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Working Group on Operating Plant Criteria (SG-ES) (SC XI)

T. J. Griesbach, *Chair*
W. H. Bamford, Jr.
H. Behnke
B. A. Bishop
W. F. Brady
E. Friedman
S. R. Gosselin
E. M. Hackett
P. J. Hijeck
S. D. Leshnoff
P. Manbeck
J. S. Panesar
W. E. Pennell
J. H. Phillips
S. Ranganath
S. T. Rosinski
W. L. Server
E. A. Siegel
F. A. Simonen
T. D. Spry
K. K. Yoon
S. Yukawa

Working Group on Pipe Flaw Evaluation (SG-ES) (SC XI)

D. A. Scarth, *Chair*
G. M. Wilkowski, *Secretary*
W. H. Bamford, Jr.
J. M. Bloom
R. C. Cipolla
N. G. Cofie
S. K. Daftuar
G. H. De Boo
E. Friedman
D. N. Hopkins
K. Iida
H. S. Mehta

J. G. Merkle
J. S. Panesar
D. Quinones
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Subgroup on Liquid-Metal-Cooled Systems (SC XI)

C. G. McCargar, *Chair*
W. L. Chase
S. Hattori
R. Hundal
W. Kwant
J. C. Tobin

Working Group on Liquid-Metal Reactor Covers (SG-LMCS) (SC XI)

W. L. Chase, *Chair*
S. Hattori
R. Hundal
W. Kwant

Subgroup on Nondestructive Examination (SC XI)

R. L. Beverly, *Chair*
N. R. Bentley, *Secretary*
D. C. Adamonis
F. L. Becker
F. T. Carr
C. B. Cheezem
W. T. Clayton
C. D. Cowfer
F. J. Dodd
T. N. Epps III
D. O. Henry
M. R. Hum
S. N. Liu
R. D. McGuire
M. C. Modes
C. R. Osman
F. J. Schaaf, Jr.
J. C. Spanner, Jr.
C. J. Wirtz

Working Group on Personnel Qualification and Surface Visual and Eddy Current Examination (SG-NDE) (SC XI)

C. J. Wirtz, *Secretary*
B. L. Curtis
N. Economos
H. B. Garland
D. O. Henry

H. E. Houserman
J. J. McArdle III
R. D. McGuire
S. A. Redner
M. F. Sherwin
A. L. Smith
D. Spake
J. C. Spanner, Sr.
J. C. Spanner, Jr.
T. V. Tran

Working Group on Pressure Testing (SG-NDE) (SC XI)

G. P. Alexander
T. M. Anselmi
T. B. Basso
J. Boughman
T. R. Bugelholll
R. J. Cimoch
C. E. Jensen
W. N. Keisler
D. Lamond
F. J. Schaaf, Jr.
D. Terao

Working Group on Procedure Qualification and Volumetric Examination (SG-NDE) (SC XI)

C. D. Cowfer, *Chair*
C. E. Larsen, *Secretary*
D. C. Adamonis
F. L. Becker
N. R. Bentley
B. Bevins
F. T. Carr
C. B. Cheezem
W. T. Clayton
S. R. Doctor
F. J. Dodd
T. N. Epps III
B. Kellerhall
G. A. Lofthus
J. K. McClanahan
M. C. Modes
M. Saporito
T. T. Taylor
S. M. Walker

Subgroup on Repairs, Replacements, and Modifications (SC XI)

R. E. Gimple, *Chair*
W. C. Holston, *Secretary*

R. W. Boyce
M. N. Bressler
S. B. Brown
C. E. Hartz
R. A. Hermann
C. A. Ireland
R. D. Kerr
D. F. Landers
R. S. Lewis
T. J. Mawson
M. S. McDonald
R. R. Stevenson
R. P. Sullivan
R. W. Swayne
R. E. Tome
D. E. Waskey
R. A. Yonekawa

Page xx

Working Group on Design Reconciliation (SG-RR&M) (SC XI)

W. C. Holston, *Chair*
J. T. Conner, *Secretary*
R. W. Boyce
S. B. Brown
J. E. Charnley
T. E. Hiss
E. V. Imbro
D. N. Irvine, Jr.
D. F. Landers
R. W. Swayne
F. Tehranchi
H. J. Thailer
R. E. Tome

Working Group on Responsibilities and Program Requirements (SG-RR&M) (SC XI)

R. A. Yonekawa, *Chair*
R. R. Stevenson, *Secretary*
S. K. Fisher
G. M. Foster
C. E. Hartz
R. S. Lewis
M. S. McDonald
U. Potapovs
S. M. Swilley
A. J. Walcutt
J. Ghergurovich, *Alternate*

Working Group on Welding and Special Repair Processes (SG-RR&M) (SC XI)

D. E. Waskey, *Chair*
R. E. Cantrell, *Secretary*
D. A. Delsignore
A. L. Finney
P. D. Fisher
A. J. Giannuzzi
R. A. Hermann
R. P. Indap
R. D. Kerr
B. R. Newton
P. P. Norris
J. E. O'Sullivan
J. H. Sodergren
K. R. Willens

Subgroup on Water-Cooled Systems (SC XI)

T. F. Lentz, *Chair*
K. Christian, *Secretary*
C. W. Allison
W. J. Briggs
T. R. Bugelholz
D. D. Davis
A. F. Deardorff
R. L. Dyle
L. B. Gross
T. C. Hinkle
S. D. Kulat
M. P. Lintz
J. E. Staffiera
C. W. Tahnk
R. J. Tamminga
D. Terao
S. M. Walker
R. A. West

Working Group on Concrete Containment (SG-WCS) (SC XI)

W. J. Briggs, *Chair*
B. Talmadge, *Secretary*
H. G. Ashar
K. K. N. Chao
M. J. Ferlisi
H. T. Hill
R. D. Hough
C. N. Krishnaswamy
D. Naus
S. C. Petitgout
C. G. Ranganath

Working Group on Implementation of Risk-Based Examination (SG-WCS) (SC XI)

T. J. Mawson, *Chair*
A. McNeill III, *Secretary*
J. Agold
S. A. Ali
B. A. Bishop
J. W. Connor
A. F. Deardorff
H. Q. Do
R. Fougrousse
S. R. Gosselin
J. T. Lindberg
I. Mach
R. K. Mattu
P. J. O'Regan
J. H. Phillips
F. A. Simonen
T. V. Vo
R. A. West

Working Group on Inspection of Systems and Components (SG-WCS) (SC XI)

R. L. Dyle, *Chair*
G. C. Park, *Secretary*
G. L. Belew
T. W. Brombach
R. Fougrousse
T. C. Hinkle
M. R. Hum
S. D. Kulat
J. T. Lindberg
M. P. Lintz
T. K. McLellan
C. Pendleton
C. M. Ross
C. W. Tahnk
K. B. Thomas
E. Throckmorton
R. A. West
J. Whitman

Working Group on Metal Containment (SG-WCS) (SC XI)

J. E. Staffiera, *Chair*
W. E. Norris, *Secretary*
W. J. Briggs
K. K. N. Chao
M. J. Ferlisi
R. W. Hammelmann
M. P. Lintz

S. C. Petitgout
C. G. Ranganath
G. W. Robin
R. T. Zak

Special Working Group on Low-Temperature Heavy Water Reactors (SG-WCS) (SC XI)

C. D. Cowfer, *Chair*
J. M. Morrison, *Secretary*
B. Awadalla
K. F. Schmidt
P. R. Vormelker
S. H. Zaidi

Working Group on General Requirements (SC XI)

A. T. Roberts III, *Chair*
R. G. Edl, *Secretary*
D. A. Graham
L. B. Gross
C. A. Ireland
D. A. Jackson
R. K. Mattu
L. Sage
R. J. Scott
J. C. Shropshire
R. J. Tamminga

Special Working Group on Editing and Review (SC XI)

R. W. Swayne, *Chair*
R. L. Beverly
L. B. Gross
M. P. Lintz
J. E. Staffiera
C. J. Wirtz

Special Working Group on Plant Life Extension (SC XI)

F. E. Gregor, *Chair*
L. B. Gross, *Secretary*
D. D. Davis
D. A. Graham
D. L. Harrison
M. P. Lintz
P. Manbeck
H. W. Massie, Jr.
D. W. Peltola
D. A. Piccione
C. M. Regan
V. N. Shah
R. J. Tamminga

SUBCOMMITTEE ON TRANSPORT TANKS (SC XII)

A. Selz, *Chair*
P. D. Stumpf, *Secretary*
A. N. Antoniou
S. C. Cyr
K. Ennis
M. Hennemand
C. H. Hochman
G. G. Karcher
P. P. Laluc
G. McRae
M. R. Minick
T. P. Pastor
M. D. Rana
C. M. Serratella
G. R. Stoeckinger
N. Surtees
J. P. Swezy
A. P. Varghese
S. V. Voorhees
W. L. White

Page xxi

Subgroup on Design and Materials (SC XII)

M. D. Rana, *Chair*
D. A. Canonico
W. D. Doty
G. G. Karcher
P. P. Laluc
T. P. Pastor
T. A. Rogers
C. M. Serratella
A. P. Varghese
E. Whittle

Subgroup on Fabrication and Inspection (SC XII)

S. V. Voorhees, *Chair*
D. A. Canonico
M. L. Coats
M. Hennemand
D. J. Kreft
G. McRae
M. R. Minick
N. Surtees
J. P. Swezy

Subgroup on General Requirements (SC XII)

C. H. Hochman, *Chair*
T. Alexander

A. N. Antoniou
D. Carter
K. Ennis
M. A. Garrett
J. C. Keenan
F. A. Licari
G. R. Stoeckinger
W. L. White

SUBCOMMITTEE ON BOILER AND PRESSURE VESSEL ACCREDITATION (SC-BPVA)

A. J. Spencer, *Chair*
A. J. Justin, *Vice Chair*
K. I. Baron, *Secretary*
M. B. Doherty
D. A. Douin
P. D. Edwards
R. M. Elliott
C. E. Ford
J. J. Greene
R. C. Howard
B. B. MacDonald
M. L. Sisk
B. C. Turczynski
R. V. Wielgoszinski
R. L. Williams
V. A. Bell, *Alternate*
V. Bogosian, *Alternate*
M. A. De Vries, *Alternate*
J. R. Farr, *Alternate*
R. G. Friend, *Alternate*
W. C. LaRochelle, *Alternate*
A. S. Lester III, *Alternate*
K. M. McTague, *Alternate*
G. P. Milley, *Alternate*
R. E. Muise, *Alternate*
P. G. Scheckermann, *Alternate*
N. Surtees, *Alternate*

SUBCOMMITTEE ON NUCLEAR ACCREDITATION (SC-NA)

T. E. Quaka, *Chair*
R. R. Stevenson, *Vice Chair*
S. Griffin, *Secretary*
C. W. Allison
M. N. Bressler
G. Deily
F. R. Drahos
J. E. Harris

M. Kotb
W. C. LaRochelle
U. Potapovs
H. B. Prasse
A. J. Spencer
G. M. Tolson
L. M. Beason, Alternate
R. W. Boyce, Alternate
S. Dasgupta, Alternate
P. D. Edwards, Alternate
J. P. Ellenberger, Alternate
R. E. Feigel, Alternate
D. Hanrath, Alternate
K. A. Huber, Alternate
A. J. Justin, Alternate
N. C. Kist, Alternate
A. A. Lotfi, Alternate
R. P. McIntyre, Alternate
O. E. Trapp, Staff Representative

SUBCOMMITTEE ON DESIGN (SC-D)

W. J. Carter, *Chair*
F. S. Fitzgerald, *Secretary*
R. W. Barnes
C. Becht IV
O. F. Hedden
R. W. Mikitka
K. Mokhtarian
W. J. O'Donnell
R. D. Schueler, Jr.
M. P. Schwartz
A. Selz

Subgroup on Design Analysis (SC-D)

T. P. Pastor, *Secretary*
P. J. Conlisk
A. G. Eggers
J. L. Hechmer
G. L. Hollinger
D. P. Jones
A. Kalnins
W. J. Koves
T. H. Liu
O. Maekawa
A. Merend
T. V. Narayanan
E. L. Thomas, Jr.

Subgroup on Elevated Temperature Design (SC-D)

C. Becht IV, *Chair*
J. M. Corum, *Secretary*
C. R. Brinkman
R. D. Campbell
D. S. Griffin
R. I. Jetter
C. Lawton
W. J. O'Donnell
D. A. Osage
C. C. Schultz, Jr.
L. K. Severud
D. F. Shaw
A. L. Snow
B. E. Thurgood

Subgroup on Fatigue Strength (SC-D)

C. R. Brinkman
P. R. Donavin
J. A. Hayward
J. L. Hechmer
D. P. Jones
G. Kharshafdjian
C. Lawton
A. Merend
H. H. Ziada

Subgroup on Openings (SC-D)

M. P. Schwartz, *Chair*
R. W. Mikitka, *Secretary*
M. R. Breach
V. T. Hwang
S. C. Lou
R. B. Luney
J. P. Madden
K. C. Morrison
D. R. Palmer
M. D. Rana
E. C. Rodabaugh

Special Working Group on Bolted Flanged Joints (SC-D)

R. W. Mikitka, *Chair*
G. D. Bibel
G. Kharshafdjian
D. L. Kurle
E. Michalopoulos
S. N. Pagay
J. R. Payne
R. W. Schneider

R. D. Schueler, Jr.
A. Selz

SUBCOMMITTEE ON SAFETY VALVE REQUIREMENTS (SC-SVR)

E. C. Kistner, Jr., *Chair*
M. D. Bernstein, *Vice Chair*
U. D'Urso, *Secretary*
J. F. Ball
J. A. Cox
R. D. Danzy
R. J. Doelling
D. A. Douin
R. G. Friend
H. I. Gregg
S. F. Harrison, Jr.
C. F. Laitner
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson
D. J. Scallan
C. M. Schroepfer
A. J. Spencer
J. C. Standfast
E. A. Steen
L. L. Thompson
J. A. West
T. J. Ferrigan, *Alternate*

Page xxii

Subgroup on Design (SC-SVR)

R. G. Friend, *Chair*
J. Cahoon, Jr.
R. D. Danzy
D. B. DeMichael
R. J. Doelling
H. I. Gregg
S. R. Irvin
C. F. Laitner
P. R. Sievert
A. J. Spencer
E. A. Steen
T. R. Tarbay
J. A. West

Subgroup on General Requirements (SC-SVR)

M. D. Bernstein, *Chair*
J. F. Ball

V. M. Deluca
D. A. Douin
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson
J. C. Standfast
L. L. Thompson

Subgroup on Testing (SC-SVR)

S. F. Harrison, Jr., *Chair*
S. Cammeresi
J. A. Cox
W. F. Hart
D. M. Papa
D. J. Scallan
C. M. Schroepfer
D. E. Snyder

Page xxiii

ORGANIZATION OF SECTION III

1. GENERAL

Section III consists of Division 1, Division 2, and Division 3. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter "N" for Division 1, by the letter "C" for Division 2, and by the letter "W" for Division 3. The following eleven books make up the three Divisions.

Subsection NCA - General Requirements for Division 1 and Division 2

Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

Division 2 - Code for Concrete Reactor Vessels and Containments

Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

Division 2 book includes Subsection CC - Concrete Containments and Division 2 Appendices.

Division 3 book includes Subsections WA and WB for General Requirements and Class TP (Type B) Containment, respectively.

2. SUBSECTIONS

Subsections are divided into Articles, Subarticles, paragraphs, and, where necessary, subparagraphs and subsubparagraphs.

3. ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections followed by Arabic numbers, such as NB-1000. Where possible, Articles dealing with the same topics are given the same number in each Subsection in accordance with the following general scheme:

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination
6000	Testing
7000	Overpressure Protection
8000	Nameplates, Stamping, and Reports

The numbering of Articles and the material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the rules have been prepared with some gaps in the numbering.

4. SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

5. SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as NB-2130, and generally have no text. When a number such as NB-1110 is followed by text, it is considered a paragraph.

6. PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

7. SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as NB-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

8. SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

Page xxiv

9. REFERENCES

References used within Section III generally fall into one of the following four categories.

A. References to Other Portions of Section III

When a reference is made to another Article, Subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to NB-3000 includes all material in Article NB-3000; reference to NB-3200 includes all

material in Subarticle NB-3200; reference to NB-3230 includes all paragraphs NB-3231 through NB-3236.

B. References to Other Sections

Other Sections referred to in Section III are:

Section II, Materials. When a requirement for a material, or for the examination or testing of a material, is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II. These references begin with the letter "S."

Section V, Nondestructive Examination. Section V references begin with the letter "T" and relate to the nondestructive examination of material or welds.

Section IX, Welding and Brazing Qualifications. Section IX references begin with the letter "Q" and relate to welding and brazing requirements.

Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components. When a reference is made to inservice inspection, the rules of Section XI shall apply.

C. Reference to Specifications and Standards Other Than Published in Code Sections

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials. At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E 71-64 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

2 The American National Standards Institute (ANSI) was formerly known as the American Standards Association. Standards approved by the Association were designated by the prefix "ASA" followed by the number of the standard and the year of publication. More recently, the American National Standards Institute was known as the United States of America Standards Institute. Standards were designated by the prefix "USAS" followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the numbers of the standards have remained unchanged.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by the American Society of Mechanical Engineers and approved by the American National Standards Institute.² When a product is to conform to such a standard, for example ANSI B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NB-3132-1, for example ANSI B16.5-1977. Standards published by the American Society of Mechanical Engineers are available from ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-6, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, 127 Park Street, N.E., Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NB-3132-1, for example MSS SP-6-1963.

(4) Specifications for welding and brazing materials are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33135. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix "SF," for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-620 and API-2000. When documents so designated are referred to in Section III, they are standards published by the American Petroleum Institute.

D. References to Appendices

Two types of Appendices are used in Section III and are designated Mandatory and Nonmandatory.

(1) Mandatory Appendices contain requirements which must be followed in construction; such references are designated by a Roman numeral followed by Arabic numerals. References to II-1100 or XI-3212, for example, relate to the Mandatory Appendices.

(2) Nonmandatory Appendices provide information or guidance for the use of Section III; such references are designated by a capital letter followed by Arabic numerals. A reference to D-1100, for example, relates to a Nonmandatory Appendix.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NC-1000

ARTICLE NC-1000 INTRODUCTION

Page 1

Page 3

NC-1100 SCOPE

(a) Subsection NC contains rules for the material, design, fabrication, examination, testing, overpressure relief, marking, stamping, and preparation of reports by the Certificate Holder for items which are intended to conform to the requirements for Class 2 construction.

(b) The rules of Subsection NC cover the strength and pressure integrity of items the failure of which would violate the pressure retaining boundary. The rules cover load stresses but do not cover deterioration which may occur in service as a result of corrosion, radiation effects, or instability of materials. NCA-1130 further limits the rules of this Subsection.

(c) Subsection NC does not contain rules to cover all details of construction of Class 2 vessels and storage tanks. Where complete details are not provided in this Subsection, it is intended that the N Certificate Holder, subject to the approval of the Owner or his designee and acceptance by the Inspector, shall provide details of construction which will be consistent with those provided by the rules of this Subsection.

NC-1120 TEMPERATURE LIMITS

Vessels are to be designed using the standard design method in NC-3300 or the alternative design rules of NC-3200, which allows the use of analysis with the higher design stress intensity values of Tables 2A, 2B, and 4, Section II, Part D, Subpart 1.

NC-1130 BOUNDARIES OF JURISDICTION APPLICABLE TO THIS SUBSECTION

NC-1131 Boundary of Components

The Design Specification shall define the boundary of a component to which piping or another component is attached. The boundary shall not be closer to a vessel, tank, pump, or valve than:

- (a) the first circumferential joint in welded connections (the connecting weld shall be considered part of the piping);
- (b) the face of the first flange in bolted connections (the bolts shall be considered part of the piping);
- (c) the first threaded joint in screwed connections.

NC-1132 Boundary Between Components and Attachments

NC-1132.1 Attachments

(a) An *attachment* is an element in contact with or connected to the inside or outside of the pressure retaining portion of a component which may have either a pressure retaining or nonpressure-retaining function and either a structural or nonstructural function.

(b) Attachments with a pressure retaining function include items such as stiffeners and branch or vessel opening reinforcement.

(c) Attachments with a nonpressure-retaining function include items such as valve guides, thermal sleeves, turning vanes, and component support load path items such as vessel saddles, support and shear lugs, brackets, pipe clamps,

vanes, and component support load path items such as vessel saddles, support and shear lugs, brackets, pipe clamps, trunnions, and skirts.

(d) Attachments with a structural function (structural attachments) perform a pressure retaining function or are in the component support load path.

(e) Attachments with a nonstructural function (nonstructural attachments) do not perform a pressure retaining function nor are they in the component support load path. Nonstructural attachments include items such as nameplates, insulation supports, and locating and lifting lugs.

NC-1132.2 Jurisdictional Boundary.

The jurisdictional boundary between a pressure retaining component and an attachment defined in the Design Specification shall not be any closer to the pressure retaining portion of the component than as defined in (a) through (g)

Page 4

below. Figures NC-1132.2-1 through NC-1132.2-3 are provided as an aid in defining the boundary and construction requirements of this Subsection.

(a) Attachments cast or forged with the component and weld buildup on the component surface shall be considered part of the component.

(b) Attachments, welds, and fasteners having a pressure retaining function shall be considered part of the component.

(c) Except as provided in (d) and (e) below, the boundary between a pressure retaining component and an attachment not having a pressure retaining function shall be at the surface of the component.

(d) The first connecting weld of a nonpressure-retaining structural attachment to a component shall be considered part of the component unless the weld is more than $2t$ from the pressure retaining portion of the component, where t is the nominal thickness of the pressure retaining material. Beyond $2t$ from the pressure retaining portion of the component, the first weld shall be considered part of the attachment.

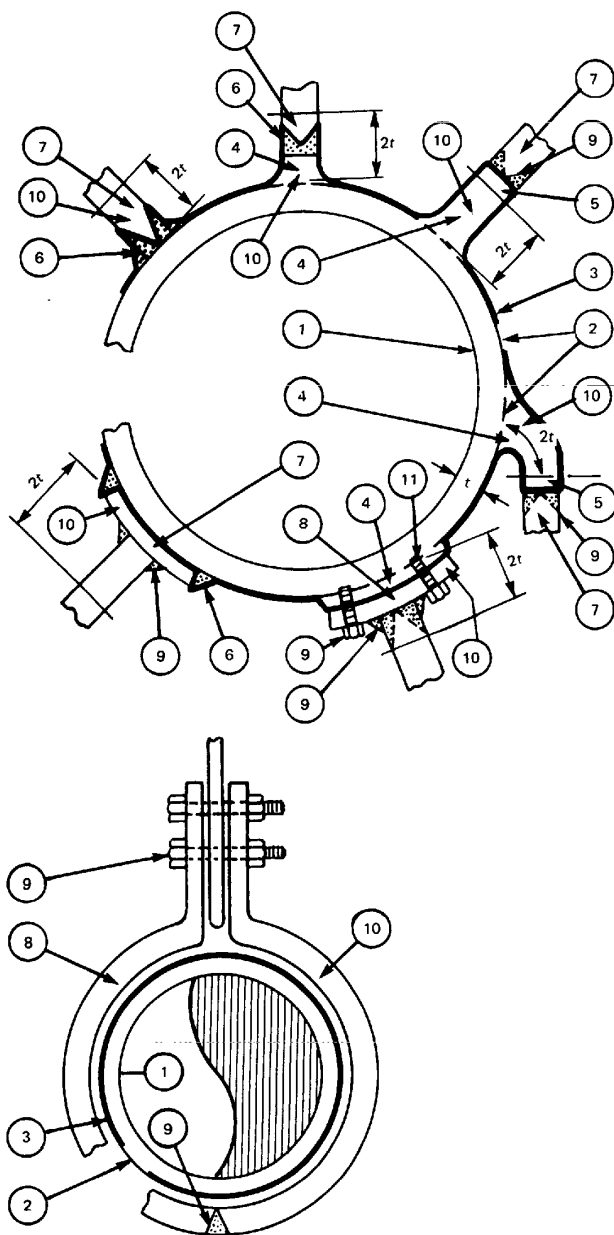
(e) The first connecting weld of a welded nonstructural attachment to a component shall be considered part of the attachment. At or within $2t$ from the pressure retaining portion of the component the first connecting weld shall conform to NC-4330.

(f) Mechanical fasteners used to connect a nonpressure-retaining attachment to the component shall be considered part of the attachment.

(g) The boundary may be located further from the pressure retaining portion of the component than as defined in (a) through (f) above when specified in the Design Specification.

Page 5

Page 6



- ① Component shall conform to Subsection NC.
- ② Pressure retaining portion of the component.
- ③ Jurisdictional boundary (heavy line).
- ④ Cast or forged attachment or weld buildup shall conform to Subsection NC.
- ⑤ Beyond $2t$ from the pressure retaining portion of the component, the design rules of NF-3000 may be used as a substitute for the design rules of NC-3000.
- ⑥ At or within $2t$ from the pressure retaining portion of the component, the first connecting weld shall conform to Subsection NC.
- ⑦ Beyond $2t$ from the pressure retaining portion of the component or beyond the first connecting weld, the attachment shall conform to Subsection NF [Note (1)].
- ⑧ Bearing, clamped, or fastened attachment shall conform to Subsection NF [Note (1)].
- ⑨ Attachment connection shall conform to Subsection NF [Note (1)].
- ⑩ At or within $2t$ from the pressure retaining portion of the component, the interaction effects of the attachment shall be considered in accordance with NC-3135.
- ⑪ Drilled holes shall conform to Subsection NC.

GENERAL NOTE:

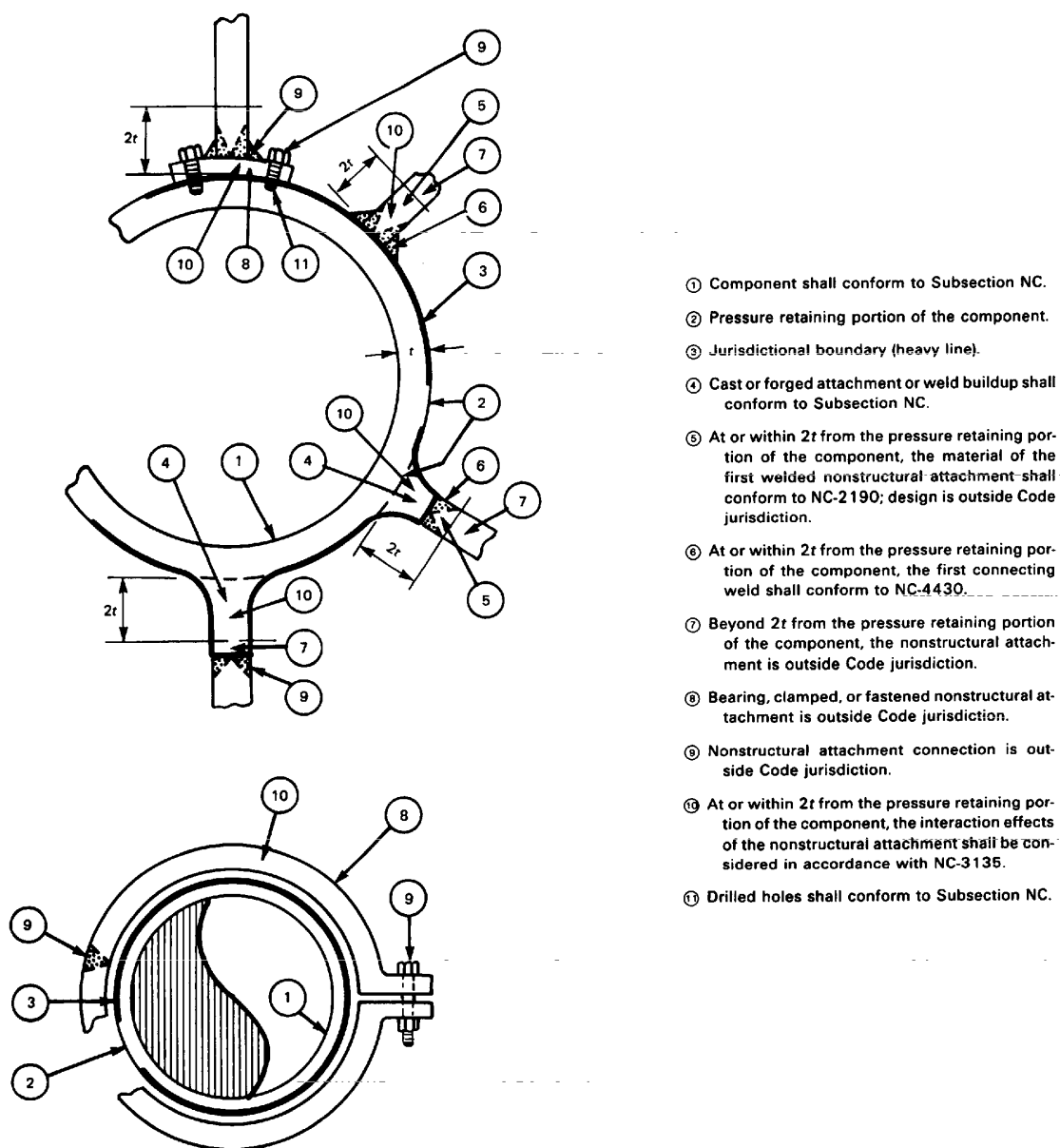
These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

NOTE:

(1) If the attachment is an intervening element [NF-1110(c)], material, design and connections, as appropriate, are outside Code jurisdiction.

FIG. NC-1132.2-1 ATTACHMENTS IN THE COMPONENT SUPPORT LOAD PATH WHICH DO NOT PERFORM A PRESSURE RETAINING FUNCTION

FIG. NC-1132.2-1 ATTACHMENTS IN THE COMPONENT SUPPORT LOAD PATH WHICH DO NOT PERFORM A PRESSURE RETAINING FUNCTION

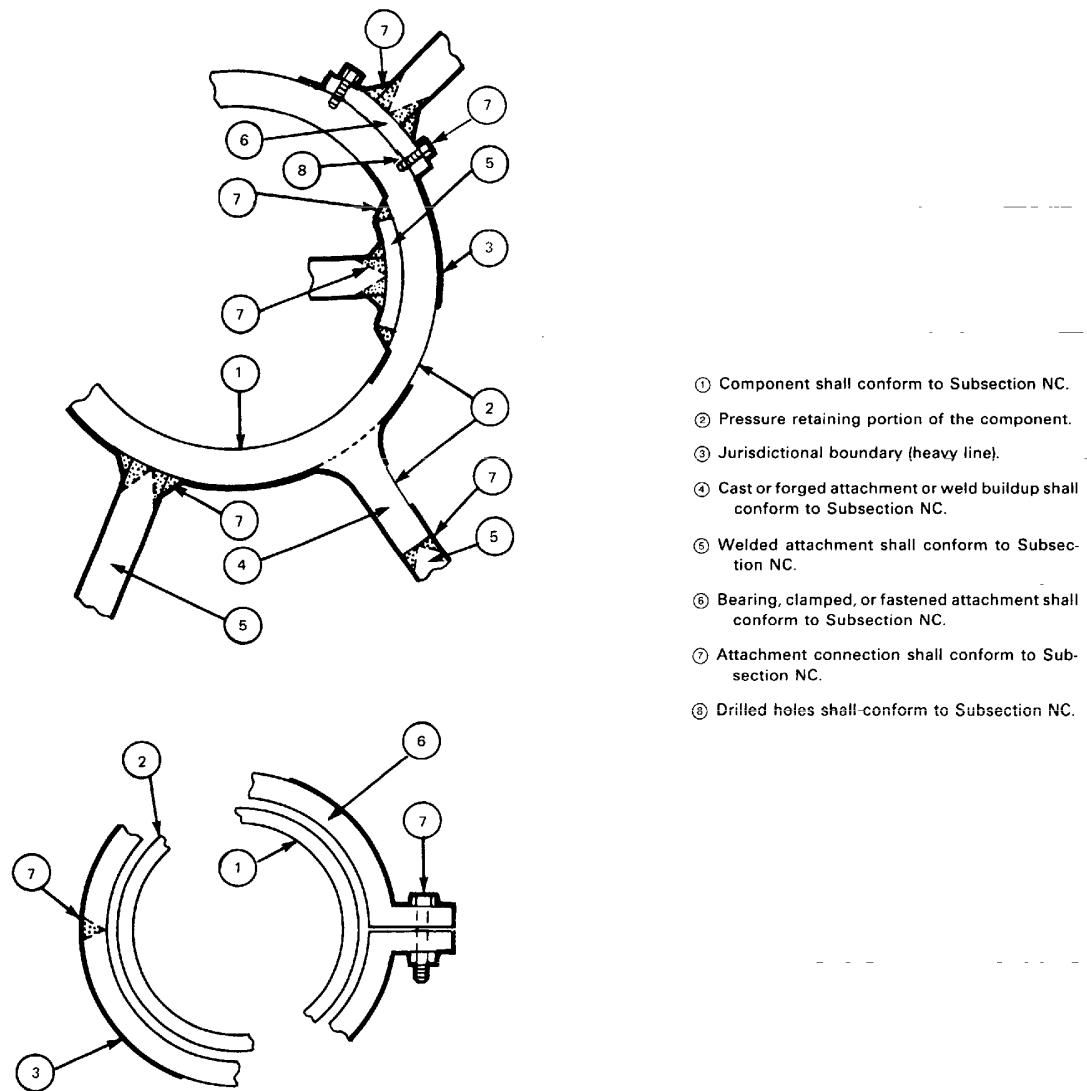


GENERAL NOTE:

These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

FIG. NC-1132.2-2 ATTACHMENTS WHICH DO NOT PERFORM A PRESSURE RETAINING FUNCTION AND ARE NOT IN THE COMPONENT SUPPORT LOAD PATH (NONSTRUCTURAL ATTACHMENTS)

FIG. NC-1132.2-2 ATTACHMENTS WHICH DO NOT PERFORM A PRESSURE RETAINING FUNCTION AND ARE NOT IN THE COMPONENT SUPPORT LOAD PATH



GENERAL NOTE:
These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

FIG. NC-1132.2-3 ATTACHMENTS WHICH PERFORM A PRESSURE RETAINING FUNCTION

FIG. NC-1132.2-3 ATTACHMENTS WHICH PERFORM A PRESSURE RETAINING FUNCTION

July 1, 1998
American Society Of Mechanical Engineers
SEC III D1 NC-2000

NC-2100 GENERAL REQUIREMENTS FOR MATERIAL

[98]

NC-2110 SCOPE OF PRINCIPAL TERMS EMPLOYED

(a) The term *material* as used in this Subsection is defined in NCA-1220. The term *Material Organization* is defined in NCA-9000.

(b) The term *pressure retaining materials* as used in this Subsection applies to vessel shells, heads, and nozzles; pipes, tubes, and fittings; valve bodies, bonnets, and disks; pump casings and covers; and bolting which joins pressure retaining items.

(c) The requirements of this Article make reference to the term *thickness*. For the purpose intended, the following definitions of nominal thickness apply:

(1) *plate* - the thickness is the dimension of the short transverse direction;

(2) *forgings* - the thickness is the dimension defined as follows:

(a) *hollow forgings* - the nominal thickness is measured between the inside and outside surfaces (radial thickness);

(b) *disk forgings* (axial length less than the outside diameter) - the nominal thickness is the axial length;

(c) *flat ring forgings* (axial length less than the radial thickness) - for axial length ≤ 2 in. (51 mm), the axial length is the nominal thickness. For axial length > 2 in. (51 mm), the radial thickness is the nominal thickness.

(d) *rectangular solid forgings* - the least rectangular dimension is the nominal thickness.

(3) *Castings*

(a) Thickness t for fracture toughness testing is defined as the nominal pipe wall thickness of the connecting piping.

(b) Thickness t for heat treatment purposes is defined as the thickness of the pressure retaining wall of the casting excluding flanges and sections designated by the designer as nonpressure retaining.

[98]

NC-2120 PRESSURE RETAINING MATERIAL

NC-2121 Permitted Material Specifications

(a) Pressure retaining material shall conform to the requirements of one of the specifications for materials given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1 and to all of the requirements of this Article which apply to the product form in which the material is used. Attachments which perform a pressure retaining function shall be pressure retaining material. For vessels which are designed in accordance with NC-3200, the materials shall be restricted to those materials listed in Tables 2A, 2B, and 4, Section II, Part D, Subpart 1 and to the following clad product specifications, provided they are composed of materials listed in Tables 2A, 2B, and 4, Section II, Part D, Subpart 1:

SA-263 Specification for Corrosion-Resisting Chromium-Steel Clad Plate, Sheet, and Strip

SA-264 Specification for Corrosion-Resisting Chromium-Nickel Steel Clad Plate, Sheet, and Strip

SA-265 Specification for Nickel and Nickel-Base Alloy Clad Steel Plate

(b) The requirements of this Article do not apply to material for items not associated with the pressure retaining function of a component such as shafts, stems, trim, spray nozzles, bearings, bushings, springs, wear plates, nor to seals, packing, gaskets, valve seats, and ceramic insulating materials and special alloys used as seal materials in electrical penetration assemblies.

(c) Material made to specifications other than those specified in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1 may be used for the following applications:

- (1) *Safety valve disks and nozzles* - when the nozzles are internally contained by the external body structure
- (2) *Control valve disks and cages* - when the valves function for flow control only
- (3) *Line valve disks in valves* - whose inlet connections are NPS 2 (DN 50) and smaller.

Page 14

(d) Material for line fittings, 1 in. nominal pipe size and less, may be of material made to specifications other than those listed in Section II, Part D, Subpart 1, provided that the fittings are in conformance with the requirements of NC-3671.4 and the material is determined to be adequate for the service conditions by the piping system designer.

(e) Welding and brazing materials used in manufacture of items shall comply with an SFA specification in Section II, Part C, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article. The requirements of this Article do not apply to materials used as backing rings or backing strips in welded joints.

(f) The requirements of this Article do not apply to hard surfacing or corrosion resistant weld metal overlay which is 10% or less of the thickness of the base material (NC-3122).

NC-2122 Special Requirements Conflicting With Permitted Material Specifications

Special requirements stipulated in this Article shall apply in lieu of the requirements of the material specifications wherever the special requirements conflict with the material specification requirements [NCA-3856]. Where the special requirements include an examination, test, or treatment which is also required by the material specification, the examination, test, or treatment need be performed only once. Required nondestructive examinations shall be performed as specified for each product form in NC-2500. Any examination, repair, test, or treatment required by the material specification or by this Article may be performed by the Material Manufacturer or the Certificate Holder as provided in NC-4121.1. Any hydrostatic or pneumatic pressure test required by a material specification need not be performed, provided the material is identified as not having been pressure tested and it is subsequently pressure tested in accordance with NC-6114, except where the location of the material in the component or the installation would prevent performing any nondestructive examination required by the material specification to be performed subsequent to the hydrostatic or pneumatic test.

NC-2124 Material Size Ranges and Tolerances

(a) Material outside the limits of size or thickness given in any specification in Section II may be used if the material is in compliance with the other requirements of the specification and no size limitation is given in this Subsection. In those specifications in which chemical composition or mechanical properties are indicated to vary with size or thickness, any material outside the specification range shall be required to conform to the composition and mechanical properties shown for the nearest specified range [NCA-3856].

(b) Plate material shall be ordered not thinner than the design thickness. Components, except for piping, made of plate furnished with an undertolerance of not more than the lesser value of 0.01 in. or 6% of the ordered thickness, may be used at the full design pressure for the thickness ordered. If the specification to which the plate is ordered allows a greater undertolerance, the ordered thickness of the material shall be sufficiently greater than the design thickness so that the thickness of the material furnished is not more than the lesser of 0.01 in. or 6% under the design thickness.

(c) If pipe or tube is ordered by its nominal wall thickness, the manufacturing undertolerance on wall thickness shall be taken into account. The manufacturing undertolerances are given in the several pipe and tube specifications listed in the applicable Tables in Section II, Part D, Subpart 1. After the minimum wall thickness is determined (NC-3641.1), it shall be increased by an amount sufficient to provide for the manufacturing undertolerance allowed in the pipe or tube specification.

NC-2125 Material in Combination¹

A component may be designed and constructed of any combination of materials permitted in NC-2000, provided the applicable rules are followed and the requirements of Section IX for welding dissimilar metals are met.

NC-2126 Integrally Finned Tubes

Integrally finned tubes may be made from tubes that conform to one of the specifications for tubes listed in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1 and to all of the special requirements of this Article which apply to that product form. In addition, the following requirements shall apply.

(a) The requirements of NC-2550 shall be met by the tube before finning.

1 Because of the different thermal coefficients of expansion of dissimilar materials, caution shall be exercised in construction under the provisions of this paragraph in order to avoid difficulties in service under extreme temperature conditions, or with unusual restraint such as may occur at points of stress concentration and also because of metallurgical changes occurring at high temperatures.

Page 15

(b) The tubes after finning shall conform to the applicable heat treatment requirements of the basic material specification.

(c) The allowable stress values shall be those given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 for the tube material from which the finned tube is made.

(d) After finning, each tube shall be subjected to one of the following tests:

(1) an internal pneumatic pressure test at not less than 250 psi without evidence of leakage; the test method, such as immersion of the tube under water during the test, shall permit visual detection of any leakage;

(2) an individual tube hydrostatic test at 1.25 times the Design Pressure which permits complete examination of the tube for leakage.

(e) A visual examination shall be performed after finning. Material having discontinuities, such as laps, seams, or cracks, is unacceptable.

NC-2128 Bolting Material

(a) Material for bolts and studs shall conform to the requirements of one of the specifications listed in Table 3, Section II, Part D, Subpart 1. Material for nuts shall conform to SA-194 or to the requirements of one of the specifications for nuts or bolting listed in Table 3, Section II, Part D, Subpart 1. Refer to Table 4, Section II, Part D, Subpart 1 for bolting material for vessels designed to the requirements of NC-3200.

(b) The use of washers is optional. When used, they shall be made of wrought material with mechanical properties compatible with the nuts with which they are to be employed.

NC-2130 CERTIFICATION OF MATERIAL

All materials used in the construction of components shall be certified as required in NCA-3862 and NCA-3861. Certified Material Test Reports are required for pressure retaining material except as provided by NCA-3861. A Certificate of Compliance may be provided in lieu of a Certified Material Test Report for all other material. Copies of all Certified Material Test Reports and Certificates of Compliance applicable to material used in a component shall be furnished with the material.

NC-2140 WELDING MATERIALS

For the requirements governing the materials to be used for welding, see NC-2400.

NC-2150 MATERIAL IDENTIFICATION

The identification of pressure retaining material shall meet the requirements of NCA-3856. Material for small items shall be controlled during manufacture and installation of the component so that they are identifiable as acceptable material at all times. Welding and brazing materials shall be controlled during the repair of material and the manufacture and installation so that they are identifiable as acceptable until the material is actually consumed in the process (NC-4122).

NC-2160 DETERIORATION OF MATERIAL IN SERVICE

Consideration of deterioration of material caused by service is generally outside the scope of this Subsection. It is the responsibility of the Owner to select material suitable for the conditions stated in the Design Specifications (NCA-3250), with specific attention being given to the effects of service conditions upon the properties of the material.

NC-2170 HEAT TREATMENT TO ENHANCE IMPACT PROPERTIES

Carbon steels, low alloy steels, and high alloy chromium (Series 4XX) steels may be heat treated by quenching and tempering to enhance their impact properties. Postweld heat treatment of the component at a temperature of not less than 1100°F (593°C) may be considered to be the tempering phase of the heat treatment.

NC-2180 PROCEDURES FOR HEAT TREATMENT OF MATERIAL

When heat treating temperature or time is required by the material specification and the rules of this Subsection, the heat treating shall be performed in temperature-surveyed and -calibrated furnaces or the heat treating shall be controlled by measurement of material temperature by thermocouples in contact with the material or attached to blocks in contact with the material or by calibrated pyrometric instruments. Heat treating shall be performed under furnace loading conditions such that the heat treatment is in accordance with the material specification and the rules of this Subsection.

Page 16

NC-2190 NONPRESSURE-RETAINING MATERIAL

(a) Material in the component support load path and not performing a pressure retaining function (see NC-1130) welded to pressure retaining material shall meet the requirements of NF-2000.

(b) Material not performing a pressure retaining function and not in the component support load path (nonstructural attachments) welded at or within $2t$ of the pressure retaining portion of the component need not comply with NC-2000 or NF-2000 provided the requirements of NC-4430 are met.

(c) Structural steel rolled shapes, which are permitted by this Subsection to be furnished with a Certificate of Compliance, may be repaired by welding using the welders, documentation, and examination requirements specified in SA-6.

NC-2200 MATERIAL TEST COUPONS AND SPECIMENS FOR FERRITIC STEEL MATERIAL

NC-2210 HEAT TREATMENT REQUIREMENTS

NC-2211 Test Coupon Heat Treatment for Ferritic Material²

Where ferritic steel material is subjected to heat treatment during fabrication or installation of a component, the material used for the tensile and impact test specimens shall be heat treated in the same manner as the component, except that test coupons and specimens for P-No. 1 material with a nominal thickness of 2 in. (51 mm) or less are not required to be so heat treated where nominal thickness for flanges refers to the wall thickness at the weld joint to the pipe or component. The Certificate Holder shall provide the Material Manufacturer with the temperature and heating and cooling rate to be used. In the case of postweld heat treatment, the total time at temperature or temperatures for the test material shall be at least 80% of the total time at temperature or temperatures during actual postweld heat treatment of the material, and the total time at temperature or temperatures for the test material, coupon, or specimen may be performed in a single cycle.

2 Any postweld heat treatment time which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

NC-2212 Test Coupon Heat Treatment for Quenched and Tempered Material

NC-2212.1 Cooling Rates.

Where ferritic steel material is subjected to quenching from the austenitizing temperature, the test coupons representing those materials shall be cooled at a rate similar to and no faster than the main body of the material except in the case of certain forgings and castings (NC-2223.3 and NC-2226.4). This rule shall apply for coupons taken directly

from the material as well as for separate test coupons representing the material, and one of the general procedures described in NC-2212.2 or one of the specific procedures described in NC-2220 shall be used for each product form.

NC-2212.2 General Procedures.

One of the general procedures in (a), (b), and (c) below may be applied to quenched and tempered material or test coupons representing the material, provided the specimens are taken relative to the surface of the product in accordance with NC-2220. Further specific details of the methods to be used shall be the obligation of the Material Manufacturer and the Certificate Holder.

(a) Any procedure may be used which can be demonstrated to produce a cooling rate in the test material that matches the cooling rate of the main body of the product at the region midway between midthickness and the surface ($\frac{1}{4}t$) and no nearer any heat treated edge than a distance equal to the nominal thickness t being quenched within 25°F (14°C) and 20 sec at all temperatures after cooling begins from the austenitizing temperature.

(b) If cooling rate data for the material and cooling rate control devices for the test specimens are available, the test specimens may be heat treated in the device to represent the material, provided that the provisions of (a) above are met.

(c) When any of the specific procedures described in NC-2220 are used, faster cooling rates at the edges may be compensated for by:

(1) taking the test specimens at least t from a quenched edge, where t equals the material thickness;

(2) attaching a steel pad at least t wide by a partial penetration weld (which completely seals the buffered surface) to the edge where specimens are to be removed; or

(3) using thermal barriers or insulation at the edge where specimens are to be removed.

It shall be demonstrated (and this information shall be included in the Certified Material Test Report) that the cooling rates are equivalent to (a) or (b) above.

Page 17

NC-2220 PROCEDURE FOR OBTAINING TEST COUPONS AND SPECIMENS FOR QUENCHED AND TEMPERED MATERIAL

NC-2221 General Requirements

The procedure for obtaining test specimens for quenched and tempered material is related to the product form. Coupon and specimen location shall be as required by the material specification, except as stated in the following paragraphs of this Subarticle. References to dimensions signify nominal values.

NC-2222 Plates

NC-2222.1 Orientation and Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from a rolled surface and with the midlength of the specimen at least t from any heat treated edge, where t is the nominal thickness of the material.

NC-2222.2 Requirements for Separate Test Coupons.

Where a separate test coupon is used to represent the component material, it shall be of sufficient size to ensure that the cooling rate of the region from which the test coupons are removed represents the cooling rate of the material at least $\frac{1}{4}t$ deep and t from any edge of the product. Unless cooling rates applicable to the bulk pieces or product are simulated in accordance with NC-2212.2, the dimensions of the coupon shall be not less than $3t \times 3t \times t$, where t is the nominal material thickness.

NC-2223 Forgings

NC-2223.1

NC-2223.1 Forgings With 2 in. (51 mm) Maximum Thickness.

For forgings with a maximum thickness of 2 in., the coupons shall be taken so that specimens shall have their longitudinal axes at the midplane of the thickness or the center of the cross section and with the midlength of the specimens at least 2 in. from any second surface.

NC-2223.2 Forgings With Thickness Exceeding 2 in. (51 mm)

For forgings exceeding a thickness of 2 in. (51 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ of the maximum heat treated thickness from any surface and with the midlength of the specimens at least t from any second surface. This is normally referred to as $\frac{1}{4}t \times t$, where t is the maximum heat treated thickness. A thermal buffer may be used to achieve the above conditions [NC-2212.2(c)(3)] unless cooling rates applicable to the bulk forgings are simulated in accordance with NC-2212.2.

NC-2223.3 Very Thick and Complex Forgings.

Test coupons for forgings which are both very thick and complex, such as contour nozzles, thick tubesheets, flanges, nozzles, and other complex forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment, may be removed from prolongations or other stock provided on the product. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service. The coupons shall be taken so that specimens shall have their longitudinal axes at a distance below the nearest heat treated surface, equivalent to at least the greatest distance that the indicated high tensile stress surface will be from the nearest surface during heat treatment, and with the midlength of the specimens a minimum of twice this distance from a second heat treated surface. In any case, the longitudinal axes of the specimens shall not be nearer than $\frac{3}{4}$ in. (19 mm) to any heat treated surface and the midlength of the specimens shall be at least $1\frac{1}{2}$ in. (38 mm) from any heat treated surface.

NC-2223.4 Coupons From Separately Produced Test Forgings.

Test coupons representing forgings from one heat and one heat treatment lot may be taken from a separately forged piece under the conditions given in (a) through (e) below.

(a) The separate test forging shall be of the same heat of material and shall be subjected to substantially the same reduction and working as the production forging it represents.

(b) The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forging.

(c) The separate test forging shall be of the same nominal thickness as the production forging.

(d) Test coupons for simple forgings shall be taken so that specimens shall have their longitudinal axes at the region midway between midthickness and the surface and with the midlength of the specimens no nearer any heat treated edge than a distance equal to the forging thickness, except when the thickness-length ratio of the production forging does not permit, in which case a production forging shall be used as the test forging and the midlength of the specimens shall be at the midlength of the test forging.

(e) Test coupons for complex forgings shall be taken in accordance with NC-2223.3.

NC-2223.5 Test Specimens for Forgings.

When test specimens for forgings are to be taken under the

Page 18

applicable specification, the Inspector shall have the option of witnessing the selection, placing an identifying stamp on them, and witnessing the testing of these specimens.

NC-2224 Bars and Bolting Material

NC-2224.1 Bars With 2 in. (51 mm) Maximum Thickness.

For bars with diameters or thicknesses 2 in. (51 mm) or less, the coupons shall be taken so that specimens shall have

their longitudinal axes on a line representing the center of the thickness and with the midlength of the specimens at least one diameter or thickness from a heat treated end.

NC-2224.2 Bars With Thicknesses Exceeding 2 in. (51 mm).

For bars with diameters or thicknesses over 2 in. (51 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside or rolled surface and with the midlength of the specimens at least t from a heat treated end, where t is either the bar diameter or thickness.

NC-2224.3 Bolting Material.

For bolting material, the coupons shall be taken in conformance with the applicable material specification and with the midlength of the specimen at least one diameter or thickness from a heat treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

NC-2225 Tubular Products

NC-2225.1 Tubular Products With 2 in. (51 mm) Maximum Thickness.

For tubular products with 2 in. (51 mm) maximum wall thickness, the coupons shall be taken so that specimens shall have their longitudinal axes on a surface midway between the outside and inside surfaces and with the midlength of the specimens at least one wall thickness from a heat treated end.

NC-2225.2 Tubular Products Exceeding 2 in. (51 mm) Nominal Thickness.

For tubular products with nominal wall thicknesses exceeding 2 in. (51 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside surface and with the midlength of the specimens at least one wall thickness from a heat treated end.

NC-2225.3 Separately Produced Coupons Representing Fittings.

Separately produced test coupons representing fittings may be used. When separately produced coupons are used, the requirements of NC-2223.4 shall be met.

NC-2226 Tensile Test Specimen Location (for Quenched and Tempered Ferritic Steel Castings)

NOTE: Users of this requirement should note that the hardenability of some grades may limit the usable section size.

(a) This section applies only to quenched-and-tempered ferritic steel castings with a thickness t exceeding 2 in. Where t is the thickness of the pressure retaining wall of the casting excluding flanges and sections designated by the designer as nonpressure-retaining. The order, inquiry, and drawing shall designate what the thickness t is for the casting.

(b) One of the following shall apply.

(1) The longitudinal centering of the thickness of the tension test specimen shall be taken at least $\frac{1}{4}t$ from the t dimension surface. For cylindrical castings, the longitudinal center line of the specimens shall be taken at least $\frac{1}{4}t$ from the outside or inside surface, and the gage length at least t from the as-heat treated end.

(2) Where separately cast test coupons are used, their dimensions shall be not less than $3t \times 3t \times T$, and each specimen cut from it shall meet the requirements of (b). The test coupon shall be of the same heat of steel and shall receive substantially the same casting practices as the production casting it represents. (Centrifugal castings may be represented by statically cast coupons.) The test coupon shall be heat treated under the same conditions as the production casting(s). The t dimension of the test coupon shall be the same maximum thickness t as defined in (a) above. Where separate test blocks require reheat treatment, thermal buffers in accordance with (b) may be used.

(3) Where specimens are to be removed from the body of the casting, a steel, thermal buffer pad $1t \times 1t \times$ at least $3t$ shall

be joined to the casting surface by a partial penetration weld completely sealing the buffered surface prior to the heat treatment process. The test specimens shall be removed from the casting in a location adjacent to the center third of the buffer pad. They shall be located at a minimum distance of $\frac{1}{2}$ in. from the buffered surface and $\frac{1}{4}$ in. from the other heat treated surfaces.

(4) Where specimens are to be removed from the body of the casting, thermal insulation or other thermal barriers shall be used during the heat treatment process

Page 19

adjacent to the casting edge where specimens are to be removed. It shall be demonstrated that the cooling rate of the test specimen is no faster than that of specimens taken by the method described in (b)(1). This information shall be included in the test reports.

(5) Where castings are cast or machined to essentially the finished product configuration prior to heat treatment, the test specimens shall be removed from a casting prolongation or other stock on the product at a location below the nearest heat treated surface indicated on the order. The specimens shall be located with their longitudinal axes a distance below the nearest heat treated surface equivalent to at least the greatest distance that the indicated high tensile stress surface will be from the nearest heat treated surface, and with their midlength a minimum of twice this distance from a second heat treated surface. In any case, the longitudinal axes of the test specimens shall be no nearer than $\frac{1}{4}$ in. (6 mm) to a heat treated surface and the midlength shall be at least $1\frac{1}{2}$ in. (38 mm) from a second heat treated surface. The component manufacturer shall specify the surfaces of the finished product subjected to high tensile stress in service.

NC-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL

NC-2310 MATERIAL TO BE IMPACT TESTED

NC-2311 Material for Which Impact Testing Is Required

(a) Pressure retaining material shall be impact tested in accordance with the requirements of NC-2330, except that impact testing of materials described in (1) through (9) below is not a requirement of this Subsection:

(1) material with a nominal section thickness of $\frac{5}{8}$ in. (16 mm) and less where thicknesses shall be taken as defined in (a) through (e) below:

(a) for pumps, valves, and fittings, use the largest nominal pipe wall thickness of the connecting pipes;

(b) for vessels and tanks, use the nominal thickness of the shell or head, as applicable;

(c) for nozzles or parts welded to vessels, use the lesser of the vessel shell thickness to which the item is welded or the maximum radial thickness of the item exclusive of integral shell butt welding projections;

(d) for flat heads, tubesheets, or flanges, use the maximum shell thickness associated with the butt welding hub;

(e) for integral fittings used to attach process piping to the containment vessel (Fig. NE-1120-1), use the larger nominal thickness of the pipe connections.

(2) bolting, including studs, nuts, and bolts, with a nominal size of 1 in. (25 mm) or less;

(3) bar with a nominal cross-sectional area which does not exceed 1 sq in. (645 mm²);

(4) all thicknesses of material for pipe, tube, fittings, pumps, and valves with a nominal pipe size 6 in. (152 mm) diameter and smaller;

(5) material for pumps, valves, and fittings with all pipe connections of $\frac{5}{8}$ in. (16 mm) nominal wall thickness and less;

(6) austenitic stainless steels;

(7) nonferrous materials;

(8) materials listed in Table NC-2311(a)-1 for which the listed value of T_{NDT}^3 is lower than the Lowest Service Temperature⁴ (LST) by an amount established by the rules in Appendix R. This exemption does not exempt either the weld metal (NC-2430) or the welding procedure qualification (NC-4335) from impact testing.

- (9) materials for components for which the Lowest Service Temperature exceeds 150°F (66°C).
- (b) The Design Specification shall state the Lowest Service Temperature for the component.
- (c) Drop weight tests are not required for the martensitic high alloy chromium (Series 4XX) steels and precipitation-hardening steels listed in Section II, Part D, Subpart 1, Table 1A. The other requirements of NC-2331 and NC-2332 apply for these steels. For nominal wall thicknesses greater than 2½ in. (64 mm), the required C_v values shall be 40 mils lateral expansion.

NC-2320 IMPACT TEST PROCEDURES

NC-2321 Types of Tests

NC-2321.1 Drop Weight Tests.

The drop weight test, when required, shall be performed in accordance with ASTM E 208-91. Specimen types P-1, P-2, or P-3 may be used. When drop weight tests are performed to meet the requirements of NC-2300, the test temperature and the results shall be reported on the Certified Material Test Report.

³ T_{NDT} - temperature at or above the nil-ductility transition temperature NDT (ASTM E 208-85); T_{NDT} is 10°F below the temperature at which at least two specimens show no-break performance.

⁴ Lowest Service Temperature (LST) is the minimum temperature of the fluid retained by the component or, alternatively, the calculated minimum metal temperature whenever the pressure within the component exceeds 20% of the preoperational system hydrostatic test pressure.

Page 20

**TABLE NC-2311(a)-1
EXEMPTIONS FROM IMPACT TESTING
UNDER NC-2311(a)(8)**

Material [Note (1)]	Material Condition [Note (2)]	T_{NDT} , °F [Notes (3), (4)]
SA-537, Class 1	N	-30
SA-516, Grade 70	Q & T	-10
SA-516, Grade 70	N	0
SA-508, Class 1	Q & T	+10
SA-533, Grade B	Q & T	+10
SA-299 [Note (5)]	N	+20
SA-216, Grades WCB, WCC	Q & T	+30
SA-36 (Plate)	HR	+40
SA-508, Class 2	Q & T	+40

NOTES:

- (1) These materials are exempt from toughness testing when LST- T_{NDT} is satisfied in accordance with the rules established in Appendix R.
- (2) Material Condition letters refer to:
N – normalize
Q & T – quench and temper
HR – hot rolled
- (3) These values for T_{NDT} were established from data on heavy section steel (thickness greater than 2½ in.). Values for sections less than 2½ in. thick are held constant until additional data are obtained.
- (4) T_{NDT} – temperature at or above nil-ductility transition temperature NDT (ASTM E 208-91); T_{NDT} is 10°F below the temperature at which at least two specimens show no-break performance.
- (5) Materials made to a fine grain melting practice.

TABLE NC-2311(a)-1 EXEMPTIONS FROM IMPACT TESTING UNDER NC-2311(a)(8)

NC-2321.2 Charpy V-Notch Tests.

The Charpy V-notch test (C_V), when required, shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Fig. 11, Type A. A test shall consist of a set of three full-size 10 mm × 10 mm specimens. The lateral expansion and absorbed energy, as applicable, and the test temperature, as well as the orientation and location of all tests performed to meet the requirements of NC-2330 shall be reported in the Certified Material Test Report.

NC-2322 Test Specimens

NC-2322.1 Location of Test Specimens.

Impact test specimens shall be removed from a depth within the material that is at least as far from the material surface as that specified for tensile test specimens in the material specification. For bolting, the C_V impact test specimens shall be taken with the longitudinal axis of the specimen located at least one-half radius or 1 in. (25 mm) below the surface plus the machining allowance per side, whichever is less. The fracture plane of the specimen shall be at least one diameter or thickness from the heat treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

NC-2322.2 Orientation of Impact Test Specimens

(a) Specimens for C_V impact tests shall be oriented as required in NC-2200 for the tensile test specimen or, alternatively, the orientation may be in the direction of maximum stress. The notch of the C_V specimen shall be normal to the surface of the material.

(b) Specimens for drop weight tests may have their axes oriented in any direction.

NC-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS

NC-2331 Pressure Retaining Material Test Methods and Temperature

(a) Pressure retaining material shall be impact tested in accordance with one of the test methods indicated below:

(1) Charpy V-notch testing at or below the Lowest Service Metal Temperature⁵⁶

(2) drop weight testing to show that the Lowest Service Metal Temperature⁵ ($LST - T_{NDT}^3$) is satisfied in accordance with the rules established in Appendix R.

NC-2332 Specific Test Methods and Acceptance Standards for Pressure Retaining Material for Tests Based on Lowest Service Metal Temperatures

5 The Lowest Service Metal Temperature shall be the lowest temperature which the metal may experience in service while the plant is in operation and shall be established by appropriate calculations based on atmospheric ambient conditions, the insulation or enclosure provided, and the minimum temperature which will be maintained inside the vessel during the plant operation.

6 The requirements for impact testing of the heat affected zone (NC-4335.2) may result in reduced impact test temperatures for the base material.

7 For pumps, valves, and fittings, use the nominal pipe wall thickness of the connecting pipe. For vessels use the lesser of:

(a) the maximum radial thickness of the item, exclusive of integral butt welded projections;

(b) the vessel shell thickness to which the item is welded;

(c) the maximum shell thickness associated with the item for flat heads, tubesheets, or flanges.

NC-2332.1 Pressure Retaining Material Other Than Bolting With 2½ in. (64 mm) Maximum Thickness.⁷

Except as limited in NC-4335, apply one of the methods of NC-2331(a) to test: base material; the base

material, the heat affected zone, and weld metal for the weld procedure qualification tests of NC-4335; and the weld metal for NC-2431. The impact test results shall meet one of the acceptance standards applicable to the specified test method.

TABLE NC-2332.1-1
REQUIRED C_v LATERAL EXPANSION VALUES^{1,2} FOR
PRESSURE RETAINING MATERIAL OTHER THAN
BOLTING

Nominal Wall Thickness, in. [Note (3)]	Lateral Expansion, mils	
	Average of 3	Lowest 1 of 3
$\frac{5}{8}$ in. or less [Note (4)]	...	...
Over $\frac{5}{8}$ in. to 1 in., incl.	20	15
Over 1 in. to $1\frac{1}{2}$ in., incl.	25	20
Over $1\frac{1}{2}$ in. to $2\frac{1}{2}$ in., incl.	35	30
Over $2\frac{1}{2}$ in. [Note (5)]	45	40

NOTES:

- (1) Where weld metal tests of NC-2400 are made to these requirements, the impact lateral expansion shall conform to the requirements of either of the base materials being joined.
- (2) Where two base materials having different required lateral expansion values are joined, the weld metal lateral expansion requirements of NC-4330 shall conform to the requirements of either of the base materials.
- (3) For pumps, valves, and fittings, use the nominal pipe wall thickness of the connecting pipe. For vessels use the least of:
 - (a) the maximum radial thickness of the item exclusive of integral butt welded projections;
 - (b) the vessel shell thickness to which the item is welded;
 - (c) the maximum shell thickness associated with the item for flat heads, tubesheets, or flanges.
- (4) No test required.
- (5) For use with NC-2332.2(b).

TABLE NC-2332.1-1 REQUIRED C_V LATERAL EXPANSION VALUES^{1,2} FOR PRESSURE RETAINING MATERIAL OTHER THAN BOLTING

(a) *Charpy V-Notch Testing for Lateral Expansion Values.* The test results of the three specimens, collectively and singly, shall meet the respective requirements of Table NC-2332.1-1.

(b) *Charpy V-Notch Testing for Absorbed Energy Values.* The test results of the three specimens, collectively and singly, shall meet the respective requirements of Table NC-2332.1-2.

(c) *Drop Weight Testing.* An acceptance test shall consist of at least two no-break specimens as described in ASTM E 208-85.

NC-2332.2 Pressure Retaining Material Other Than Bolting With Thickness ⁷ Exceeding 2½ in.(64 mm)

(a) The base material, and the weld procedure qualification weld metal tests of NC-4335, shall be tested by the drop weight method as specified in NC-2321.1 and NC-2331(a)(2).

(b) Except as limited in NC-4335, apply one of the methods of NC-2331(a) to test: the base material and the heat affected zone of the weld procedure qualification tests for NC-4335; and the weld metal for NC-2431.

(c) The acceptance standards shall be as given in NC-2332.1(a), (b), or (c), as applicable.

NC-2332.3 Bolting Material.

For bolting material, including nuts, studs, and bolts, a Charpy V-notch test shall be performed. The tests shall be performed at or below the Lowest Service Metal Temperature, and all three specimens shall meet the requirements of Table NC-2332.3-1.

NC-2340 NUMBER OF IMPACT TESTS REQUIRED

NC-2341 Plates

One test shall be made from each plate as heat treated. Where plates are furnished in the nonheattreated condition and qualified by heat treated test specimens, one test shall be made for each plate as rolled. The term *as-rolled* refers to the plate rolled from a slab or directly from an ingot, not to its heat treated condition.

NC-2342 Forgings and Castings

(a) Where an individual forging or casting is less than 1000 lb (454 kg), one test shall be made to represent each heat in each heat treatment charge.

(b) When heat treatment is performed in a continuous-type furnace with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a heat treatment charge shall be considered as the lesser of a continuous run not exceeding 8 hr duration or a total weight, so treated, not exceeding 2,000 lb (907 kg).

(c) One test shall be made for each forging or casting of 1,000 lb to 10,000 lb (454 kg to 4540 kg).

(d) As an alternative to NC-2342(c), a separate test forging or casting may be used to represent forgings or castings of different sizes in one heat and heat treat lot, provided the test piece is a representation of the greatest thickness in the heat treat lot. In addition, test forgings shall have been subjected to substantially the same reduction and working as the forgings represented.

**TABLE NC-2332.1-2
REQUIRED C_v ENERGY VALUES¹ FOR PRESSURE RETAINING MATERIAL
OTHER THAN BOLTING**

Nominal Wall Thickness, in. [Note (3)]	Energy, ft-lb for Base [Note (2)] Materials of Specified Minimum Yield Strength, ksi					
	55 ksi or below		Over 55 ksi to 75 ksi, incl.		Over 75 ksi to 105 ksi, incl.	
	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3
5/8 in. or less [Note (4)]	...	...	...	...	...	...
Over 5/8 in. to 1 in., incl.	20	15	25	20	30	25
Over 1 in. to 1 1/2 in., incl.	25	20	30	25	35	30
Over 1 1/2 in. to 2 1/2 in., incl.	35	30	40	35	45	40
Over 2 1/2 in. [Note (5)]	45	40	50	45	55	50

NOTES:

- (1) Where weld metal tests of NC-2400 are made to these requirements, the impact energy shall conform to the requirements of either of the base materials being joined.
- (2) Where two base materials having different required energy values are joined, the weld metal impact energy requirements of the procedure qualification tests of NC-4330 shall conform to the requirements of either of the base materials.
- (3) For pumps, valves, and fittings, use the nominal pipe wall thickness of the connecting pipe. For vessels use the least of:
 - (a) the maximum radial thickness of the item exclusive of integral butt welded projections;
 - (b) the vessel shell thickness to which the item is welded;
 - (c) the maximum shell thickness associated with the item for flat heads, tubesheets, or flanges.
- (4) No test required.
- (5) For use with NC-2332.2(b).

TABLE NC-2332.1-2 REQUIRED C_v ENERGY VALUES¹ FOR PRESSURE RETAINING MATERIAL OTHER THAN BOLTING

**TABLE NC-2332.3-1
REQUIRED C_v VALUES FOR BOLTING MATERIAL
TESTED IN ACCORDANCE WITH NC-2332.3**

Nominal Diameter, in.	Lateral Expansion, mils	Absorbed Energy, ft-lb
1 or less	No test required	No test required
Over 1 through 4	25	No requirements
Over 4	25	45

TABLE NC-2332.3-1 REQUIRED C_v VALUES FOR BOLTING MATERIAL TESTED IN ACCORDANCE WITH

NC-2332.3

(e) Forgings or castings larger than 10,000 lb (4540 kg) shall have two tests per part for Charpy V-notch and one test for drop weights. The location of drop weight or C_v test specimens shall be selected so that an equal number of specimens is obtained from positions in the forging or casting 180 deg. apart.

(f) As an alternative to NC-2342(e) for static castings, a separately cast coupon [NC-2226(b)(2)] may be used; one test shall be made for Charpy V-notch and one test for drop weight.

NC-2343 Bars

One test shall be made for each lot of bars with a cross-sectional area greater than 1 sq in. (645 mm²) where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed 6000 lb (2720 kg).

NC-2344 Tubular Products and Fittings

On products which are seamless or welded without filler metal, one test shall be made from each lot. On products which are welded with filler metal, one additional test with the specimens taken from the weld area shall also be made on each lot. A lot shall be defined as stated in the applicable material specification, but in no case shall a lot consist of products from more than one heat of material and of more than one diameter, with the nominal thickness of any product included not exceeding that to be impact tested by more than $\frac{1}{4}$ in. (6 mm); such a lot shall be in a single heat treatment load or in the same continuous run in a continuous furnace controlled within a 50°F (28°C) range and equipped with recording pyrometers.

NC-2345 Bolting Material

One test shall be made for each lot of material where a lot is defined as one heat of material heat treated

Page 23

in one charge or as one continuous operation, not to exceed the following:

$1\frac{3}{4}$ in. diameter and less	1,500 lb
Over $1\frac{3}{4}$ in. to $2\frac{1}{2}$ in. diameter	3,000 lb
Over $2\frac{1}{2}$ in. to 5 in. diameter	6,000 lb
Over 5 in. diameter	10,000 lb

NC-2350 RETESTS

NC-2351 Retests for Material Other Than Bolting

(a) For Charpy V-notch tests required by NC-2330, one retest at the same temperature may be conducted, provided:

(1) the average value of the test results meets the average of three requirements specified in Table NC-2332.1-1 or Table NC-2332.1-2, as applicable;

(2) not more than one specimen per test is below the lowest one of three requirements specified in Table NC-2332.1-1 or Table NC-2332.1-2, as applicable;

(3) the specimen not meeting the requirements is not lower than 5 ft-lb (6.8 J) or 5 mils (0.13 mm) below the lowest one of three requirements specified in Table NC-2332.1-1 or Table NC-2332.1-2, as applicable.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall be equal to or greater than the average of three requirements specified in Table NC-2332.1-1 or Table NC-2332.1-2, as applicable.

NC-2352 Retests for Bolting Material

(a) For Charpy V-notch tests required by NC-2330, one retest at the same temperature may be conducted, provided:

- (1) not more than one specimen per test is below the acceptance requirements;
 - (2) the specimen not meeting the acceptance requirements is not lower than 5 ft-lb (6.8 J) or 5 mils (0.13 mm) below the acceptance requirements.
- (b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall meet the specified acceptance requirements.

[98]

NC-2360 CALIBRATION OF INSTRUMENTS AND EQUIPMENT

Calibration of temperature instruments and C_v impact test machines used in impact testing shall be performed at the frequency specified in (a) or (b) below.

(a) Temperature instruments used to control test temperature of specimens shall be calibrated and the results recorded to meet the requirements of NCA-3868 at least once in each 3 month interval.

(b) C_v impact test machines shall be calibrated and the results recorded to meet the requirements of NCA-3868. The calibrations shall be performed at least once per year using methods outlined in ASTM E 23-72 and employing standard specimens obtained from the National Institute of Standards and Technology.

[98]

NC-2400 WELDING MATERIAL

NC-2410 GENERAL REQUIREMENTS

(a) All welding material used in the construction and repair of components or material, except welding material used for cladding or hard surfacing, shall conform to the requirements of the welding material specification or to the requirements for other welding material as permitted in Section IX. In addition, welding material shall conform to the requirements stated in this Subarticle and to the rules covering identification in NC-2150.

(b) The Certificate Holder shall provide the organization performing the testing with the information listed below, as applicable:

- (1) welding process;
- (2) SFA specification and classification;
- (3) other identification if no SFA specification applies;
- (4) minimum tensile strength [NC-2431.1(e)] in either the as-welded or heat treated condition, or both [NC-2431.1(c)];
- (5) drop weight test for material in either the as-welded or heat treated condition, or both (NC-2332);
- (6) Charpy V-notch test for material as-welded, or heat treated, or both (NC-2331); the test temperature and the lateral expansion or the absorbed energy shall be provided;
- (7) the preheat and interpass temperatures to be used during welding of the test coupon [NC-2431.1(c)];
- (8) postweld heat treatment time, temperature range, and maximum cooling rate, if the production weld will be heat treated [NC-2431.1(c)];
- (9) elements for which chemical analysis is required per the SFA specification or WPS, and NC-2432;
- (10) minimum delta ferrite (NC-2433).

Page 24

NC-2420 REQUIRED TESTS

The required tests shall be conducted for each lot of covered, flux cored, or fabricated electrodes; for each heat of bare electrodes, rod, or wire for use with the OFW, GMAW, GTAW, PAW, and EGW (electrogas welding) processes (Section

IX, QW-492); for each heat of consumable inserts; for each combination of heat of bare electrodes and lot of submerged arc flux; for each combination of lot of fabricated electrodes and lot of submerged arc flux; for each combination of heat of bare electrodes or lot of fabricated electrodes and dry blend of supplementary powdered filler metal and lot of submerged arc flux; or for each combination of heat of bare electrodes and lot of electroslag flux. Tests performed on welding material in the qualification of weld procedures will satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used, provided the tests required by NC-4000 and this Subarticle are made and the results conform to the requirements of this Article. The definitions in (a) through (h) below apply.

(a) A *dry batch of covering mixture* is defined as the quantity of dry covering ingredients mixed at one time in one mixing vessel; a dry batch may be used singly or may be subsequently subdivided into quantities to which the liquid binders may be added to produce a number of wet mixes.

(b) A *dry blend* is defined as one or more dry batches mixed in a mixing vessel and combined proportionately to produce a uniformity of mixed ingredients equal to that obtained by mixing the same total amount of dry ingredients at one time in one mixing vessel.

(c) A *wet mix* is defined as the combination of a dry batch (a) or dry blend (b) and liquid binder ingredients at one time in one mixing vessel.

(d) A *lot of covered, flux cored, or fabricated electrodes* is defined as the quantity of electrodes produced from the same combination of heat of metal and dry batch, dry blend, or chemically controlled mixes of flux or core materials. Alternatively, a lot of covered, flux cored, or fabricated electrodes may be considered one type and size of electrode, produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (453,600 kg), from chemically controlled tube, wire, or strip and a dry batch, a dry blend, or chemically controlled mixes of flux, provided each container of welding materials is coded for identification and traceable to the production period, the shift, line, and the analysis range of both the mix and the rod, tube, or strip used to make the electrode.

(1) *Chemically controlled tube, wire, or strip* is defined as consumable tube, wire, or strip material supplied on coils with a maximum of one splice per coil that has been chemically analyzed to assure that the material conforms to the electrode manufacturer's chemical control limits for the specific type of electrode. Both ends of each coil shall be chemically analyzed except that those coils which are splice free need only be analyzed on one end of the coil.

(2) *Chemically controlled mixes of flux* are defined as flux material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the electrode manufacturer's standard for each chemical element for that type electrode. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending.

(e) A *heat of bare electrode, rod, wire, or consumable insert* is defined as the material produced from the same melt of metal.

(f) Alternatively, for carbon and low alloy steel bare electrode, rod, wire, or consumable inserts for use with of SAW, OFW, GMAW, GTAW, PAW, and EGW processes, a heat may be defined as either the material produced from the same melt of metal or the material produced from one type and size of wire when produced in a continuous period (not to exceed 24 hr and not to exceed 100,000 lb) from chemically controlled wire, subject to requirements of (1), (2), and (3) below.

(1) For the chemical control of the product of the rod mill, coils shall be limited to a maximum of one splice prior to processing the wire. Chemical analysis shall be made from a sample taken from both ends of each coil of mill coiled rod furnished by mills permitting spliced coil practice of one splice maximum per coil. A chemical analysis need be taken from only one end of rod coils furnished by mills prohibiting spliced coil practice.

(2) Carbon, manganese, silicon, and other intentionally added elements shall be identified to ensure that the material conforms to the SFA or user's material specification.

(3) Each container of wire shall be coded for identification and traceability to the lot, production period, shift, line, and analysis of rod used to make the wire.

(g) A *lot of submerged arc or electroslag flux* is defined as the quantity of flux produced from the same combination of raw materials under one production schedule.

(h) A *dry blend of supplementary powdered filler metal* is defined as one or more mixes of material produced in a

and traceable to the production period, the shift, and the mixing vessel. A chemically controlled mix of powdered filler metal is defined as powdered filler metal material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the powdered filler metal manufacturer's standard, for each chemical element, for that type of powdered filler metal. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending. The chemical analysis range of the supplemental powdered filler shall be the same as that of the welding electrode, and the ratio of powder to electrode used to make the test coupon shall be the maximum permitted for production welding.

NC-2430 WELD METAL TESTS

NC-2431 Mechanical Properties Test

Tensile and impact tests shall be made in accordance with this paragraph, of welding materials which are used to join P-Nos. 1, 3, 4, 5, 6, 7, 9, and 11 base materials in any combination, with the exceptions listed in (a) through (d) below.

- (a) austenitic stainless steel and nonferrous welding material used to join the listed P-Numbers;
- (b) consumable inserts (backing filler material);
- (c) welding material used for GTAW root deposits with a maximum of two layers;
- (d) welding material to be used for the welding of base materials exempted from impact testing by NC-2311(a)(1) through (a)(7) or NC-2311(a)(9) shall also be exempted from the impact testing required by this paragraph.

NC-2431.1 General Test Requirements.

The welding test coupon shall be made in accordance with (a) through (f) below, using each process with which the weld material will be used in production welding.

- (a) Test coupons shall be of sufficient size and thickness such that the test specimens required herein can be removed.
- (b) The weld metal to be tested for all processes except electroslag welding shall be deposited in such a manner as to substantially eliminate the influence of the base material on the results of the tests. Weld metal to be used with the electroslag process shall be deposited in such a manner as to conform to one of the applicable Welding Procedure Specifications (WPS) for production welding, Section IX, QW-201.1. The base material shall conform to the requirements of Section IX, QW-403.1 or QW-403.4, as applicable.
- (c) The welding of the test coupon shall be performed within the range of preheat and interpass temperatures that will be used in production welding. Coupons shall be tested in the as-welded condition, or they shall be tested in the applicable postweld heat treated condition when the production welds are to be postweld heat treated. The postweld heat treatment holding time⁸ shall be at least 80% of the maximum time to be applied to the weld metal in production application. The total time for postweld heat treatment of the test coupon may be applied in one heating cycle. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the component. In addition, weld coupons for weld metal to be used with the electroslag process, which are tested in the as-welded condition or following a postweld heat treatment within the holding temperature ranges of Table NC-4622.1-1 or NC-4622.4(c)-1, shall have a thickness within the range of 0.5 to 1.1 times the thickness of the welds to be made in production. Electroslag weld coupons to be tested following a postweld heat treatment, which will include heating the coupon to a temperature above the Holding Temperature Range of Table NC-4622.1-1 for the type of material being tested, shall have a thickness within the range of 0.9 to 1.1 times the thickness of the welds to be made in production.
- (d) Regardless of the welding process or welding material being tested, the tensile specimens, and the C_v impact specimens when required, shall be located and prepared in accordance with the requirements of SFA-5.1, Specification for Mild Steel Covered Electrodes. Drop weight impact test specimens, where required, shall be oriented so that the longitudinal axis is transverse to the weld, with the notch in the weld face or in a plane parallel to the weld face. For impact specimen preparation and testing, the applicable parts of NC-2321.1 and NC-2321.2 shall apply. The longitudinal

axis of the specimen shall be at a minimum depth of $\frac{1}{4}t$ from a surface, where t is the thickness of the test weld.

(e) One all-weld-metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the base material specification. Where base materials of different specifications are to be welded, the tensile strength requirements shall conform to the specified minimum tensile strength requirement of either of the base material specifications.

8 Any postweld heat treatment time which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

Page 26

(f) Impact specimens of the weld metal shall be tested where impact tests are required for either of the base materials of the production weld. The weld metal shall conform to the parts of NC-2331 or NC-2332 applicable to the base material. Where different requirements exist for the two base materials, the weld metal may conform to either of the requirements for either base material.

NC-2431.2 Standard Test Requirements.

In lieu of the use of the General Test Requirements specified in NC-2431.1, tensile and impact tests may be made in accordance with this subparagraph where they are required for mild and low alloy steel covered electrodes. The material combinations to require weld material testing, as listed in NC-2431, shall apply for this option. The limitations and testing under this option shall be in accordance with (a) through (f) below.

(a) Testing to the requirements of this subparagraph shall be limited to electrode classifications included in SFA-5.1 or SFA-5.5.

(b) The assembly required by SFA-5.1 or SFA-5.5, as applicable, shall be used for test coupon preparation, except that it shall be increased in size to obtain the number of impact specimens required by NC-2331 or NC-2332, as applicable.

(c) The welding of the test coupon shall conform to the requirements of the SFA specification for the classification of electrode being tested. Coupons shall be tested in the as-welded condition and also the postweld heat treated condition. The postweld heat treatment temperatures shall be in accordance with Table NC-4622.1-1 for the applicable P-Number equivalent. The time at postweld heat treatment temperature shall be 8 hr (this qualifies postweld heat treatments of 10 hr or less). When the postweld heat treatment of the production weld exceeds 10 hr or the PWHT temperature is other than that required, the general test of NC-2431.1 shall be used.

(d) The tensile and C_v specimens shall be located and prepared in accordance with the requirements of SFA-5.1 or SFA-5.5, as applicable. Drop weight impact test specimens, where required, shall be located and oriented as specified in NC-2431.1(d).

(e) One all-weld-metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirement of the SFA specification for the applicable electrode classification.

(f) The requirements of NC-2431.1(f) shall be applicable to the impact testing.

**TABLE NC-2432.1-1
SAMPLING OF WELDING MATERIALS FOR
CHEMICAL ANALYSIS**

	GTAW/PAW	GMAW	All other Processes
A-No. 8 filler metal	Filler metal or weld deposit	Weld deposit	Weld deposit
All other filler metal	Filler metal or weld deposit	Filler metal or weld deposit	Weld deposit

TABLE NC-2432.1-1 SAMPLING OF WELDING MATERIALS FOR CHEMICAL ANALYSIS

NC-2432 Chemical Analysis Test

Chemical analysis of filler metal or weld deposits shall be made in accordance with NC-2420 and as required by the following subparagraphs.

NC-2432.1 Test Method.

The chemical analysis test shall be performed in accordance with this subparagraph and Table NC-2432.1-1, and the results shall conform to NC-2432.2.

(a) A-No. 8 welding material to be used with GTAW and PAW processes and any other welding material to be used with any GTAW, PAW, or GMAW process shall have chemical analysis performed either on the filler metal or on a weld deposit made with the filler metal in accordance with (c) or (d) below.

(b) A-No. 8 welding material to be used with other than the GTAW and PAW processes and other welding material to be used with other than the GTAW, PAW, or GMAW process shall have chemical analysis performed on a weld deposit of the material or combination of materials being certified in accordance with (c) or (d) below. The removal of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c) below. As an alternative, the deposit shall be made in accordance with (d) below for material that will be used for corrosion resistant overlay cladding. Where the Welding Procedure Specification or the welding material specification specifies percentage composition limits for analysis, it shall state that the specified limits apply for the filler metal analysis, the undiluted weld deposit analysis, or the *in situ* cladding deposit analysis in conformance with the above required certification testing.

(c) The preparation of samples for chemical analysis of undiluted weld deposits shall comply with the method given in

specification, the sample shall be removed from a weld pad, groove, or other test weld⁹ made using the welding process that will be followed when the welding material or combination of welding materials being certified is consumed. The weld for A-No. 8 material to be used with the GMAW or EGW process shall be made using the shielding gas composition specified in the Welding Procedure Specifications that will be followed when the material is consumed. The test sample for ESW shall be removed from the weld metal of the mechanical properties test coupon. Where a chemical analysis is required for a welding material which does not have a mechanical properties test requirement, a chemical analysis test coupon shall be prepared as required by NC-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of NC-2431.1(c) do not apply.

(d) The alternate method provided in (b) above for the preparation of samples for chemical analysis of welding material to be used for corrosion resistant overlay cladding shall require a test weld made in accordance with the essential variables of the welding procedure specification that will be followed when the welding material is consumed. The test weld shall be made in conformance with the requirements of Section IX, QW-214.1. The removal of chemical analysis samples shall conform to QW-214.3 for the minimum thickness for which the Welding Procedure Specification is qualified.

NC-2432.2 Requirements for Chemical Analysis.

The chemical elements to be determined, the composition requirements of the weld metal, and the recording of results of the chemical analysis shall be in accordance with (a), (b), and (c) below.

(a) Welding material of ferrous alloy A-No. 8 (Section IX, QW-442) shall be analyzed for the elements listed in Table NC-2432.2-1 and for any other elements specified either in the welding material specification referenced by the Welding Procedure Specification or in the Welding Procedure Specification.

⁹ The methods given in the Appendix of SFA 5.9, Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Rods and Bare Electrodes, shall be used to establish a welding and sampling method for the pad, groove, or other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution.

(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition limits. Where the Welding Procedure Specification contains a modification of the composition limits of SFA or other referenced welding material specifications, or provides limits for additional elements, these composition limits of the Welding Procedure Specification shall apply for acceptability.

TABLE NC-2432.2-1 WELDING MATERIAL CHEMICAL ANALYSIS

Cr-Ni stainless materials	C, Cr, Mo, Ni, Mn, Si, Cb
------------------------------	------------------------------

TABLE NC-2432.2-1 WELDING MATERIAL CHEMICAL ANALYSIS

(c) The results of the chemical analysis shall be reported in accordance with NCA-3867. Elements listed in Table NC-2432.2-1 but not specified in the welding material specification or Welding Procedure Specification shall be reported for information only.

NC-2433 Delta Ferrite Determination

A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, QW-442) backing filler metal (consumable inserts); bare electrode, rod, or wire filler metal; or weld metal, except that delta ferrite determinations are not required for SFA-5.4 Type 16-8-2 or A-No. 8 weld filler metal to be used for weld metal cladding.

NC-2433.1 Method.

Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of the chemical analysis of NC-2432 in conjunction with Fig. NC-2433.1-1.

(a) Calibration of magnetic instruments shall conform to AWS-A 4.2-91.

(b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with NC-2432.1(c).

(c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number.

NC-2433.2 Acceptance Standards.

The minimum acceptable delta ferrite shall be 5FN (Ferrite Number). The results of the delta ferrite determination shall be included in the Certified Material Test Report of NC-2130 or NC-4120.

Page 28

Page 29

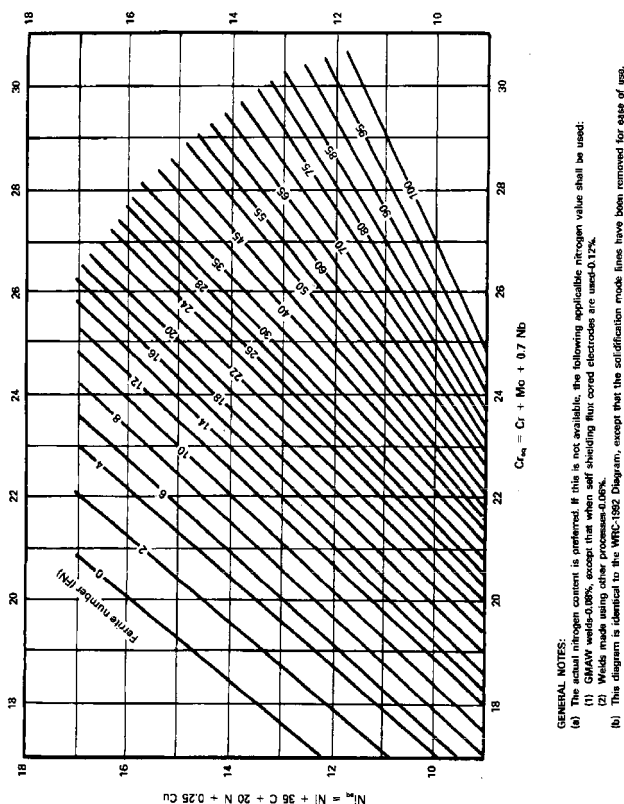


FIG. NC-2433.1-1 WELD METAL DELTA FERRITE CONTENT

FIG. NC-2433.1-1 WELD METAL DELTA FERRITE CONTENT

NC-2440 STORAGE AND HANDLING OF WELDING MATERIAL

Suitable storage and handling of electrodes, flux, and other welding materials shall be maintained. Precautions shall be taken to minimize absorption of moisture by fluxes and cored, fabricated, and coated electrodes.

NC-2500 EXAMINATION AND REPAIR OF PRESSURE RETAINING MATERIAL

NC-2510 PRESSURE RETAINING MATERIAL

Pressure retaining material shall be examined and repaired in accordance with the material specification and as otherwise required by this Subarticle. Pressure retaining material for ASME B16.34 Special Class category valves (NC-3513) shall be examined and repaired in accordance with the requirements therein and as otherwise required by this Subarticle. If the examination and repair requirements of this Subarticle either duplicate or exceed the ASME B16.34 requirements, then only the requirements of this Subarticle need to be met. Size exclusions or quality factor pressure ratings of this Subarticle shall not be applied so as to reduce the examination requirements of ASME B16.34 for Special Class category valves.

NC-2530 EXAMINATION AND REPAIR OF PLATE

NC-2531 Required Examination

Plates shall be examined in accordance with the requirements of the material specification.

NC-2537 Time of Examination

Acceptance examinations shall be performed at the time of manufacture as required in (a) through (c) below.

(a) Examinations required by the material specification shall be performed at the time of manufacture as specified in the material specification.

(b) Radiographic examination of repair welds, when required, may be performed prior to any required postweld heat treatment.

(c) Magnetic particle or liquid penetrant examination of repair welds shall be performed after any required postweld heat treatment, except for P-No. 1 material, which may be examined before or after any required postweld heat treatment.

NC-2538 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) and (b) below are met:

(a) the depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) When the elimination of the defect reduces the thickness of the section below the minimum required by the design, the material shall be repaired in accordance with NC-2539.

NC-2539 Repair by Welding

The Material Manufacturer may repair by welding materials from which defects have been removed, provided the depth of the repair cavity does not exceed one-third of the nominal thickness and the requirements of the following subparagraphs are met. Prior approval of the Certificate Holder shall be obtained for the repair of plates to be used in the manufacture of vessels.

NC-2539.1 Defect Removal.

The defect shall be removed or reduced to an imperfection of acceptable limit by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair (NC-4211.1).

NC-2539.2

The welding procedure and welders or welding operators shall be qualified in accordance with NC-4000 and Section IX.

NC-2539.3 Blending of Repaired Areas.

After repair, the surface shall be blended uniformly into the surrounding surface.

NC-2539.4 Examination of Repair Welds.

Each repair weld shall be examined by the magnetic particle method (NC-2545) or by the liquid penetrant method (NC-2546). In addition, when the depth of the repair cavity exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness, the repair weld shall be radiographed in accordance with and to the applicable acceptance standards of NC-5320. The penetrometer shall be based upon the section thickness of the repaired area.

NC-2539.5 Heat Treatment After Repairs.

The product shall be heat treated after repair in accordance with the requirements of NC-4620.

NC-2539.6 Material Report Describing Defects and Repair.

Each defect repair that is required to be radiographed

Page 30

shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart which shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and a report of the results of the examinations, including radiographic film.

NC-2540 EXAMINATION AND REPAIR OF FORGINGS AND BARS

NC-2541 Required Examinations

Forgings and bars shall be examined in accordance with the requirements of the material specification, except when magnetic particle or liquid penetrant examination is specifically required by the rules of this Subsection, in which case the examination shall conform to the requirements of NC-2545 or NC-2546, as applicable.

NC-2545 Magnetic Particle Examination

NC-2545.1 Examination Procedure.

The procedure for magnetic particle examination shall be in accordance with the methods of Section V, Article 7.

NC-2545.2 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication in excess of the NC-2545.3 acceptance standards which is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are those which result from imperfections. Linear indications are those indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width. Indications resulting from nonmetallic inclusions are not considered relevant indications.

NC-2545.3 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for material less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for material 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 sq in. (3871 mm²) of area whose major dimension is no more than 6 in. (152 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

NC-2546 Liquid Penetrant Examinations

NC-2546.1 Examination Procedure.

The procedure for liquid penetrant examination shall be in accordance with the methods of Section V, Article 6.

NC-2546.2 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities, such as may occur from machining marks or surface conditions, may produce similar indications which are not relevant.

(b) Any indication in excess of the NC-2546.3 acceptance standards, which is believed to be nonrelevant, shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are those which result from imperfections. Linear indications are those indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NC-2546.3 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for material less than $\frac{5}{8}$ in. (16 mm) thick,

greater than $\frac{1}{8}$ in. (3.2 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for material 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 sq in. (3871 mm²) of area whose major dimension is no more than 6 in. (152 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

NC-2547 Time of Examination

The requirements for time of examination shall be the same as stated in NC-2537.

NC-2548 Elimination of Surface Defects

Elimination of surface defects shall be made in accordance with NC-2538.

NC-2549 Repair by Welding

Repair by welding shall be performed in accordance with NC-2539, except that the depth of repair that is permitted is not limited.

NC-2550 EXAMINATION AND REPAIR OF SEAMLESS AND WELDED (WITHOUT FILLER METAL) TUBULAR PRODUCTS AND FITTINGS

NC-2551 Required Examination

(a) Wrought seamless tubular products and fittings shall comply with the requirements of NC-2557, NC-2558, and NC-2559, in addition to the basic material specification.

(b) Welded (without filler metal) tubular products, except copper and nickel alloy pipe and tubing, shall comply with the requirements of NC-2557, NC-2558, and NC-2559; in addition, the welds shall be examined by one of the following methods:

- (1) ultrasonic examination in accordance with NC-2552;
- (2) eddy current examination in accordance with NC-2554;
- (3) radiographic examination in accordance with NC-2553.

(c) Copper alloy and nickel alloy seamless pipe and tubing shall comply with the requirements of NC-2558, in addition to the basic material specification.

NC-2552 Ultrasonic Examination¹⁰

NC-2552.1 Examination Procedure for Welds in Pipe and Tubing

(a) *Circumferential Direction - $6\frac{3}{4}$ in. (171 mm) O.D. and Smaller.* The welds in pipe and tubing shall be examined in two circumferential directions. The procedure for ultrasonic examination of pipe and tubing in the circumferential direction shall be in accordance with ASTM E 213-79, Standard Method for Ultrasonic Examination of Pipe and Tubing for Longitudinal Discontinuities, and the requirements of this paragraph. The procedure shall provide a sensitivity which will consistently detect defects that produce indications equal to or greater than the indications produced by standard defects included in the reference specimens specified in NC-2552.3.

(b) *Pipe and Tubing Larger Than $6\frac{3}{4}$ in. (171 mm) O.D.* The welds in pipe and tubing shall be examined in two circumferential directions. The procedure for ultrasonic examination of pipe and tubing larger than $6\frac{3}{4}$ in. (171 mm) O.D. shall be in accordance either with the requirements of SA-388 for angle beam scanning in the circumferential direction, or with the requirements of ASTM E 213-79. The reference standard shall be in accordance with NC-2552.3 below.

(c) *Acceptance Standard.* Products with defects that produce indications in excess of the indications produced by the standard defects in the reference specimen are unacceptable unless the defects are eliminated or repaired in accordance with NC-2558 or NC-2559.

NC-2552.2 Examination Procedure for Welds in Fittings

(a) *Procedure.* The procedure for ultrasonic examination of welds in fittings shall be in accordance with the requirements of Recommended Practice SA-388 for angle beam examination in two circumferential directions.

(b) *Acceptance Standard.* Fittings shall be unacceptable if angle beam examination results show one or more reflectors which produce indications exceeding in amplitude the indications from the calibrated notch.

NC-2552.3 Reference Specimens

(a) The reference specimen shall be of the same nominal diameter and thickness and of the same nominal composition and heat treated condition as the product which is being examined. For circumferential scanning, the standard defects shall be axial notches or grooves on the outside and inside surfaces of the reference specimen and shall have a length of approximately 1 in. (25 mm) or less, a width not to exceed $\frac{1}{16}$ in. (1.6 mm) for a square notch or U-notch, a width proportional to the depth for a V-notch, and a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the nominal wall thickness.

(b) The reference specimen shall be long enough to simulate the handling of the product being examined through the examination equipment. When more than one standard defect is placed in a reference specimen, the defects shall be located so that indications from each defect are separate and distinct without mutual interference or amplification. All upset metal and burrs adjacent to the reference notches shall be removed.

NC-2552.4 Checking and Calibration of Equipment.

The proper functioning of the examination equipment shall be checked, and the equipment shall be calibrated by the use of the reference specimens, as a minimum:

- (a) at the beginning of each production run of a given size and thickness of a given material;
- (b) after each 4 hr or less during the production run;
- (c) at the end of the production run;
- (d) at any time that malfunctioning is suspected.

If, during any check, it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid equipment calibration shall be reexamined.

NC-2553 Radiographic Examination

(a) *General.* When radiographic examination is performed as an alternative to ultrasonic examination of the entire volume of the material, it shall apply to the entire volume of the pipe, tube, or fitting material. Acceptance standards specified for welds shall apply to the entire volume of material examined.

(b) *Examination Procedure.* The radiographic examination shall be performed in accordance with Article 2 of Section V, as modified by NC-5111.

(c) *Acceptance Standard.* Welds that are shown by radiography to have any of the following types of discontinuities are unacceptable:

- (1) any type of crack or zone of incomplete fusion or penetration;
- (2) any other elongated indication which has a length greater than:
 - (a) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive
 - (b) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (57 mm), inclusive
 - (c) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm)

where t is the thickness of the thinner portion of the weld;

- (3) any group of aligned indications having an aggregate length greater than t in a length of $12t$, unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication;

(4) rounded indications in excess of that shown as acceptable in Appendix VI.

NC-2554 Eddy Current Examination

This examination method is restricted to materials with uniform magnetic properties and of sizes for which meaningful results can be obtained.

NC-2554.1 Examination Procedure.

The procedure for eddy current examination shall provide a sensitivity that will consistently detect defects by comparison with the standard defects included in the reference specimen specified in NC-2552.3. Products with defects that produce indications in excess of the reference standards are unacceptable unless the defects are eliminated or repaired in accordance with NC-2558 or NC-2559 as applicable.

NC-2554.2 Reference Specimens.

The reference specimen shall be of the same nominal diameter and thickness and of the same nominal composition and heat treated condition as the product that is being examined. The standard shall contain tangential or circumferential notches on the outside surface plus a $\frac{1}{16}$ in. (1.6 mm) diameter hole drilled through the wall. These shall be used to establish the rejection level for the product to be tested. The reference notches shall have a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the wall thickness. The width of the notch shall not exceed $\frac{1}{16}$ in. (1.6 mm). The length shall be approximately 1 in. (25 mm) or less. The size of reference specimens shall be as specified in NC-2552.3.

NC-2554.3 Checking and Calibration of Equipment.

The checking and calibration of examination equipment shall be the same as in NC-2552.4.

Page 33

NC-2557 Time of Examination

(a) Products that are quenched and tempered shall be examined, as required, after the quenching and tempering heat treatment.

(b) Products that are not quenched and tempered shall receive the required examinations as follows:

(1) ultrasonic or eddy current examination, when required, shall be performed after final heat treatment, except postweld heat treatment;

(2) radiographic examination, when required, may be performed prior to any required postweld heat treatment;

(3) magnetic particle or liquid penetrant examination of welds, including repair welds, shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment for P-No. 1 (Section IX of the Code) materials of 2 in. (51 mm) and less nominal thickness;

(4) forgings and rolled bars which are to be bored and/or turned to form tubular parts or fittings shall be examined after boring and/or turning, except for threading; fittings shall be examined after final forming;

(5) when surface examination is required, all external surfaces and all accessible internal surfaces shall be examined, except for bolt holes and threads.

NC-2558 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (c) below are met:

(a) the depression, after defect elimination, is blended uniformly into the surrounding surface;

(b) after defect elimination, the area is examined by the method which originally disclosed the defect to assure that the defect has been removed or reduced to an imperfection of acceptable size;

(c) if the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of

NC-3000, the product shall be repaired in accordance with NC-2559.

NC-2559 Repair by Welding

Repair of defects shall be in accordance with NC-2539, except repair by welding is not permitted on copper alloy and nickel alloy heat exchanger tubes.

NC-2560 EXAMINATION AND REPAIR OF TUBULAR PRODUCTS AND FITTINGS WELDED WITH FILLER METAL

NC-2561 Required Examination

(a) Welded (with filler metal) tubular products, such as pipe made in accordance with SA-358, SA-409, SA-671, SA-672, and SA-691 and fittings made in accordance with the WPW grades of SA-234, SA-403, and SA-420, which are made by welding with filler metal, shall be treated as material; however, inspection by an Inspector and stamping with an NPT symbol shall be in accordance with Section III requirements. In addition to the NPT symbol, a numeral 2 shall be stamped below and outside the official Code symbol.

(b) In addition to the requirements of the material specification and of this Article, all welds shall be examined 100% by radiography in accordance with the basic material specification. When radiographic examination is not specified in the basic material specification, the welds shall be examined in accordance with NC-2563.

(c) Tubular products and fittings which have been radiographed shall be marked to indicate that radiography has been performed. The radiographic film and a radiographic report showing film locations shall be provided with the Certified Material Test Report.

(d) The Authorized Inspector shall certify by signing the Partial Data Report Form NM-1 in accordance with NCA-5290.

NC-2563 Radiographic Examination

The radiographic examination shall be performed in accordance with the requirements of NC-2553.

NC-2567 Time of Examination

The time of examination shall be in accordance with the requirements of NC-2557.

NC-2568 Elimination of Surface Defects

Unacceptable surface defects shall be removed in accordance with the requirements of NC-2558.

NC-2569 Repair by Welding

When permitted by the basic material specification, base material defects shall be repair welded in accordance to the requirements of NC-2559. Repair welding

Page 34

of weld seam defects shall be in accordance with NC-4450.

NC-2570 EXAMINATION AND REPAIR OF STATICALLY AND CENTRIFUGALLY CAST PRODUCTS

In addition to the requirements of the material specification and of this Article NC-2000, statically and centrifugally cast products shall comply with the following paragraphs.

NC-2571 Required Examination

(a) Cast products shall be examined by volumetric and/or surface methods, including repairs, as required for the product form by Table NC-2571-1 Class 2 castings.

(b)

pressure ratings of Table NC-2571-2 shall be applied so as to reduce the required examinations of that Standard. The required examinations by ASME B16.34 for Special Class category valves shall be performed in accordance with the procedures and acceptance standards of this Subsection.

NC-2572 Time of Nondestructive Examination

NC-2572.1 Acceptance Examinations.

Acceptance examinations shall be performed at the time of manufacture as stipulated in the following and Table NC-2571-1.

(a) *Ultrasonic Examination.* Ultrasonic examination, if required, shall be performed at the same stage of manufacture as required for radiography.

(b) *Radiographic Examination.* Radiography may be performed prior to heat treatment and may be performed prior to or after finish machining at the following limiting thicknesses.

(1) For finished thicknesses under $2\frac{1}{2}$ in. (64 mm), castings shall be radiographed within 20% of the finished thickness when Type 2 radiographic film is used or within $\frac{1}{2}$ in. (13 mm) of the finished thickness when Type 1 radiographic film is used. The penetrometer and the acceptance reference radiographs shall be based on the finished thickness.

(2) For finished thickness from $2\frac{1}{2}$ in. (64 mm) up to 6 in. (152 mm), castings shall be radiographed within 20% of the finished thickness. The penetrometer and the acceptance reference radiographs shall be based on the finished thickness.

(3) For finished thicknesses over 6 in. (152 mm), castings shall be radiographed with $\frac{1}{2}$ in. (13 mm) or 15% of the finished thickness, whichever is greater. The penetrometer and the acceptance reference radiographs shall be based on the finished thickness.

(c) Radiography of castings for pumps and valves may be performed in as-cast or rough machined thickness exceeding the limits of NC-2572.1(b)(1), (b)(2), or (b)(3) subject to the following conditions.

(1) When the thickness of the as-cast or rough machined section exceeds 2 in. (51 mm) acceptance shall be based on reference radiographs for the next lesser thickness; e.g., if the section being radiographed exceeds $4\frac{1}{2}$ in. (114 mm), use reference radiographs of ASTM E 186-75 (reapproved 1979). The penetrometer shall be based on the thickness of the section being radiographed.

(2) When the thickness of the as-cast or rough machined section is 2 in. (51 mm) or less, the reference radiographs of ASTM E 446-78 shall be used, and the penetrometer shall be based on the final section thickness.

(3) Weld ends for a minimum distance of t or $\frac{1}{2}$ in. (13 mm), whichever is less (where t is the design section thickness of the weld), from the final welding end shall be radiographed at a thickness within the limits given in NC-2572.1 (b)(1), (b)(2), or (b)(3) as applicable. As an alternative, the weld ends may be radiographed in the as-cast or rough machined thickness in accordance with (c)(1) and (c)(2) above, and the penetrometer shall be based on the final section thickness.

(d) *Magnetic Particle or Liquid Penetrant Examination.* Magnetic particle or liquid penetrant examination shall be performed after the final heat treatment required by the material specification. Repair weld areas shall be examined after postweld heat treatment when a postweld heat treatment is performed, except that repair welds in P-No. 1 (see Section IX of the Code) material 2 in. (51 mm) nominal thickness and less may be examined prior to postweld heat treatment. For cast products with machined surfaces, all finished machine surfaces, except threaded surfaces and small deep holes, shall also be examined by magnetic particle or liquid penetrant methods.

NC-2573 Provisions for Repair of Base Material by Welding

The Material Manufacturer may repair, by welding, products from which defects have been removed, provided the requirements of this Article are met.

**TABLE NC-2571-1
REQUIRED EXAMINATIONS**

Nominal Pipe Size	Item	Applicable Special Requirements for Class 2 Castings
Inlet piping connections of 2 in. and less	Cast pipe fittings, pumps, and valves	None, except for ASME B16.34 Special Class category valves which shall be in accordance with NC-2571(b).
	Cast pressure retaining material other than pipe fittings, pumps, and valves	Cast pressure retaining materials shall be examined by either radiographic or ultrasonic methods, or a combination of the two methods. Castings or sections of castings, which have coarse grains or configurations which do not yield meaningful results by ultrasonic examination, shall be examined by radiographic methods (NC-2575).
	Repair welds in pumps and valves of P-No. 1 or P-No. 8 material	None
	Repair welds in cast pressure retaining material other than pumps and valves of P-No. 1 or P-No. 8 material	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, when radiography of the casting is required, repair welds in cavities, the depth of which exceeds the lesser of $\frac{3}{8}$ in. or 10% of the section thickness, shall be radiographed in accordance with NC-2575.
Inlet piping connections over 2 in. up to and including 4 in.	Cast pumps and valves with a quality factor of 1.00	Magnetic particle or liquid penetrant examination may be performed on all external surfaces and on all accessible internal surfaces, in lieu of volumetric examination, except the weld ends of cast pumps and valves shall be radiographed for a minimum distance of t (where t is the design section thickness of the weld) from the final weld end. For ASME B16.34 Special Class category valves, see NC-2571(b).
	Cast pumps and valves with a quality factor of 0.70	None
	Cast pressure retaining material other than cast pumps and valves	Cast pressure retaining materials shall be examined by either radiographic or ultrasonic methods, or a combination of the two methods. Castings or sections of castings, which have coarse grains or configurations which do not yield meaningful results by ultrasonic examination, shall be examined by radiographic methods.
	Repair welds in pumps and valves of P-No. 1 or P-No. 8 material with a quality factor of 0.70	None
	Repair welds in cast pressure retaining material other than pumps and valves of P-No. 1 or P-No. 8 material with a quality factor of 0.70	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, when radiography of the casting is required, repair welds in cavities, the depth of which exceeds the lesser of $\frac{3}{8}$ in. or 10% of the section thickness, shall be radiographed in accordance with NC-2474.
Inlet piping connections over 4 in.	Cast pressure retaining materials	Cast pressure retaining materials shall be examined by either radiographic or ultrasonic methods, or a combination of the two methods. Castings or sections of castings, which have coarse grains or configurations which do not yield meaningful results by ultrasonic examination, shall be examined by radiographic methods. For ASME B16.34 Special Class category valves, see NC-2571(b).
	Repair welds	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, when radiography of the casting is required, repair welds in cavities, the depth of which exceeds the less of $\frac{3}{8}$ in. or 10% of the section thickness, shall be radiographed in accordance with NC-2575.

TABLE NC-2571-1 REQUIRED EXAMINATIONS

NC-2573.1 Defect Removal.

The defects shall be removed or reduced to an imperfection of acceptable size by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair. When thermal cutting is performed, consideration shall be given to preheating the material.

NC-2573.2 Repair by Welding.

The Material Manufacturer may repair castings by welding after removing the material containing unacceptable defects. The depth of the repair is not limited. A cored hole or access hole may be closed by the Material Manufacturer by welding in accordance with the requirements of this subparagraph, provided the hole is closed by filler metal only. If the hole is closed by welding in a metal insert, the welding shall be performed by a holder of a Certificate of Authorization in accordance with the requirements of the Code.

NC-2573.3 Qualification of Welding Procedures and Welders.

Each manufacturer is responsible for the welding done by his organization and shall establish the procedures and conduct the tests required by NC-4000 and by Section IX of the Code in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures. He is also responsible for the welding performed by his subcontractors and shall assure himself that the subcontractors conduct the tests required by NC-4000 and by Section IX of the Code in order to qualify their welding procedures and the performance of their welders and welding operators.

NC-2573.4 Blending of Repaired Areas.

After repair, the surface shall be blended uniformly into the surrounding surface.

NC-2573.5 Examination of Repair Welds

(a) Each repair weld shall be examined by the magnetic particle method in accordance with the requirements of NC-2577, or by the liquid penetrant method in accordance with the requirements of NC-2576. In addition, when radiography is specified in the order for the original casting, repair cavities, the depth of which exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the nominal wall thickness, shall be radiographed after repair except that weld slag, including elongated slag, shall be considered as inclusions under Category B of the applicable reference radiographs. The total area of all inclusions, including slag inclusions, shall not exceed the limits of the applicable severity level of Category B of the reference radiographs. The penetrameter and the acceptance standards for radiographic examination of repair welds shall be based on the actual section thickness at the repair area.

(b) Examination of repair welds in P-No. 1 and P-No. 8 materials is not required for pumps and valves with inlet piping connections 2 NPS and less.

NC-2573.6 Heat Treatment After Repairs.

The material shall be heat treated after repair in accordance with the heat treatment requirements of NC-4620, except that the heating and cooling rate limitations of NC-4623 do not apply.

NC-2573.7 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (c) below are met:

(a) the depression, after defect elimination, is blended uniformly into the surrounding surface;

(b) after defect elimination, the area is reexamined by the magnetic particle method in accordance with NC-2577, or the liquid penetrant method in accordance with NC-2576, to assure that the defect has been removed or reduced to an imperfection of acceptable size;

(c) if the elimination of the defect reduces the section thickness below the minimum required by the specification or drawing, the casting shall be repaired in accordance with NC-2539.

NC-2573.8 Material Report Describing Defects and Repairs.

Each defect repair exceeding in depth the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the nominal wall thickness shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart that shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographic film, when radiographic film is specified in the order for the original casting.

NC-2574 Ultrasonic Examination of Ferritic Steel Castings

Ultrasonic examination shall be performed in accordance with T-541.4 of Article 5 of Section V. Each manufacturer shall certify that the procedure is in accordance with the requirements of NC-2574 and shall make the procedure available for approval upon request.

NC-2574.1 Acceptance Standards

(a) The Quality Levels of SA-609 as shown in Section V shall apply for the casting thicknesses indicated:

(1) Quality Level 1 for thicknesses up to 2 in. (51 mm);

Page 37

(2) Quality Level 3 for thicknesses 2 to 4 in. (51 mm to 102 mm);

(3) Quality Level 4 for thicknesses greater than 4 in. (152 mm).

(b) In addition to the Quality Level requirements stated in (a) above, the requirements in (1) through (5) below shall apply for both straight beam and angle beam examination.

(1) Areas giving indications exceeding the Amplitude Reference Line with any dimension longer than those specified in the following tabulation are unacceptable.

UT Quality Level

	Longest Dimension of Area¹¹¹²¹³
1	1.5 in.
2	2.0 in.
3	2.5 in.
4	3.0 in.

(2) Quality Level 1 shall apply for the volume of castings within 1 in. of the surface regardless of the overall thickness.

(3) Discontinuities indicated to have a change in depth equal to or greater than $\frac{1}{2}$ the wall thickness or 1 in. (25 mm) (whichever is less) are unacceptable.

(4) Two or more imperfections producing indications in the same plane with amplitudes exceeding the Amplitude Reference Line and separated by a distance less than the longest dimension of the larger of the adjacent indications are unacceptable if they cannot be encompassed within an area less than that of the quality level specified in (1) above.

11 The areas for the Ultrasonic Quality Levels in SA-609 refer to the surface area on the casting over which a continuous indication exceeding the transfer corrected distance amplitude curve is maintained.

12 Areas are to be measured from dimensions of the movement of the search unit, using the center of the search unit as the reference point.

13 In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting. In such cases, other criteria which incorporate a consideration of beam angles or beam spread must be used for realistic evaluation of the discontinuity.

(5) Two or more imperfections producing indications greater than permitted for Quality Level 1 for castings less than 2 in. (51 mm) in thickness, greater than permitted for Quality Level 2 for thicknesses 2 in. (51 mm) through 4 in. (102 mm), and greater than permitted for Level 3 for thicknesses greater than 4 in. (102 mm), separated by a distance less than the longest dimension of the larger of the adjacent indications are unacceptable, if they cannot be encompassed in an area less than that of the Quality Level requirements stated in (a) above.

NC-2575 Radiographic Examination

NC-2575.1 Examination.

Cast pressure retaining materials shall be examined by radiographic methods when specified in the order for the original castings, except that cast ferritic steels may be examined by either radiographic or ultrasonic methods, or a combination of both methods. Castings or sections of castings that have coarse grains or configurations that do not yield meaningful examination results by ultrasonic methods shall be examined by radiographic methods.

NC-2575.2 Extent.

Radiographic examination shall be performed on pressure retaining castings such as vessel heads and flanges, valve bodies, bonnets and disks, pump casings and covers, and piping and fittings. The extent of radiographic coverage shall be of the maximum feasible volume and, when the shape of the casting precludes complete coverage, the coverage shall be at least as exemplified in the typical sketches as shown in Fig. NC-2575.2-1.

NC-2575.3 Examination Procedure.

The radiographic examination shall be performed in accordance with Article 2 of Section V, with the following modifications.

(a) *Film Selection.* Only Types 1, 2, and 3 are permitted.

(b) *Radiographic Density.* The transmitted film density through the radiographic image of the body of the appropriate penetrometer, and the area of interest shall be 1.3 minimum for single film viewing. For composition viewing of multiple film exposures, each film of the composite set shall have a minimum density of 1.0. The maximum density shall be 4.0 for either single or composite viewing. A tolerance of 0.05 in density is allowed for variations between densitometer readings.

(c) The requirements of T-274 and T-285 of Article 2 of Section V need not be met.

(d) *Image Quality Indicator (IQI) Design.* Penetrators shall be manufactured and identified in accordance with the requirements or alternates allowed in SE-142 and Appendices.

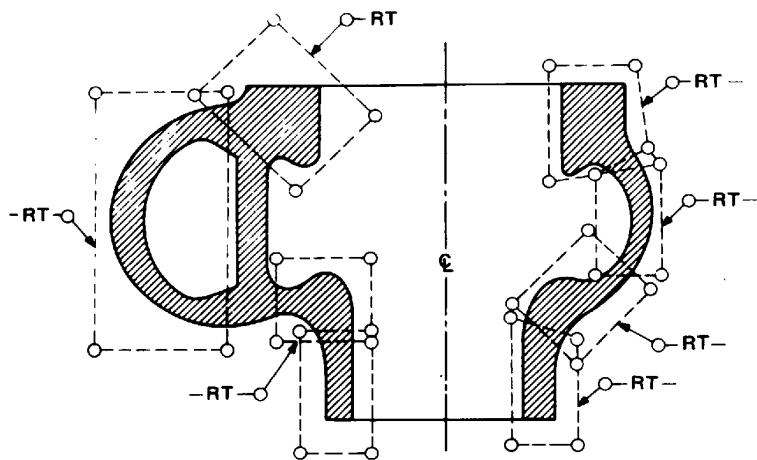
(e) *Image Quality Indicator (IQI) Selection.* The radiographic quality level shall be 2-4T for section thicknesses up to and including $\frac{3}{4}$ in. (19 mm), and 2-2T for section thicknesses greater than $\frac{3}{4}$ in. (19 mm). Radiographic quality is defined in Note 2 of SE-94.

(f) When radiographing weld ends of cast valves NPS 4 and less, double wall radiography may be used subject to the conditions of (1) and (2) below.

Page 38

Page 40

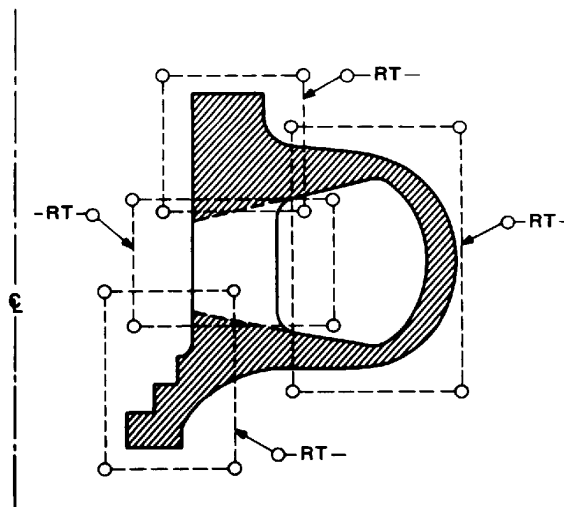
Pages 39-39



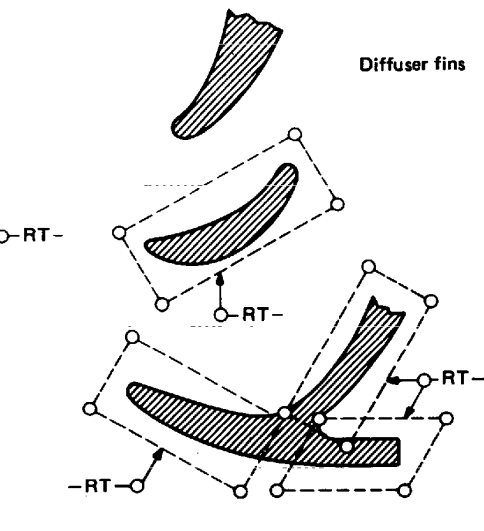
(a) Typical Volute-Type Pump Case

GENERAL NOTES:

- (a) Radiographic examination areas shall be indicated by a circle at each change of direction. The examination symbol for radiography shall be indicated as RT.
- (b) For nondestructive examination areas of revolution, the area shall be indicated by the examine-all-around symbol: — RT — ⌀
- (c) The sketches are typical and are to be used as a guide for minimum required coverage. Even though a sketch may be titled, "pump" or "valve," the coverage shown by the configurations may be applied interchangeably.



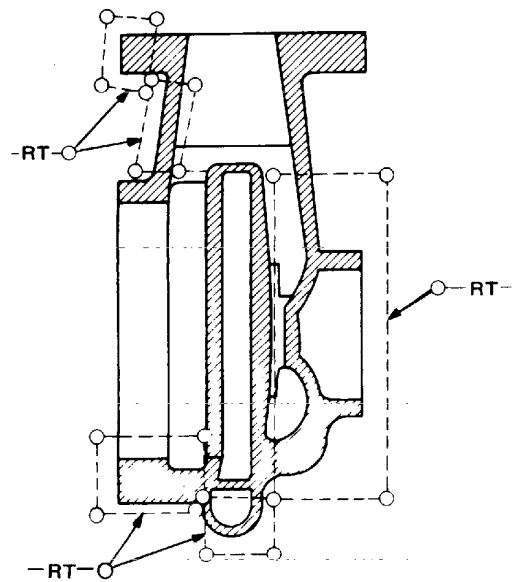
(b) Typical Diffuser-Type Pump Case



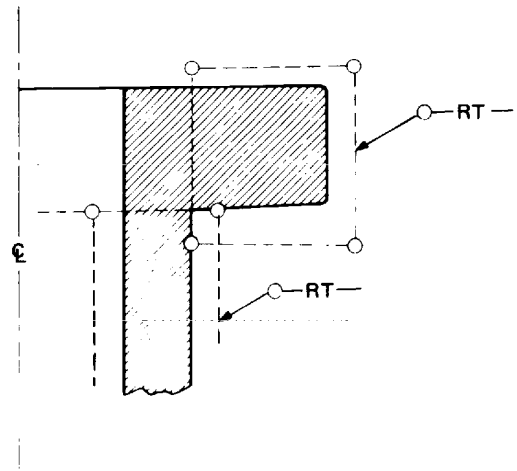
(c) Typical Diffuser-Type Pump Case Detail

FIG. NC-2575.2-1 TYPICAL PRESSURE RETAINING PARTS OF PUMPS AND VALVES

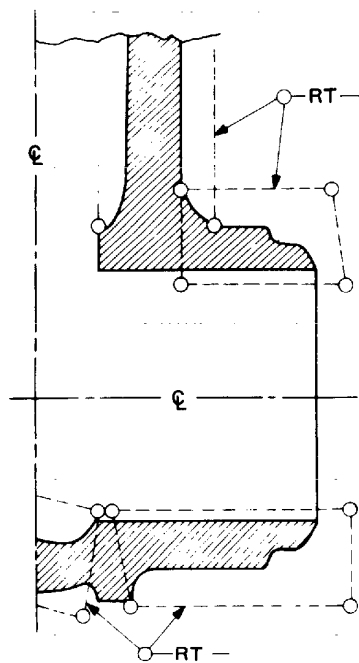
FIG. NC-2575.2-1 TYPICAL PRESSURE RETAINING PARTS OF PUMPS AND VALVES



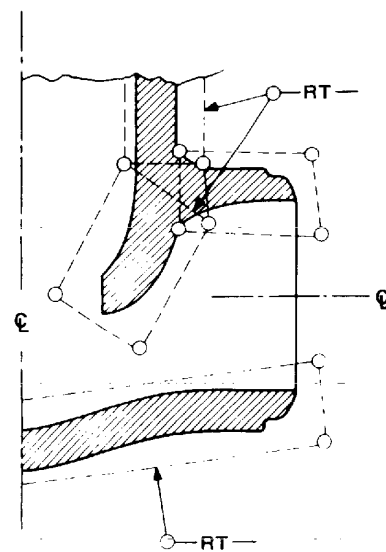
(d) Typical Single Stage Pump Case



(e) Typical Flange



(f) Typical Gate Valve



(g) Typical Globe Valve

FIG. NC-2575.2-1 TYPICAL PRESSURE RETAINING PARTS OF PUMPS AND VALVES (CONT'D)

FIG. NC-2575.2-1 TYPICAL PRESSURE RETAINING PARTS OF PUMPS AND VALVES (CONT'D)

(1) The penetrameter thickness shall be based on the design section thickness of the double wall, excluding the weld preparation lip.

(2) Acceptance standards shall be based on nominal single wall thickness.

NC-2575.4 Procedure Requirements.

Radiographic examination shall be performed in accordance with a written procedure. Each manufacturer shall certify that the procedure is in accordance with the requirements of NB-2575. The procedure shall be available for the interpretation of the films and shall be submitted together with the radiographs. Each procedure shall include at least the following information:

(a) the type of material to be radiographed;

(b) the material thickness ranges to be radiographed;

(c) the type of radiation source, actual or maximum source size or focal spot, X-ray equipment voltage rating and manufacturer. The equipment manufacturer's or supplier's publications, such as technical manuals, decay curves, or written statements documenting the actual or maximum source size or focal spot, shall be acceptable as source size verification; for X-ray machines 320 KV and less, the focal spot size may be determined by the pinhole method;¹⁴

(d) type and thickness of intensifying screens and filters;

(e) minimum source-to-film distance.

NC-2575.5 Radiographic Setup Information.

To aid in proper interpretation of radiographs, details of the radiographic examination setup used shall accompany each group of radiographs. As a minimum, the information shall include:

(a) film brand and the type and number of films in the cassette;

(b) for multiple film technique, a statement whether viewing is to be single or superimposed;

(c) blocking or masking technique, if used;

(d) isotope or X-ray voltage used;

(e) source to film distance used;

(f) distance between film and object when film/cassette is not in contact with object;

(g) geometric arrangement for the radiograph(s) (sketch);

(h) orientation of location markers;

(i) description of how internal markers, when used, locate area of interest;

14 Nondestructive Testing Handbook, Volume I, First Edition, pp. 14.32-14.33, "Measuring Focal-Spot Size." Also, pp. 20-21 of "Radiography in Modern Industry," Fourth Edition.

(j) location markers, such as lead numbers or letters, which shall appear as radiographic images on the film, shall be permanently stamped on the surface of the casting being radiographed in a manner permitting the area of interest on a radiograph to be accurately located on the casting and providing evidence on the radiograph that the extent of coverage required by NC-2575.2 has been obtained. On castings or sections of castings where stamping is not feasible, the radiographic procedure shall so state, in which case a radiographic film location map shall be provided.

NC-2575.6 Acceptance Criteria.

Castings shall meet the acceptance requirements of Severity Level 2 of ASTM E 446-72, E 446-75 or E 446-78, Reference Radiographs for Steel Castings up to 2 in. in Thickness, ASTM E 186-67, ASTM E 186-73, or E 186-75,

Reference Radiographs for Heavy-Walled [2 to 4 1/2 in. (51 to 114 mm)] Steel Castings, or ASTM E 280-68, ASTM E 280-72, or ASTM E 280-75, Reference Radiographs for Heavy Walled [4 1/2 to 12 in. (114 mm to 305 mm)] Steel Castings, as applicable for the thickness being radiographed, except Category D, E, F, or G defects are not acceptable. The requirements of ASTM 280-68, ASTM E 280-72, or ASTM E 280-75 shall apply for castings over 12 in. in thickness.

NC-2576 Liquid Penetrant Examination

(a) Castings shall be examined, if required, on all accessible surfaces by liquid penetrant method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by bleeding out of the penetrant; however, localized surface discontinuities, as may occur from machining marks, scale, or dents, may produce indications which are not relevant. Any indication in excess of the acceptance standards believed to be nonrelevant shall be reexamined to verify whether actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation that would mask indications of defects are unacceptable. Relevant indications are those which result from imperfections and have a major dimension greater than 1/16 in. Linear indications are those whose length is more than three times the width. Rounded indications are those which are circular or elliptical with the length less than three times the width.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) linear indications greater than 1/16 in. (1.6 mm) long for materials less than 5/8 in. (16 mm) thick, greater than 1/8 in. (3.2 mm) long for materials from

Page 41

5/8 in. (16 mm) thick to under 2 in. (51 mm) thick, and 3/16 in. (4.8 mm) long for materials 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than 1/8 in. (3.2 mm) for thicknesses less than 5/8 in. (16 mm), and greater than 3/16 in. (4.8 mm) for thicknesses 5/8 in. (16 mm) and greater;

(3) four or more indications in a line separated by 1/16 in. or less edge to edge;

(4) ten or more indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

NC-2577 Magnetic Particle Examination (for Ferritic Steel Products Only)

(a) Castings of magnetic material shall be examined, if required, on all accessible surfaces by a magnetic particle method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by retention of the examination medium. All indications are not necessarily defects since certain metallurgical discontinuities and magnetic permeability variations may produce indications that are not relevant. Any indication in excess of the acceptance standards believed to be nonrelevant shall be reexamined to verify whether actual defects are present. Nonrelevant indications which would mask indications of defects are unacceptable. Surface conditioning may precede the reexamination. Relevant indications are those which result from imperfections and have a major dimension greater than 1/16 in. (1.6 mm). Linear indications are those whose length is more than three times the width. Rounded indications are those which are circular or elliptical with the length less than three times the width.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) linear indications greater than 1/16 in. (1.6 mm) long for materials less than 5/8 in. (16 mm) thick; greater than 1/8 in. (3.2 mm) long for materials from 5/8 in. (16 mm) thick to under 2 in. (51 mm) thick; and 3/16 in. (4.8 mm) long for materials 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than 1/8 in. (3.2 mm) for thicknesses less than 5/8 in. (16 mm), and

greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

NC-2580 EXAMINATION OF BOLTS, STUDS, AND NUTS

NC-2581 Requirements

All bolting material shall be visually examined in accordance with NC-2582.

NC-2582 Visual Examination

Visual examination shall be applied to the areas of threads, shanks, and heads of final machined parts. Harmful discontinuities such as laps, seams, or cracks that would be detrimental to the intended service are unacceptable.

[98]

NC-2600 MATERIAL ORGANIZATIONS' QUALITY SYSTEM PROGRAMS

[98]

NC-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS

(a) Except as provided in (b) below, Material Organizations shall have a Quality System Program or an Identification and Verification Program, as applicable, which meets the requirements of NCA-3800.

(b) The requirements of NCA-3862 shall be met as required by NC-2130. The other requirements of NCA-3800 need not be used by Material Organizations for small products, as defined in (c) below, for brazing material, and for material which is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Assurance Program (NCA-4000) shall include measures to provide assurance that the material is furnished in accordance with the material specification and with the applicable requirements of this Subsection.

Page 42

(c) For the purpose of this paragraph, small products are defined as given in (1) through (4) below:

(1) pipe, tube (except heat exchanger tube), pipe fittings, and flanges 2 in. nominal pipe size (DN 50) and less;

(2) bolting materials, including studs, nuts, and bolts of 1 in. (25 mm) nominal diameter and less;

(3) bars with a nominal cross-sectional area of 1 sq in. (645 mm²) and less;

(4) material for pumps and valves with inlet pipe connections of 2 in. nominal pipe size (DN 50) and less;

(5) materials exempted by NC-2121(c).

[98]

NC-2700 DIMENSIONAL STANDARDS

Dimensions of standard items shall comply with the standards and specifications of Table NC-3132-1

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NC-3000

ARTICLE NC-3000 DESIGN

NC-3100 GENERAL DESIGN

NC-3110 LOADING CRITERIA

NC-3111 Loading Conditions

The loadings that shall be taken into account in designing a component shall include, but are not limited to, those in (a) through (g) below:

- (a) impact forces caused by either external or internal conditions;
- (b) impact loads, including rapidly fluctuating pressures;
- (c) weight of the component and normal contents under operating or test conditions, including additional pressure due to static and dynamic head of liquids;
- (d) superimposed loads such as other components, operating equipment, insulation, corrosion resistant or erosion resistant linings, and piping;
- (e) wind loads, snow loads, vibrations, and earthquake loads, where specified;
- (f) reactions of supporting lugs, rings, saddles, or other types of supports;
- (g) temperature effects.

NC-3112 Design Loadings

The Design Loadings shall be established in accordance with NCA-2142.1 and the following subparagraphs.

NC-3112.1 Design Pressure.

The specified internal and external Design Pressures to be used in this Subsection shall be established in accordance with NCA-2142.1(a).

NC-3112.2 Design Temperature.

The specified Design Temperature shall be established in accordance with NCA-2142.1(b). It shall be used in conjunction with the Design Pressure. If necessary, the metal temperature shall be determined by computation using accepted heat transfer procedures or by measurement from equipment in service under equivalent operating conditions. In no case shall the temperature at the surface of the metal exceed the maximum temperature listed in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1, nor exceed the maximum temperature limitations specified elsewhere in this Subsection.

NC-3112.3 Design Mechanical Loads.

The specified Design Mechanical Loads shall be established in accordance with NCA-2142.1(c). They shall be used in conjunction with the Design Pressure.

NC-3112.4 Design Allowable Stress Values

(a) Allowable stresses for design for materials are listed in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1, except for vessels designed to the requirements of NC-3200, for which the design stress intensity values are listed in Tables 2A, 2B, and 4, Section II, Part D, Subpart 1. The materials shall not be used at metal and design temperatures above those for which stress or stress intensity values are given. The values in the Tables may be interpolated for intermediate temperatures.

(b) The maximum allowable compressive stress to be used in the design of cylindrical shells subjected to loadings that produce longitudinal compressive stress in the shell shall be the smaller of the following values:

(1) the maximum allowable tensile stress value permitted in (a) above;

(2) the value of the factor B determined from NC-3133.6(b).

It is recognized that high localized and secondary stresses may exist in components designed and fabricated in accordance with the rules of this Subsection; however, insofar as practical, design rules for details have been written to hold such stresses at a safe level consistent with experience.

(c) The wall thickness of a component computed by the rules of this Subsection shall be determined so that the general membrane stress due to any combination of mechanical loadings listed in NC-3111 which are expected to occur simultaneously during a condition of loading for which service Level A is designated for the component does not exceed¹ the maximum allowable stress value permitted at the Design Temperature unless

Page 58

specifically permitted in other paragraphs of this Subsection. These allowable stress values may be interpolated for intermediate Design Temperature.

NC-3113 Service Conditions

(a) Each service condition to which the components may be subjected shall be classified in accordance with NCA-2142, and Service Limits [NCA-2142.4(b)] shall be designated in the Design Specifications in such detail as will provide a complete basis for design in accordance with this Article.

(b) When any loadings for which Level B, C, or D Service Limits are designated are specified in the Design Specifications, they shall be evaluated in accordance with NCA-2140 and in compliance with the applicable design and stress limits of this Article.

NC-3120 SPECIAL CONSIDERATIONS

NC-3121 Corrosion

Materials subject to thinning by corrosion, erosion, mechanical abrasion, or other environmental effects shall have provision made in the Design Specifications for these effects by indicating the increase in the thickness of the base metal over that determined by the design formulas (NC-2160). Other suitable methods of protection may be used. Material added or included for these purposes need not be of the same thickness for all areas of the component if different rates of attack are expected for the various areas.

NC-3122 Cladding

The rules of this paragraph apply to the design of clad components constructed of material permitted in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1.

NC-3122.1 Stresses.

Except as permitted by NC-3214, no structural strength shall be attributed to the cladding.

NC-3122.2 Design Dimensions.

The dimensions given in (a) and (b) below shall be used in the design of the component:

(a) for components subjected to internal pressure, the inside diameter shall be taken at the nominal inner face of the cladding;

(b) for components subjected to external pressure, the outside diameter shall be taken at the outer face of the base metal.

NC-3123 Welds Between Dissimilar Metals

In satisfying the requirements of this Subarticle, caution shall be exercised in construction involving dissimilar metals having different chemical compositions, mechanical properties, and coefficients of thermal expansion in order to avoid difficulties in service.

difficulties in service.

NC-3124 Ductile Behavior Evaluation

The use of material below the temperature established by the methods of NC-2331(a) may be justified by methods equivalent to those contained in Appendix G.

NC-3125 Configuration

Accessibility to permit the examinations required by the Edition and Addenda of Section XI as specified in the Design Specification for the component shall be provided in the design of the component.

NC-3130 GENERAL DESIGN RULES

NC-3131 General Requirements

The design shall be such that the rules of this Article are satisfied for all configurations and loadings, using the maximum allowable stress values S of Tables 1A, 1B, and 3, Section II, Part D, Subpart 1 in the various equations and including the use of the standard products listed in Table NC-3132-1. Use of the maximum allowable stress values of Tables 1A, 1B, and 3, Section II, Part D, Subpart 1 does not apply to vessels designed to the rules of NC-3200.

NC-3131.1 Design Reports

(a) The N Certificate Holder is required to provide a Design Report as part of the responsibility for achieving structural integrity of the component. The Design Report shall be certified when required by NCA-3550.

(b) The Certificate Holder for construction of a vessel conforming to the design requirements of NC-3200 shall provide a Design Report conforming to the requirements of NC-3211 and NC-3223.2.

NC-3131.2 Proof Test to Establish Maximum Design Pressure.

When the configuration of a component is such that the stresses resulting from internal or external pressure cannot be determined with adequate accuracy by the rules of this Article, the maximum Design Pressure shall be determined by proof testing in accordance with the rules of NC-6900 except for piping as otherwise provided in this Article. This procedure

does not apply to vessels designed to the requirements of NC-3200.

**TABLE NC-3132-1
DIMENSIONAL STANDARDS**

Standard	Designation
Pipe and Tubes	
Welded and Seamless Wrought Steel Pipe	ANSI B36.10-1985
Stainless Steel Pipe	ANSI B36.19-1985
Fittings, Flanges, and Gaskets	
Steel Pipe Flanges and Flanged Fittings	ANSI B16.5-1988
Factory Made Wrought Steel Buttwelding Fittings	ANSI B16.9-1986 [Note (1)]
Forged Steel Fittings, Socket-Welding and Threaded	ANSI B16.11-1980
Cast Copper Alloy Solder-Joint Pressure Fitting	ANSI B16.18-1984
Ring-Joint Gaskets and Grooves for Steel Pipe Flanges	ANSI B16.20-1973
Nonmetallic Gaskets for Pipe Flanges	ANSI B16.21-1978
Wrought Copper and Bronze Solder-Joint Pressure Fittings	ANSI B16.22-1980
Buttwelding Ends	ANSI B16.25-1986
Wrought Steel Buttwelding Short Radius Elbows and Returns	ANSI B16.28-1986 [Note (2)]
Refrigeration Tube Fittings	SAE J513f-1981
Stainless Steel Buttwelding Fittings	MSS SP-43-1982(R1986)
Steel Pipeline Flanges	MSS SP-44-1985
Large Diameter Carbon Steel Flanges	API 605-1980
Standard for Steel Pipe Flanges	AWWA C207-1978
Bolting	
Square and Hex Bolts and Screws, Including Askew Head Bolts, Hex Cap Screws and Lag Screws	ANSI B18.2.1-1981
Square and Hex Nuts	ANSI B18.2.2-1987
Socket Cap, Shoulder, and Set Screws	ANSI B18.3-1986
Threads	
Unified Inch Screw Threads (UN and UNR Thread Form)	ANSI B1.1-1982
Pipe Threads (Except Dryseal)	ANSI B1.20.1-1983
Dryseal Pipe Threads	ANSI B1.20.3-1976(R1982)
Gaging for Dryseal Piping Threads	ANSI B1.20.5-1978
Valves	
Valves — Flanged and Buttwelding End	ANSI B16.34-1988
Qualification Requirements for Elastomer Diaphragms for Nuclear Service Diaphragm Type Valves	MSS SP 100-1988

NOTES:

- (1) Analysis per ANSI B16.9, paragraph 2.2, is acceptable only for caps and reducers.
(2) Analysis per ANSI B16.28, paragraph 2.2, is not acceptable.

TABLE NC-3132-1 DIMENSIONAL STANDARDS

NC-3132 Dimensional Standards for Standard Products

Dimensions of standard products shall comply with the standards and specifications listed in Table NB-3132-1 when the standard or specification is referenced in the specific design Subarticle. However, compliance with these standards does not replace or eliminate the requirements for stress analysis when called for by the design Subarticle for a specific component.

NC-3133 Components Under External Pressure

NC-3133.1 General.

Rules are given in this paragraph for determining the thickness under external pressure loading in spherical shells, cylindrical shells with or without stiffening rings, and tubular products consisting of pipes, tubes, and fittings. Charts for determining the stresses in shells and hemispherical heads are given in Section II, Part D, Subpart 3. For vessels

designed to NC-3200, see NC-3240.

NC-3133.2 Nomenclature.

The symbols used in this paragraph are defined as follows:

A	= factor determined from Fig. G, Section II, Part D, Subpart 3 in Section II, Part D, Subpart 3 and used to enter the applicable material chart in Section II, Part D, Subpart 3. For the case of cylinders having D_o/T values less than 10, see NC-3133.3(b).
B	= factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a stiffening ring, corresponding to the factor B and the design metal temperature for the shell under consideration.
A_s	= cross-sectional area of a stiffening ring, sq in.
D_o	= outside diameter of the cylindrical shell course or tube under consideration, in.
E	= modulus of elasticity of material at Design Temperature, psi. For external pressure and axial compression design in accordance with this Section the modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 3. (Interpolation may be made between lines for intermediate temperatures.) The modulus of elasticity values shown in Section II, Part D, Subpart 3 for material groups may differ from those values listed in Tables TM, Section II, Part D, Subpart 2 for specific materials. Section II, Part D, Subpart 3 values shall be applied only to external pressure and axial compression design.
I	= available moment of inertia of the stiffening ring about its neutral axis, parallel to the axis of the shell, in. ⁴
I'	= available moment of inertia of the combined ring-shell cross section about its neutral axis, parallel to the shell, in. ⁴ The width of the shell which is taken as contributing to the combined moment of inertia shall not be greater than $1.10 \sqrt{D_o T_n}$ and shall be taken as lying one half on each side of the centroid of the ring. Portions of shell plates shall not be considered as contributing to more than one stiffening ring.
I_s	= required moment of inertia of the stiffening ring about its neutral axis parallel to the axis of the shell, in.
I'_s	= required moment of inertia of the combined ring-shell section about its neutral axis parallel to the axis of the shell, in. ⁴
L	= total length of a tube between tubesheets, or the design length of a vessel section, taken as the largest of the following:

	(1) the distance between head tangent lines plus one-third of the depth of each head if there are no stiffening rings; (2) the greatest center-to-center distance between any two adjacent stiffening rings; or (3) the distance from the center of the first stiffening ring to the head tangent line plus one-third of the depth of the head, all measured parallel to the axis of the vessel, in.
L_s	= one-half of the distance from the center line of the stiffening ring to the next line of support on one side, plus one-half of the center line distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the component, in. A line of support is: (1) a stiffening ring that meets the requirements of this paragraph; (2) a circumferential line on a head at one-third the depth of the head from the head tangent line; or (3) a circumferential connection to a jacket for a jacketed section of a cylindrical shell.
P	= external Design Pressure, psi (gage or absolute, as required)
P_a	= allowable external pressure, psi (gage or absolute, as required)
R	= inside radius of spherical shell, in.
S	= the lesser of twice the allowable stress at design metal temperature from Tables 1A, 1B, and 3, Section II, Part D, Subpart 1 or 0.9 times the tabulated yield strength at design metal temperature from Tables Y-1, Section II, Part D, Subpart 2, psi
T	= minimum required thickness of cylindrical shell or tube, or spherical shell, in.
T_n	= nominal thickness used, less corrosion allowance, of a cylindrical shell or tube, in.

NC-3133.3 Cylindrical Shells and Tubular Products.

The thickness of cylinders under external pressure shall be determined by the procedure given in (a) or (b) below.

(a) Cylinders having D_o/T values ≥ 10 :

Step 1: Assume a value for T and determine the ratios L/D_o and D_o/T .

Step 2: Enter Fig. G, Section II, Part D, Subpart 3 in Section II, Part D, Subpart 3 at the value of L/D_o determined in Step

1. For values of L/D_o greater than 50, enter the chart at a value of $L/D_o = 50$. For values of L/D_o

Page 61

less than 0.05, enter the chart at a value of L/D_o of 0.05.

Step 3: Move horizontally to the line for the value of D_o/T determined in Step 1. Interpolation may be made for immediate values of D_o/T . From this point of intersection move vertically downward to determine the value of factor A .

Step 4: Using the value of A calculated in Step 3, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value of A

falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 7.

Step 5: From the intersection obtained in Step 4, move horizontally to the right and read the value of B .

Step 6: Using this value of B , calculate the value of the maximum allowable external pressure P_a using the following formula:

$$P_a = \frac{4B}{3(D_o/T)}$$

Step 7: For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following formula:

$$P_a = \frac{2AE}{3(D_o/T)}$$

Step 8: Compare P_a with P . If P_a is smaller than P , select a larger value for T and repeat the design procedure until a value of P_a is obtained that is equal to or greater than P .

(b) Cylinders having D_o/T values <10:

Step 1: Using the same procedure as given in (a) above, obtain the value of B . For values of D_o/T less than 4, the value of

factor A can be calculated using the following formula:

o

$$A = \frac{1.1}{(D_o / T)^2}$$

For values of A greater than 0.10, use a value of 0.10.

Step 2: Using the value of B obtained in Step 1, calculate a value P_{a1} using the following formula:

$$P_{a1} = \left[\frac{2.167}{(D_o / T)} - 0.0833 \right] B$$

Step 3: Calculate a value P_{a2} using the following formula:

$$P_{a2} = \frac{2S}{D_o/T} \left[1 - \frac{1}{D_o/T} \right]$$

Step 4: The smaller of the values of P_{a1} calculated in Step 2, or P_{a2} calculated in Step 3 shall be used for the maximum allowable external pressure P_a . Compare P_a with P . If P_a is smaller than P , select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P .

NC-3133.4 Spherical Shells and Formed Heads

(a) *Spherical Shells*. The minimum required thickness of a spherical shell under external pressure, either seamless or of built-up construction with butt joints, shall be determined by the procedure given in Steps 1 through 6.

Step 1: Assume a value for T and calculate the value of factor A using the following formula:

$$A = \frac{0.125}{(R/T)}$$

Step 2: Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 5.

Page 62

Step 3: From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B .

Step 4: Using the value of B obtained in Step 3, calculate the value of the maximum allowable external pressure P_a using the following formula:

$$P_a = \frac{B}{(R/T)}$$

Step 5: For values of A falling to the left of the applicable material/temperature line for the Design Temperature, the value of P_a can be calculated using the following formula:

$$P_a = \frac{0.0625E}{(R/T)^2}$$

Step 6: Compare P_a obtained in Steps 4 or 5 with P . If P_a is smaller than P , select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P .

(b) The nomenclature defined below is used in the formulas of (c) through (e) below.

D_o	= outside diameter of the head skirt or the outside diameter of a cone head at the point under consideration, measured perpendicular to the longitudinal axis of the cone, in.
K_1	= a factor depending on the ellipsoidal head proportions, given in Table NC-3332.2-1
R	= for hemispherical heads, the inside radius in the corroded condition, in.
R	= for ellipsoidal heads, the equivalent inside spherical radius taken as $K_1 D_o$ in the corroded condition, in.

R	= for torispherical heads, the inside radius of the crown portion of the head in the corroded condition, in.
T	= minimum required thickness of head after forming, exclusive of corrosion allowance, in.

(c) *Hemispherical Heads.* The required thickness of a hemispherical head having pressure on the convex side shall be determined in the same manner as outlined in (a) above for determining the thickness for a spherical shell.

(d) *Ellipsoidal Heads.* The required thickness of an ellipsoidal head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the following procedure.

Step 1: Assume a value for T and calculate the value of factor A using the following formula:

$$A = \frac{0.125}{(R/T)}$$

Step 2: Using the value of A calculated in Step 1, follow the same procedure as that given for spherical shells in (a) above, Steps 2 through 6.

(e) *Torispherical Heads.* The required thickness of a torispherical head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the same design procedure as is used for ellipsoidal heads given in (d) above, using the appropriate value for R .

NC-3133.5 Stiffening Rings for Cylindrical Shells

(a) The required moment of inertia of a circumferential stiffening ring shall be not less than that determined by one of the following two formulas:

$$I_s = \frac{D_o^2 L_s (T + A_s / L_s) A}{14}$$

$$I'_s = \frac{D_o^2 L_s (T + A_s / L_s) A}{10.9}$$

If the stiffeners should be so located that the maximum permissible effective shell sections overlap on either or both sides of a stiffener, the effective shell section for that stiffener shall be shortened by one-half of each overlap.

(b) The available moment of inertia I or I' for a stiffening ring shall be determined by the following procedure.

Step 1: Assuming that the shell has been designed and D_o , L_s , and T_n are known, select a member to be used for the stiffening ring and determine its cross-sectional area A_s . Then calculate factor B using the following formula:

$$B = 3/4 \left[\frac{PD_o}{T_n + A_s / L_s} \right]$$

Step 2: Enter the right-hand side of the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening

ring, use the material chart resulting in the larger value of A in Step 4 or 5, below.

Step 3: Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5.

Step 4: Move vertically to the bottom of the chart and read the value of A .

Step 5: For values of B falling below the left end of the material/temperature line for the design temperature, the value of A can be calculated using the formula

$$A = \frac{2B}{E}$$

Step 6: Compute the value of the required moment of inertia from the formulas for I_s or I'_s above.

Step 7: Calculate the available moment of inertia I or I' of the stiffening ring using the section corresponding to that used in Step 6.

Step 8: If the required moment of inertia is greater than the moment of inertia for the section selected in Step 1, a new section with a larger moment of inertia must be selected and a new moment of inertia determined. If the required moment of inertia is smaller than the moment of inertia for the section selected in Step 1, that section should be satisfactory.

(c) For fabrication and installation requirements for stiffening rings, see NC-4437.

NC-3133.6 Cylinders Under Axial Compression.

The maximum allowable compressive stress to be used in the design of cylindrical shells and tubular products subjected to loadings that produce longitudinal compressive stresses in the shell or wall shall be the lesser of the values given in (a) or (b) below:

(a) the S value for the applicable material at design temperature given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1;

(b) the value of the B determined from the applicable chart in Section II, Part D, Subpart 3 using the following definitions for the symbols on the charts:

T = minimum required thickness of the shell or tubular product, exclusive of the corrosion allowance, in.

R = inside radius of the cylindrical shell or tubular product, in.

The value of B shall be determined from the applicable chart contained in Section II, Part D, Subpart 3 as given in Steps 1 through 5.

Step 1: Using the selected values of T and R , calculate the value of factor A using the following formula:

$$A = \frac{0.125}{(R/T)}$$

Step 2: Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 4.

Step 3: From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B . This is the maximum allowable compressive stress for the values of T and R used in Step 1.

Step 4: For values of A falling to the left of the applicable material/temperature line, the value of B shall be calculated using the following formula:

$$B = \frac{AE}{2}$$

Step 5: Compare the value of B determined in Steps 3 or 4 with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of T and R . If the value of B is smaller than the computed

compressive stress, a greater value of T must be selected and the design procedure repeated until a value of B is obtained which is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

NC-3133.7 Conical Heads.

The required thickness of a conical head under external pressure shall not be less than that determined by the rules of (a), (b), and (c) below.

Page 64

(a) When one-half of the included apex angle of the cone is equal to or less than $22\frac{1}{2}$ deg., the thickness of the cone shall be the same as the required thickness of a cylindrical shell, the length of which equals the axial length of the cone or the axial distance center to center of stiffening rings, if used, and the outside diameter of which is equal to the outside diameter at the large end of the cone or section between stiffening rings.

(b) When one-half of the included apex angle of the cone is greater than $22\frac{1}{2}$ deg. and not more than 60 deg., the thickness of the cone shall be the same as the required thickness of a cylindrical shell, the outside diameter of which equals the largest inside diameter of the cone measured perpendicularly to the cone axis, and the length of which equals an axial length that is the lesser of either the distance center to center of stiffening rings, if used, or the largest inside diameter of the section of the cone considered.

(c) When one-half of the included apex angle of the cone is greater than 60 deg., the thickness of the cone shall be the same as the required thickness for a flat head under external pressure, the diameter of which equals the largest inside diameter of the cone (NC-3325).

NC-3133.8 Tubes and Pipes When Used as Tubes.

The required wall thickness for tubes and pipes under external pressure shall be determined in accordance with Fig. NC-3133.8-1.

NC-3135 Attachments

(a) Except as in (c) and (d) below, attachments and connecting welds within the jurisdictional boundary of the component as defined in NC-1130 shall meet the stress limits of the component.

(b) The design of the component shall include consideration of the interaction effects and loads transmitted through the attachment to and from the pressure retaining portion of the component. For vessels designed to NC-3200, thermal stresses, stress concentrations, and restraint of the pressure retaining portion of the component shall be considered.

(c) Beyond $2t$ from the pressure retaining portion of the component, where t is the nominal thickness of the pressure retaining material, the appropriate design rules of NF-3000 may be used as a substitute for the design rules of NC-3000 for portions of attachments which are in the component support load path.

(d) Nonstructural attachments shall meet the requirements of NC-4435.

NC-3200 ALTERNATIVE DESIGN RULES FOR VESSELS

NC-3210 GENERAL REQUIREMENTS

NC-3211 Basis for Use

NC-3211.1 Scope

(a) This Subarticle contains design rules for vessels which may be used as an alternative to the design rules in NC-3300. When these requirements are met for design, the stress intensity values of 2A, 2B, and 4, Section II, Part D, Subpart 1 may be used.

(b) These requirements provide specific design rules for some commonly used vessel shapes under pressure loadings and, within specified limits, rules for treatment of other loadings. Simplified rules are also included for the approximate

evaluation of design cyclic service life. Rules are not given which cover all details of design.

(c) When complete rules are not provided or when the vessel designer chooses, a complete stress analysis of the vessel or vessel region shall be performed considering all the loadings of NC-3212 and the Design Specifications. This analysis shall be done in accordance with Appendix XIII for all applicable stress categories. Alternatively, an experimental stress analysis shall be performed in accordance with Appendix II.

(d) When these alternative design rules are used, the special requirements of NC-4260, NC-5250, NC-6221, and NC-6222 shall be met.

(e) A Design Report shall be prepared by the Certificate Holder showing compliance with this Subarticle. This Design Report shall meet the requirements of NCA-3550 for a Design Report (Appendix C).

NC-3211.2 Requirements for Acceptability

(a) The design shall be such that the requirements of NC-3100 and this Subarticle are satisfied. In cases of conflict, the requirements of this Subarticle shall govern.

(b) The design shall be such that stress intensities do not exceed the limits given in NC-3216.

(c) For configurations where compressive stresses occur, the critical buckling stress shall be taken into account. For the special case of external pressure, the rules of NC-3133 shall be met.

NC-3211.3 Materials in Combination

(a) A vessel may be designed for and constructed of any combination of materials permitted in 2A, 2B, and 4, Section II, Part D, Subpart 1, provided the applicable rules are followed and the requirements in Section IX for welding dissimilar metals are met.

Page 65

Page 66

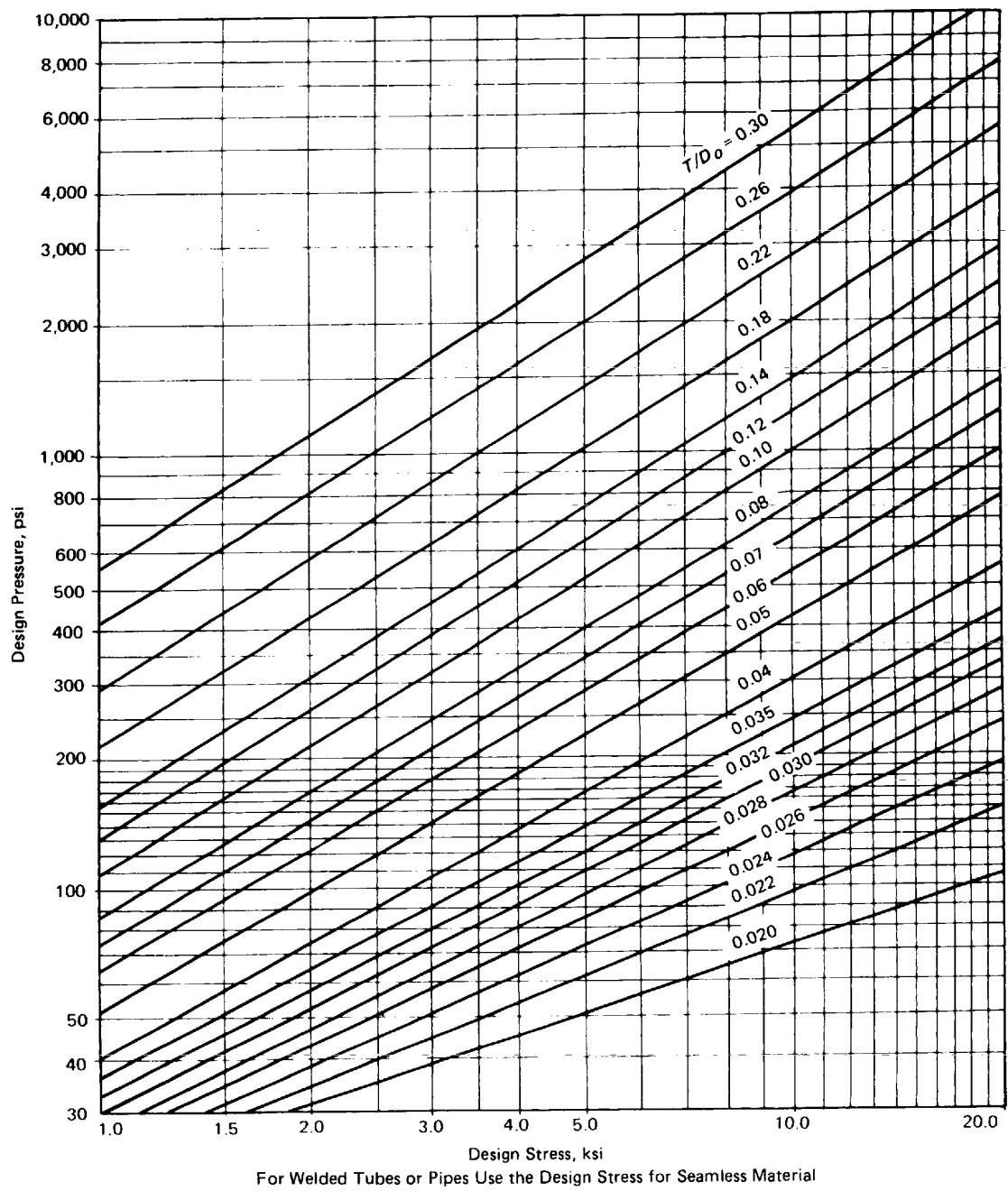


FIG. NC-3133.8-1 CHART FOR DETERMINING WALL THICKNESS OF TUBES UNDER EXTERNAL PRESSURE

FIG. NC-3133.8-1 CHART FOR DETERMINING WALL THICKNESS OF TUBES UNDER EXTERNAL PRESSURE

(b) A stress analysis of a vessel region shall be made in accordance with Appendix XIII unless all of the provisions of (c) or (d) below apply. This does not obviate the need for such analysis where required by other provisions of this Subarticle.

(c)(1) The junction is a girth seam between pressure parts.

(2) Any taper required because of different thickness shall be in the material having the higher design stress intensity, or in weld deposit appropriate for the stronger material.

(3) No discontinuity is involved except that due to thickness and modulus of elasticity difference.

(4) $S_{m2} \leq 1.2 S_{m1}(E_2/E_1)$ where subscripts 1 and 2 denote the material having the lower and higher design stress intensity value, respectively, and S_m and E are as defined in NC-3216 and NC-3219, respectively.

(d)(1) The junction is at a seam between pressure parts other than a girth seam covered by (c) above.

(2) Any taper required because of different thickness is in material having the higher design stress intensity or in weld deposit appropriate for the stronger material.

(3) $S_{m2} \leq 1.1 S_{m1}(E_2/E_1)$ where subscripts and symbols are as given in (c)(4) above.

NC-3211.4 Combination Units.

When a vessel unit consists of more than one independent chamber, operating at the same or different pressures and temperatures, each chamber or vessel shall be designed and constructed to withstand the most severe condition of coincident pressure and temperature expected. Chambers which come within the scope of this Subarticle may be connected to chambers constructed to the rules of NC-3300, provided the connection between such chambers meets all of the requirements of this Subarticle.

NC-3211.5 Minimum Thickness of Shell or Head.

The thickness after forming and without allowance for corrosion of any shell or head subject to pressure shall be not less than $\frac{1}{4}$ in. (6 mm) for carbon and low alloy steels or $\frac{1}{8}$ in. (3.2 mm) for stainless steel.

NC-3211.6 Selection of Material Thickness.

The selected thickness of material shall be such that the forming, heat treatment, and other fabrication processes will not reduce the thickness of the material at any point below the minimum value required by these rules.

NC-3212 Loadings

The requirements of NC-3111 shall apply.

NC-3214 Cladding

The design calculations shall be based on a thickness equal to the nominal thickness of the base plate plus S_c/S_b times the nominal thickness of the cladding, less any allowance provided for corrosion, provided the conditions of (a), (b), and (c) below are met.

(a) The clad product conforms to one of the clad plate products referenced in NC-2121 or is overlay weld clad.

(b) The joints are completed by depositing corrosion resisting weld metal over the weld in the base material to restore the cladding.

(c) The S_m value of the weaker material is at least 70% of the S_m value of the stronger. Where

S_c

= design stress intensity value for the cladding or, for the weld overlay, that of the wrought material whose chemistry most closely approximates that of the cladding, at the Design Temperature, psi

S_b

= design stress intensity value for the base material at the Design Temperature, psi

the design stress intensity value shall be that given for base material in 2A, 2B, and 4, Section II, Part D, Subpart 1. When S_c is greater than S_b , the multiplier S_c/S_b shall be taken equal to unity.

NC-3215 Design Basis

NC-3215.1 Pressure and Temperature Relationships

(a) Table NC-3215.1(a)-1 sets forth the pressure, temperature, and static head relationships which shall be considered by the designer.

(b) The design for a vessel part is usually controlled by coincident pressure and temperature at a point. The design shall take into account the maximum difference in fluid pressure, which exists under the specified service conditions, between the inside and outside of the vessel at any point or between two chambers of a combination unit. The design thickness for pressure shall not include any metal added as corrosion or erosion allowance or any metal required for any combination of loadings listed in NC-3218 which are likely to occur coincident with the service pressure and temperature.

NC-3215.2 Definitions

(a) *Design Pressure.* The provisions of NC-3112.1 shall apply.

(b) *Design Temperature.* The provisions of NC-3112.2 shall apply.

(c) *Service Conditions.* The provisions of NC-3113 shall apply.

Page 67

Page 68

TABLE NC-3215.1(a)-1
PRESSURE AND TEMPERATURE RELATIONSHIPS

Condition	Pressure at Top of Vessel	Pressure Due to Static Head [Note (1)]	Temperature	Remarks
Condition 1 For vessel as a whole	Design Pressure	None	Coincident metal	Pressure and temperature to be stamped on nameplate
At any point	Coincident pressure	Pressure to point under consideration due to static head of vessel contents	Design coincident temperature	Temperature at various points may vary, in which case the maximum for these conditions shall be used for the vessel as a whole or coincident conditions for specific locations shall be listed on the Certificate Holder's Data Report and Stamping.
Condition 2 At any point	Coincident pressure	Coincident pressure to point under consideration due to static head	Design Temperature	Higher temperature and lower pressure combinations (than Condition 1) shall be checked or a part may be designed for the Maximum Design Pressure and the Design Temperature.
Condition 3 For vessel as a whole	Test pressure	None	Test temperature	
At any point	Test pressure	Pressure at point under consideration due to static head	Test Temperature	
Condition 4 For vessel as a whole or any part	Coincident pressure		Minimum permissible temperature	Minimum permissible temperature is used together with impact testing to determine suitability of material at service temperature.
	Safety valve setting			Usually set above the service pressure but not over the limits set in NC-7000

NOTE:

(1) Similar applications shall be made for other sources of pressure variation such as that resulting from flow.

TABLE NC-3215.1(a)-1 PRESSURE AND TEMPERATURE RELATIONSHIPS

(d) *Test Pressure.* The test pressure is the pressure to be applied at the top of the vessel during the test. This pressure plus any pressure due to static head at any point under consideration is used in the applicable formula to check the vessel under test conditions.

(e) *Safety Valve Setting.* The pressure for which the safety or safety relief valves are set to open is established by NC-7000.

NC-3216 Design Stress Intensity Values

NC-3216.1 Stress Tables.

The design stress intensity values S_m are given in Tables 2A, 2B, and 4, Section II, Part D, Subpart 1. Values for intermediate temperatures may be found by interpolation. These S_m values form the basis for the various stress limits which are described in Appendix XIII and are used in determining the membrane stress intensity limits for the various load combinations given in Table NC-3217-1.

NC-3216.2 Coefficients of Thermal Expansion and Moduli of Elasticity.

Values of the coefficients of thermal expansion are in Tables TE, Section II, Part D, Subpart 2 and values of the moduli of elasticity are in Tables TM, Section II, Part D, Subpart 2.

NC-3216.3 Special Stress Limits.

The deviations given in (a), (b), and (c) below from the basic stress limits are provided to cover special conditions or configurations.

(a) *Bearing Loads*

(1) The average bearing stress for resistance to crushing under the maximum design load shall be limited to the yield strength S_y at temperature except that, when the distance to a free edge is greater than the distance over which the bearing load is applied, a stress of $1.5S_y$ at temperature is permitted. For clad surfaces, the yield strength of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.

(2) When bearing loads are applied on parts having free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. The average shear stress shall be limited to $0.6S_m$ in the case of design load stress [XIII-1123(k)] and to $0.5S_y$ in the case of design load stress plus secondary stress [XIII-1123(h)]. For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

(3) When considering bearing stresses in pins and similar members, the S_y value at temperature is applicable, except that a value of $1.5S_y$ may be used if no credit is given to bearing area within one pin diameter from a plate edge.

(b) *Pure Shear.* The average primary shear stress across a section under Design Loadings in pure shear, for example, keys, shear rings, and screw threads, shall be limited to $0.6S_m$. The maximum primary shear under Design Loadings, exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.8S_m$.

(c) *Progressive Distortion of Nonintegral Connections.* Screwed-on caps, screwed-in plugs, shear ring closures, and breech lock closures are examples of nonintegral connections which are subject to failure by bell mouthing or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore, primary plus

secondary stress intensities (XIII-1145), which result in slippage between the parts of a nonintegral connection in which disengagement could occur as a result of progressive distortion, shall be limited to the value S_y given in Tables Y-1, Section II, Part D, Subpart 2.

NC-3217 Design Criteria

These design requirements provide specific design rules for certain commonly used pressure vessel shapes under pressure loading and, within prescribed limits, rules for the treatment of other loadings. Simplified criteria are included for determining whether an analysis for cyclic operation shall be made. The thickness of the vessel parts and attached supports covered by these rules shall be determined by the applicable formula using the most severe combination of loadings and design stress intensities kS_m expected to occur simultaneously during Design, Service, and Test. The basis for these formulas is given in (a) through (d) below. Table NC-3217-1 lists values of k that are appropriate for various load combinations.

(a) The theory of failure used in this Subarticle is the maximum shear stress theory, except in the case

Page 69

of some specifically designated configurations, shapes, or design rules included as a part of this Subarticle. Stress intensity is defined as two times the maximum shear stress.

**TABLE NC-3217-1
STRESS INTENSITY k FACTORS FOR DESIGN,
SERVICE, AND TEST LOAD COMBINATIONS**

Service Limits [Note (1)]	k [Note (2)]
Design	1.0
Level A [Note (3)]	1.0
Level B [Note (3)]	1.1
Level C	1.2
Level D [Note (4)]	2.0
Test	1.25 for hydrostatic test and 1.15 for pneumatic test (see NC-3218.1 for special limits)

NOTES:

- (1) For Design Limits, use Design Pressure at design metal temperature; for Service Limits, use service pressure at service metal temperature; for Test Limits, use test pressure at test metal temperature.
- (2) The condition of structural instability or buckling must be considered.
- (3) See NC-3219 and Appendix XIV.
- (4) When a complete analysis is performed in accordance with NC-3211.1(c), the stress limits of Appendix F may be applied.

TABLE NC-3217-1 STRESS INTENSITY k FACTORS FOR DESIGN, SERVICE AND TEST LOAD COMBINATIONS

(b) The average value of the general primary membrane stress intensity across the thickness of the section under consideration P_m , due to any combination of pressure and mechanical loadings expected to occur simultaneously, should not exceed the design stress intensity value kS_m .

(c) The local primary membrane stress intensity P_L due to any combination of pressure and mechanical loadings expected to occur simultaneously is limited to $1.5kS_m$. The distance over which the stress intensity exceeds $1.1kS_m$ shall not extend in the meridional direction more than $1.0\sqrt{Rt}$, where R is the mean radius at the midsurface of the shell or head and t is the nominal thickness of the shell or head at the point under consideration.

(d) The general or local primary membrane plus bending stress intensity (P_m or P_L) + P_b due to any combination of pressure and mechanical loadings expected to occur simultaneously shall not exceed $1.5kS_m$. When the design of vessels involves combinations of calculated stresses, the provisions of Appendix XIII apply.

NC-3217.1 Secondary Stresses.

Secondary stresses may exist in vessels designed and fabricated in accordance with the rules of this Subarticle, but limitations are provided to restrict such stresses to levels consistent with the rules in Appendix XIII. Where details are not covered or where design conditions exceed the formula limitations, a detailed stress analysis in accordance with the rules of Appendix XIII shall be made. Secondary stresses need be evaluated only for Level A and Level B Limits.

NC-3217.2 Definitions

P_m	= general primary membrane stress intensity, psi. This stress intensity is derived from the average value across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.
P_L	= local primary membrane stress intensity, psi. This stress intensity is derived from the average value across the solid section under consideration. It considers discontinuities but not concentrations.
P_b	= primary bending stress intensity, psi. This stress intensity is the component of primary stress proportional to distance from centroid of solid section. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.
S_m	= design stress intensity values given in Tables 2A, 2B, and 4, Section II, Part D, Subpart 1, psi
S_y	= yield strength values given in Tables Y-1, Section II, Part D, Subpart 2, psi

NC-3218 Upper Limits of Test Pressure

If the test pressure at any point in a vessel, including static head, exceeds the required test pressure defined in NC-6221 or NC-6231 by more than 6%, the upper limit shall be established by the designer using all the loadings that may exist during the test.

(a) *Hydrostatically Tested Vessels.* The hydrostatic test pressure of a completed vessel shall not exceed that value which results in the following stress intensity limits:

(1) a calculated primary membrane stress intensity P of 90% of the tabulated yield strength S at test temperature as

given in Tables Y-1, Section II, Part D, Subpart 2;

m

y

(2) a calculated primary membrane plus primary bending stress intensity $P_m + P_b$ shall not exceed the applicable limits given in (a) or (b) below:

$$(a) P_m + P_b \leq 1.35 S_y$$

$$\text{for } P_m \leq 0.67 S_y$$

$$(b) P_m + P_b \leq (2.15 S_y - 1.2 P_m) \\ \text{for } 0.67 S_y < P_m \leq 0.90 S_y$$

where S_y is the tabulated yield strength at test temperature.

(b) *Pneumatically Tested Vessels.* The limits given in (a) above shall apply to pneumatically tested vessels, except that the calculated membrane stress intensity shall be limited to 80% of the yield strength at the test temperature.

(c) *Multichamber Vessels.* In the case of multichamber vessels, pressure may be applied simultaneously to the appropriate adjacent chamber to maintain the stress intensity limits given in (a) and (b) above (NC-6600).

NC-3219 Fatigue Evaluation

When determining whether or not a fatigue analysis shall be specified, the Owner may consider experience with comparable vessels under similar conditions in accordance with the provisions of NC-3219.1. When not based upon significant applicable service experience, the need for a fatigue analysis shall be determined in accordance with the provisions of NC-3219.2 and NC-3219.3.

NC-3219.1 Service Experience.

When the Owner is considering experience with comparable vessels under similar service conditions as related to the design and service contemplated, particular attention shall be given to the possible deleterious effects of the design features of (a) through (e) below:

(a) nonintegral construction, such as the use of pad type reinforcements or of fillet welded attachments, as opposed to integral construction;

(b) use of pipe threaded connections, particularly for diameters in excess of $2\frac{3}{4}$ in. (70 mm);

(c) stud bolted attachments;

(d) partial penetration welds;

(e) major thickness changes between adjacent members.

NC-3219.2 Rules to Determine Need for Fatigue Analysis of Integral Parts of Vessels.

A fatigue analysis need not be made, provided *all* of Condition A or *all* of Condition B is met. If neither Condition A nor B is met, a detailed fatigue analysis shall be made in accordance with the rules of Appendices XIII and XIV for those parts which do not satisfy the conditions. The rules of Condition A or Condition B are applicable to all integral parts of the vessel, including integrally reinforced type nozzles. For vessels having pad-type nozzles or nonintegral attachments, the requirements of NC-3219.3 apply.

Condition A

Fatigue analysis is not mandatory for materials having a specified minimum tensile strength not exceeding 80.0 ksi (552 MPa) when the total of the expected number of cycles of types (a) plus (b) plus (c) plus (d), defined below, does not exceed 1000 cycles:

(a) is the expected design number of full range pressure cycles including startup and shutdown;

(b) is the expected number of service pressure cycles in which the range of pressure variation exceeds 20% of the Design Pressure. Cycles in which the pressure variation does not exceed 20% of the Design Pressure are not limited in number. Pressure cycles caused by fluctuations in atmospheric conditions need not be considered;

(c) is the effective number of changes in metal temperature² between any two adjacent points³ in the pressure vessel, including nozzles. The effective number of such changes is determined by multiplying the number of changes in metal temperature of a certain magnitude by the factor given in the following table, and by adding the resulting numbers. The factors are as follows:

Metal Temperature Differential,

°F	Factor
50 or less	0
51 to 100	1
101 to 150	2
151 to 250	4
251 to 350	8
351 to 450	12
Excess of 450	20

(For example: Consider a design subjected to metal temperature differentials for the following number of times:

² Thermal protection devices, such as thermal sleeves in nozzles, may be used to reduce temperature differences or thermal shock.

³ Adjacent points are defined in (a) and (b) below.

(a) For surface temperature differences:

(1) on surfaces of revolution, in the meridional direction, adjacent points are defined as points which are less than the distance $2\sqrt{Rt}$, where R is the radius measured normal to the surface from the axis of rotation to the midjoint wall, and t is the thickness of the part at the point under consideration; if the product of Rt varies, the average value of the points shall be used;

(2) on surfaces of revolution, in the circumferential direction and on flat parts (such as flanges and flat heads) adjacent points are defined as any two points on the same surface.

(b) For through-thickness temperature differences, adjacent points are defined as any two points on a line normal to any surface.

Page 71

ΔT , °F	Cycles
50	1000
90	250
400	5

the effective number of changes in metal temperature is

$$1000 (0) + 250 (1) + 5 (12) = 310$$

The number used as type (c) in performing the comparison with 1000 is then 310. Temperature cycles caused by fluctuations in atmospheric conditions need not be considered.)

(d) for vessels with welds between materials having different coefficients of expansion, is the number of temperature cycles which causes the value of $(\alpha_1 - \alpha_2) \Delta T$ to exceed 0.00034 where α_1 and α_2 are the mean coefficients of thermal expansion (Tables TE, Section II, Part D, Subpart 2) and ΔT is the operating temperature range, °F. This does not apply to cladding.

Condition B

Fatigue analysis is not mandatory when all of the conditions of (a) through (f) below are met.

(a) The expected design number of full range pressure cycles, including startup and shutdown, does not exceed the number of cycles in the applicable fatigue curve of Appendix XIV corresponding to an S_a value of 3 times the S_m value in Tables 2A, 2B, and 4, Section II, Part D, Subpart 1 for the material at the service temperature.

(b) The expected design range of pressure cycles during normal service⁴ does not exceed the quantity $(\frac{1}{3})$ times the Design Pressure times S_d/S_m , where S_d is the value obtained from the applicable fatigue curve of Appendix XIV for the specified number of significant pressure fluctuations, and S_m is the design stress intensity value found in Tables 2A, 2B, and 4, Section II, Part D, Subpart 1 for the service temperature. If the specified number of significant pressure fluctuations exceeds the maximum number of cycles defined on the applicable design fatigue curve, the S_d value corresponding to the maximum number of cycles defined on the curve may be used. Significant pressure fluctuations are those for which the range exceeds the quantity: Design Pressure times $(\frac{1}{3})$ times S/S_m , where S is defined as follows.

(1) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_d obtained from the applicable design fatigue curve for 10^6 cycles.

⁴ Normal service is defined as any set of service conditions other than startup and shutdown which are specified for the vessel to perform its intended function.

(2) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_d obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(c) The temperature difference in °F between any two adjacent points of the vessel during normal service and during startup and shutdown does not exceed $S_d/(2E\alpha)$, where S_d is the value obtained from the applicable design fatigue curve for the specified number of startup and shutdown cycles, and α is the value of the instantaneous coefficient of thermal expansion at the mean value of the temperature at the two points, as given by Tables TE, Section II, Part D, Subpart 2. E is taken from Tables TM, Section II, Part D, Subpart 2 at the mean value of the temperatures at the two points.

(d) The range of temperature difference in °F between any two adjacent points of the vessel does not change during normal service by more than the quantity $S_d/(2E\alpha)$, where S_d is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature difference fluctuations. A temperature difference fluctuation shall be considered to be significant if its total algebraic range exceeds the quantity $S/2E\alpha$, where S is defined as follows.

(1) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_d obtained from the applicable design fatigue curve for 10^6 cycles.

(2) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_d obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(e) For components fabricated from materials of differing moduli of elasticity or coefficients of thermal expansion, the total algebraic range of temperature fluctuation in °F experienced by the vessel during normal service does not exceed the magnitude $S_d/[2(E_1\alpha_1 - E_2\alpha_2)]$, where S_d is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature fluctuations, E_1 and E_2 are the moduli of elasticity, and α_1 and α_2 are the value of the instantaneous coefficients of thermal expansion at the mean temperature value involved for the two materials of construction (Tables TE, Section II, Part D, Subpart 2 and TM, Section II, Part D, Subpart 2). A temperature fluctuation shall be considered to be significant if its total excursion exceeds the quantity $S/2(E_1\alpha_1 - E_2\alpha_2)$, where S is defined as follows.

(1) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_d obtained from the applicable design fatigue curve for 10^6 cycles.

Page 72

(2) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_d obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve. If the two materials used have different applicable design fatigue curves, the lower value of S_d shall be used in applying the rules of this paragraph. This does not apply to cladding.

(f) The specified full range of mechanical loads, excluding pressure but including piping reactions, does not result in load stress intensities whose range exceeds the S_d value obtained from the applicable design fatigue curve for the total specified number of significant load fluctuations. If the total specified number of significant load fluctuations exceeds the maximum number of cycles defined on the applicable design fatigue curve, the S_d value corresponding to the maximum number of cycles defined on the curve may be used. A load fluctuation shall be considered to be significant if the total excursion of load stress intensity exceeds the quantity S , where S is defined as follows.

(1) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(2) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

NC-3219.3 Rules to Determine Need for Fatigue Analysis of Nozzles With Separate Reinforcement and Nonintegral Attachments.

A fatigue analysis of pad-type nozzles and nonintegral attachments need not be made, provided *all* of Condition AP or *all* of Condition BP is met. The rules of Condition AP are applicable only to vessels constructed of materials covered by Figs. XIV-1221.3(c)-1, XIV-1221.3(c)-2, and XIV-1221.3(c)-3. If neither Condition AP nor BP is met, a detailed fatigue analysis must be made in accordance with the rules of Appendices XIII and XIV. NC-3237 gives further limitations on pad-type nozzles.

Condition AP

Fatigue analysis of pad-type nozzles and nonintegral attachments is not mandatory for materials having specified minimum tensile strength not exceeding 80.0 ksi (552 MPa) when the total of the expected number of cycles of types (a) plus (b) plus (c) plus (d), defined below, does not exceed 400:

(a) is the expected design number of full range pressure cycles including startup and shutdown;

(b) is the expected number of service pressure cycles in which the range of pressure variation exceeds 15% of the Design Pressure. Cycles in which the pressure variation does not exceed 15% of the Design Pressure are not limited in number. Pressure cycles caused by fluctuations in atmospheric conditions need not be considered.

(c) is the effective number of changes in metal temperature² between any two adjacent points⁵ in the pressure vessel, including nozzles. In calculating the temperature difference between adjacent points, conductive heat transfer shall be considered only through welded or integral cross sections with no allowance for conductive heat transfer across unwelded contact surfaces. The effective number of changes is determined by multiplying the number of changes in metal temperature of a certain magnitude by the factor, given in the following table, and by adding the resulting numbers. The factors are as follows:

Metal Temperature Differential,

°F	Factor
50 or less	0
51 to 100	1
101 to 150	2
151 to 250	4
251 to 350	8
351 to 450	12
Excess of 450	20

(For example: Consider a design subjected to metal temperature differentials for the following number of times:

ΔT , °F	Cycles
50	1000
90	250
400	5

the effective number of changes in metal temperature is

$$1000 (0) + 250 (1) + 5 (12) = 310$$

The number used as type (c) in performing the comparison with 1000 is then 310. Temperature cycles caused by fluctuations

in atmospheric conditions need not be considered.)

5 Adjacent points are defined as points which are spaced less than the distance $2\sqrt{Rt}$ from each other, where R and t are the mean radius and thickness, respectively, of the vessel, nozzle, flange, or other part in which the points are located.

(d) for vessels with welds between materials having different coefficients of expansion, is *the number of temperature cycles* which causes the value of $(\alpha_1 - \alpha_2) \Delta T$ to exceed 0.00034, where α_1 and α_2 are the mean coefficients of thermal expansion (Tables TE,

Page 73

Section II, Part D, Subpart 2) and ΔT is the service temperature range, °F. This does not apply to cladding.

Condition BP

All of the requirements of NC-3219.2, Condition B, are met using the adjusted values in (a) through (c) below.

(a) Use a value of 4 instead of 3 in Condition B(a).

(b) Use a value of one-quarter instead of one-third in Condition B(b).

(c) Use a value of 2.7 instead of 2 in the denominator of Conditions B(c), B(d), and B(e).

NC-3220 DESIGN CONSIDERATIONS

NC-3221 Design Loadings

The provisions of NC-3210 apply.

NC-3222 Special Considerations

The provisions of NC-3121 and NC-3214 apply.

NC-3223 General Design Rules

NC-3223.1 General Requirements.

The design shall be such that the design rules of NC-3200 are satisfied for all configurations and loadings, using the design stress intensity values S_m of Tables 2A, 2B, and 4, Section II, Part D, Subpart 1 in the various formulas.

NC-3223.2 Design Reports.

The Certificate Holder shall provide a Design Report conforming to the requirements of NC-3211.1(e).

NC-3224 Vessels and Parts Under Internal Pressure

NC-3224.1 General Requirements.

The thickness of vessels and parts under internal pressure shall be not less than that computed by the formulas in the following paragraphs. In addition, provision shall be made for the applicable load combinations listed in NC-3218 in establishing the value of F as defined below.

NC-3224.2 Nomenclature.

The symbols used are defined below. Except for test conditions, dimensions used or calculated shall be in the corroded condition.

t	= minimum required thickness of shell, in.
P	= internal pressure at the top of vessel plus any pressure due to the static head of the fluid, at any point under consideration,

	psi
R	= inside radius of the shell under consideration, in. This radius is measured normal to the surface from the axis of revolution.
R_L	= radius of a cylinder at the large end of a cone to cylinder junction, in.
R_s	= radius of a cylinder at the small end of a cone to cylinder junction, in.
α	= one-half of the apex angle of a cone to cylinder junction
t_r	= Q times the required thickness of a cylinder calculated in accordance with NC-3224.13(b)(6)(b), in.
Q	= a factor in the formulas for cone to cylinder junctions depending on P/S and α
r	= inside knuckle radius of torispherical and toriconical heads, in.
S	= membrane stress intensity limit from Tables 2A, 2B, and 4, Section II, Part D, Subpart 1 multiplied by the stress intensity factor in Table NC-3217-1 = kS_m lb/sq in.
D	= inside diameter of a head skirt or inside length of the major axis of an ellipsoidal head or inside diameter of a conical head at the point under consideration measured perpendicular to the axis of revolution, in.
F	= meridional membrane force in the shell wall at the point under consideration resulting from primary loadings other than internal pressure, lb/in. length of circumference. If this force is not uniform, as when resulting from wind or earthquake moment loading, the loading requiring the greatest shell thickness shall be used where the tensile load is positive.
h	= one-half the length of the minor axis of an ellipsoidal head or the inside depth of an ellipsoidal head, measured from the tangent line, in.
k	= stress intensity factor for design, service, and test load combination from Table NC-3217-1
L	= inside spherical or crown radius of torispherical and hemispherical heads, in.

NC-3224.3 Minimum Thickness of Cylindrical Shells.

The minimum thickness of cylindrical shells shall be the greatest of the thicknesses determined by (a), (b), and (c) below.

(a)

$$t = \frac{PR}{S - 0.5P}$$

If $P > 0.4S$, the following equation must be used:

Page 74

$$\ln \frac{(R + t)}{R} = \frac{P}{S}$$

where $\ln$ is the natural log.

(b) If F is positive and exceeds $0.5PR$,

$$t = \frac{0.5PR + F}{S - 0.5P}$$

(c) If F is negative, the condition of axial structural instability or buckling shall be considered separately (see NC-3245).

NC-3224.4 Minimum Thickness of Spherical Shells.

The minimum thickness of spherical shells shall be the greatest of the thicknesses determined by (a), (b), and (c) below.

(a)

$$t = \frac{0.5PR}{S - 0.25P}$$

If $P > 0.4S$, the following equation may be used:

$$\ln \frac{(R + t)}{R} = \frac{0.5P}{S}$$

(b) If F is positive,

$$t = \frac{0.5PR + F}{S - 0.25P}$$

(c) If F is negative, the condition of instability shall be considered. NC-3245 for cylinders may be used for spheres, provided biaxial compression does not exist.

NC-3224.5 Minimum Thickness of Formed Heads.

The minimum thickness at the thinnest point after forming of ellipsoidal, torispherical, and hemispherical heads under pressure acting against the concave surface shall be determined by the appropriate rule or formula in the following subparagraphs.

6 The head design curves have been developed considering membrane stress requirements, plastic collapse, cyclic load conditions, and the effects of maximum allowable tolerances in accordance with NC-4222. See A-4000 of Appendix A for the design formulas for the curves of Fig. NC-3224.6-1.

7 Heads having $D/2h = 2$ have equivalent torispherical properties of a torisphere of $LD = 0.90$ and $r/D = 0.17$.

NC-3224.6 Minimum Thickness of Ellipsoidal Heads.^{6,7}

The minimum thickness of a 2:1 ellipsoidal head shall be established using the procedures given in NC-3224.8 and the curve of Fig. NC-3224.6-1 which is labeled "2:1 ellipsoidal head." Ellipsoidal head designs which have $D/2h$ values

different from 2 shall be analyzed as equivalent torispherical heads or according to Appendix II, XIII, or XIV. The cylindrical shell to which the head is attached shall be equal to or greater in thickness than the required head thickness for a distance, measured from the tangent line along the cylinder, of not less than $\sqrt{Rt}$. Transition joints to shells of thickness less than the required head thickness shall not be located within the minimum distance. Transition joints to shells of thickness greater than the required head thickness may be located within this minimum distance and shall be in accordance with NC-3361 and Fig. NC-3358-1.

NC-3224.7 Minimum Thickness of Hemispherical Heads.

For hemispherical heads, the thickness shall be as required for spherical shells, NC-3224.4. The requirements for the transition to cylindrical shells of different thickness, given in NC-3361 and Fig. NC-3361-1, shall be met.

NC-3224.8 Minimum Thickness of Torispherical Heads.⁷

The minimum thickness of a torispherical head having $t/L \geq 0.002$ up to a t/L where $P/S \leq 0.08$ (approximately $t/L = 0.04$ to 0.05) shall be established by using the curves in Fig. NC-3224.6-1. Interpolation may be used for r/D values which fall within the range of the curves; however, no extrapolation of the curves is permitted. For designs where $P/S > 0.08$, which is above the upper limit of Fig. NC-3224.6-1, the thickness shall be set by the following formula:

$$t = \frac{D}{2} (e^{P/S} - 1)$$

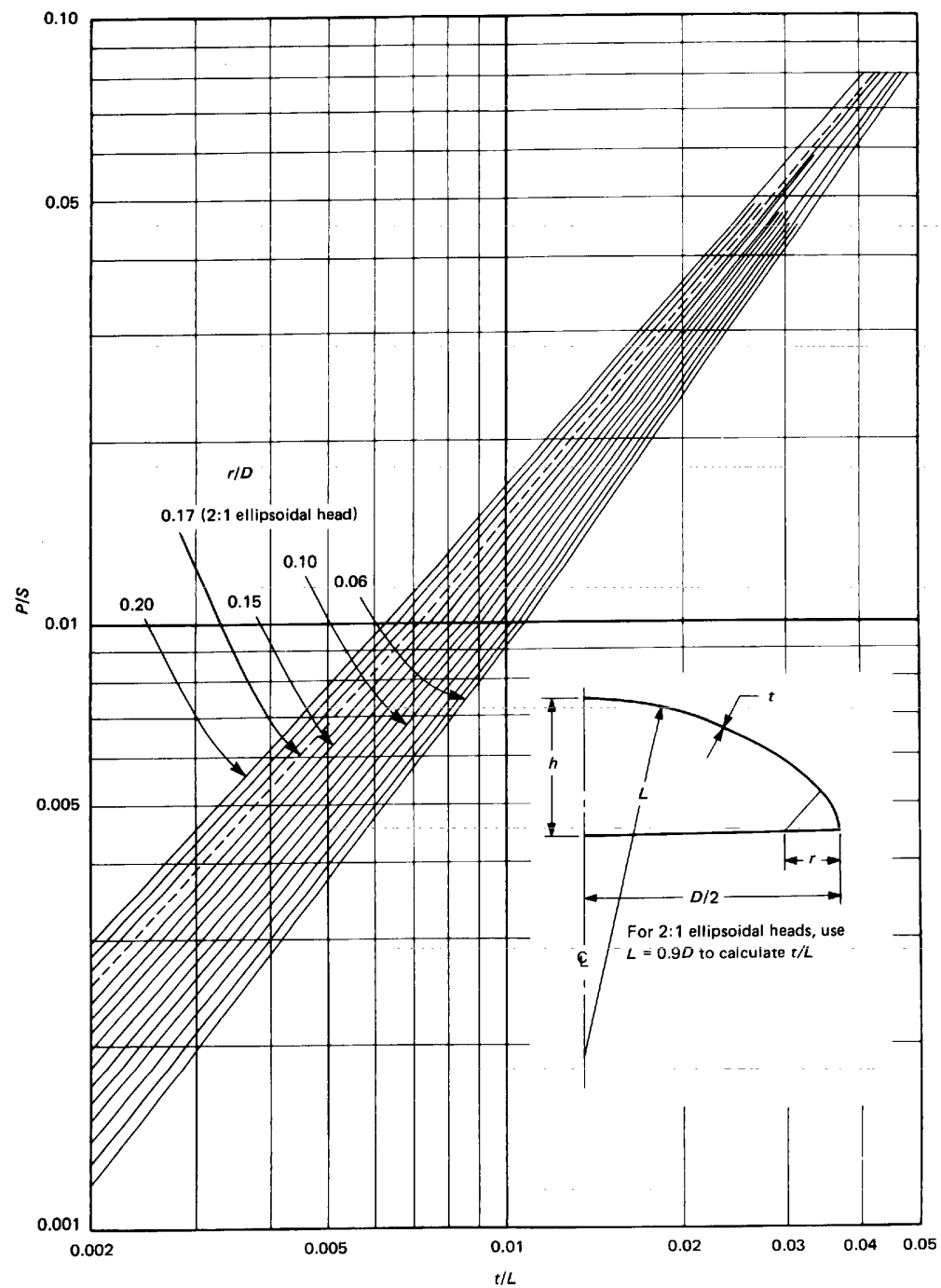
Where $t/L < 0.002$, which is below the lower limit of Fig. NC-3224.6-1, the head design must be analyzed according to Appendix II, XIII, or XIV. The cylindrical shell to which the head is attached shall be equal to or greater in thickness than the required head thickness for a distance, measured from the tangent line along the cylinder, of not less than $\sqrt{Rt}$. Transition joints to shells of thickness less than the required head thickness shall not be located within this minimum distance. Transition joints to shells of thickness greater than the required head thickness may be located within this minimum distance and shall be in accordance with NC-3361 and Fig. NC-3358-1.

NC-3224.8.1 Crown and Knuckle Radii.

In connection with the design procedures of NC-3224.8 and Fig. NC-3224.6-1, the inside crown radius to which

Page 75

an unstayed head is formed shall not be greater than the inside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall not be less than 6% of the outside diameter of the skirt nor less than three times the head thickness.



[98]

FIG. NC-3224.6-1 DESIGN CURVES FOR TORISPHERICAL HEADS AND 2:1 ELLIPSOIDAL HEADS

NC-3224.9 Minimum Thickness of Integral Head Skirts.

In addition to the requirements of NC-3224.8 or NC-3224.6, when an integral head skirt is provided, the skirt thickness shall not be less than the required thickness of a seamless shell of the same diameter. All transition joints shall be in accordance with NC-3361 and Fig. NC-3358-1.

NC-3224.10 Composite Head Shapes.

A head for a cylindrical shell may be built up of several head shapes, the thicknesses of which satisfy the requirements of the appropriate formulas above. The adjoining shapes must be so formed that they have a common tangent transverse to the joint. Any taper at a joint shall be within the boundary of the shape having the thinner wall (Fig. NC-3361-1).

NC-3224.11 Loadings on Heads Other Than Pressure.

Provision shall be made for other loadings given in NC-3212. For torispherical and ellipsoidal heads, the effect of other loadings must be determined in accordance with Appendix II, XIII, or XIV. For the conical or spherical portions of heads, the effect of composite loading may be treated as in NC-3224.3, NC-3224.4, and NC-3224.13(a)(4).

NC-3224.12 Toriconical Heads.

(In preparation.)

NC-3224.13 Reducer Sections

(a) General Requirements

(1) *Applicable Formulas and Rules.* These rules apply to concentric reducer sections when all the longitudinal loads are transmitted wholly through the shell of the reducer. When loads are transmitted in part or as a whole by other elements, such as inner shells, stays, or tubes, these rules do not apply.

(2) *Minimum Thickness of Reducer Elements.* The thickness of each element of a reducer under internal pressure shall not be less than that computed by the applicable formula. In addition, provisions shall be made for any of the other loadings listed in NC-3212.

(3) *Transition Section Reducers Joining Two Cylindrical Shells.* A transition section reducer consisting of one or more elements may be used to join two cylindrical shell sections of different diameters but with a common axis, provided these requirements are met.

(4) *Minimum Thickness of Conical Shells.* The minimum thickness of conical shells shall be determined by the same formulas as for cylindrical shells in which R is the radius measured normal to the wall surface at the point under consideration. NC-3224.13(b) and NC-3224.13(c) give rules for cone to cylinder junctions of the large and small end, respectively.

(a)

$$t = \frac{PR}{S - 0.5P}$$

If $P > 0.4S$,

$$\ln \frac{(R + t)}{R} = \frac{P}{S}$$

(b) If F is positive and exceeds $0.5 PR$,

$$t = \frac{0.5PR + F}{S - 0.5P}$$

(c) If F is negative, the condition of axial structural instability or buckling must be considered separately. NC-3245 for cylinders may be used for conical sections.

(5) *Knuckle Tangent to the Larger Cylinder.* When a knuckle is used at the large end of a reducer section, it shall have a shape that is a portion of an ellipsoidal, hemispherical, toriconical, or torispherical head. The thickness and other dimensions shall satisfy the requirements of NC-3224.5.

(6) *Combination of Elements to Form a Reducer.* When elements having different thicknesses are combined to form a reducer, the joints including the plate taper shall lie entirely within the limits of the thinner element being joined.

(7) *Combination of Shapes to Form a Toriconical Reducer.* A toriconical reducer may be shaped as a portion of a toriconical head or a portion of an ellipsoidal head plus a conical section, provided the design of the small end of the reducer element satisfies the requirements of NC-3224.13(c).

(b) *Supplementary Requirements for Reducer Sections and Conical Heads, Large End.* These rules apply, provided the requirements of (1) through (6) below are met:

(1) the two parts to be joined have the same rotational axis;

(2) the load is internal pressure (see NC-3224.11);

(3) the joint is a butt weld having its surfaces merge smoothly, both inside and outside, with the adjacent cone and cylinder surfaces without reducing the thickness [NC-3252.2(b)];

Page 77

(4) the weld at the junction is radiographed and meets the requirements of NC-5250;

(5) the junction is not closer than $4\sqrt{R_L \times t_r}$ to another junction or major discontinuity;

(6) *Reinforcement Requirements:*

(a) *When Inherent Reinforcement Is Adequate.* The thickness of the cone and cylinder forming a junction at the large end for half apex angles up to 30 deg. need not be thicker than required by NC-3224.3 or NC-3224.13(a)(4)(a), if the point representing the junction lies in the Adequate region of Fig. NC-3224.13(b)(6)(a)-1.

(b) *Requirements for Integral Reinforcement.* When the half-apex angle exceeds the maximum permitted by Fig. NC-3224.13(b)(6)(a)-1, the cone and cylinder must be reinforced in the area adjacent to the junction. Figure NC-3224.13(b)(6)(b)-1 gives Q values for ratios of Design Pressure P to S and values of α up to 30 deg. The junction may be reinforced by making both the cylinder and cone thickness equal to t_r and provided that the requirements of

(1) through (3) below are met.

(1) The increased cylinder thickness extends a minimum distance of $2.0\sqrt{R_L t_r}$ from the junction, where R_L is the radius of the cylinder at the large end of the cone.

(2) The increased cone thickness extends a minimum distance of $2.0\sqrt{R_L t_r / \cos \alpha}$ from the junction.

(3) In no case shall t be less than the thickness required for the cone in accordance with NC-3224.3.

(c) *Supplementary Requirements for Reducer Section's Small End.* These rules apply, provided the requirements of (1) through (6) below are met:

(1) the two parts to be joined have the same rotational axis;

(2) the load is internal pressure (NC-3224.11);

(3) the joint is a butt weld having its surfaces merge smoothly, both inside and outside, with the adjacent cone and cylinder surfaces without reducing the thickness [NC-3252.2(b)];

(4) the weld at the junction is radiographed and meets the requirements of NC-5250;

(5) the junction is not closer than $2.8\sqrt{R_s t_r}$ to another junction or discontinuity, where R_s is the radius of the cylinder at the small end of the cone;

(6) *Reinforcement Requirements:*

(a) *When Inherent Reinforcement Is Adequate.* The thickness of the cone and cylinder forming a junction at the small end of half apex angles up to 30 deg. need not be thicker than required by NC-3224.3 if the point representing the junction lies in the Adequate region of Fig. NC-3224.13(c)(6)(a)-1.

(b) *Requirements for Integral Reinforcement.* When the half apex angle exceeds the maximum permitted by Fig. NC-3224.13(c)(6)(a)-1, the cone and cylinder must be reinforced in the area adjacent to the junction. Figure NC-3224.13(c)(6)(b)-1 gives Q values for ratios of Design Pressure P to S and values of α up to 30 deg. The junction may be reinforced by making both the cylinder and cone thickness equal to t_r and provided that the requirements of (1) through (3) below are met.

(1) The increased cylinder thickness t_r extends a minimum distance $1.4\sqrt{R_s t_r}$ from the junction.

(2) The increased cone thickness t_r extends a minimum distance $1.4\sqrt{R_s t_r / \cos \alpha}$ from the junction.

(3) In no case shall t_r be less than the thickness required for the cone in accordance with NC-3224.3 at a distance $1.4\sqrt{R_s t_r / \cos \alpha}$ from the junction.

(d) *Supplementary Requirements for Reducer Sections, Small End, Treated As Openings.* Cone to cylinder junctions at the small ends of reducers as shown in Fig. NC-3224.13(d)-1 may be treated as openings in conical heads provided the requirements of (1) through (4) below are met.

(1) The diameter d of the small end is not more than one-half the diameter of the large end.

(2) The half apex angle α is greater than 30 deg. but not greater than 60 deg.

(3) The reinforcement meets the requirements of NC-3232 and NC-3234.1, except that the total cross-sectional area of reinforcement A required at the junction in any plane for a vessel under internal pressure shall not be less than $A = dt \tan \alpha/2$ and two-thirds of this area shall be provided within a limit of $0.5 \sqrt{dt/2}$ measured along the cylinder and $0.5 \sqrt{dt / 2 \cos^2 \alpha}$ measured along the cone.

(4) Reinforcement shall be integral with cone or cylinder and all other applicable requirements of NC-3230 are met.

NC-3224.14 Minimum Thickness of Nozzle Necks and Other Connections.

The wall thickness of a nozzle neck or other connection shall not be less than the thickness computed for the applicable loadings plus the thickness added for corrosion and erosion allowance and, except for access openings and openings for inspection only, not less than the smaller of (a) and (b) below:

(a) the required thickness of the shell or head to which the connection is attached plus the corrosion allowance provided in the shell or head adjacent to the connection;

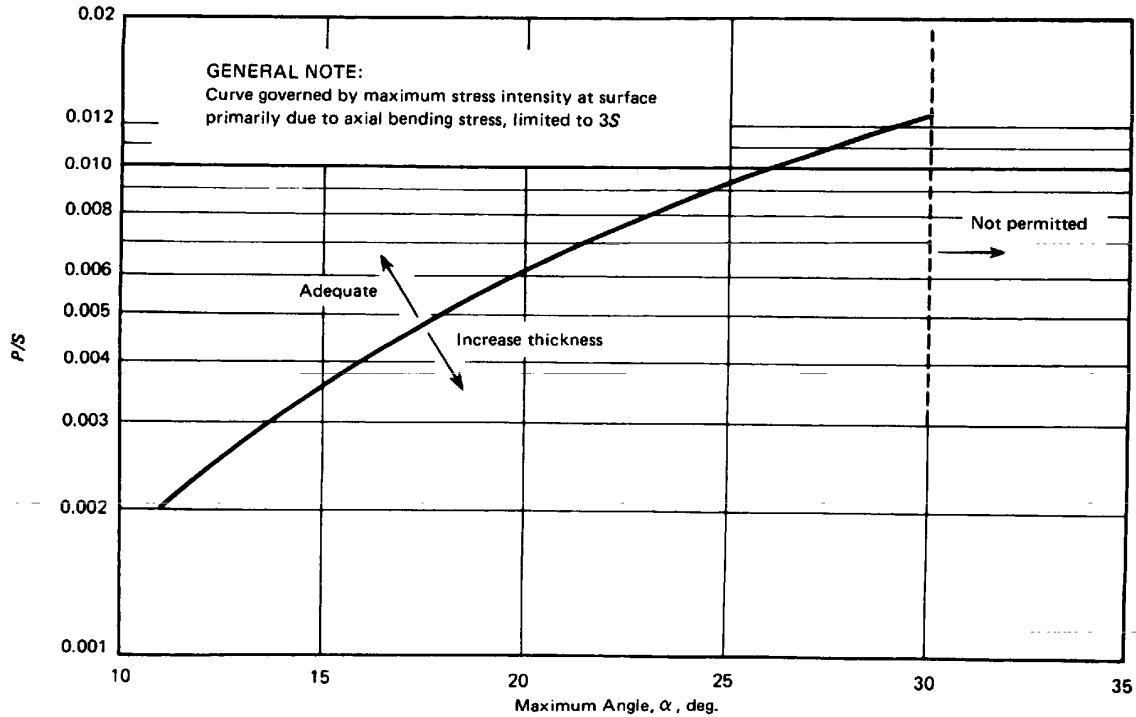


FIG. NC-3224.13(b)(6)(a)-1 INHERENT REINFORCEMENT FOR LARGE END OF CONE-CYLINDER JUNCTION

FIG. NC-3224.13(b)(6)(a)-1 INHERENT REINFORCEMENT FOR LARGE END OF CONE-CYLINDER JUNCTION

(b) the minimum thickness⁸ of standard wall pipe plus the corrosion allowance on the connections.

NC-3224.15 Other Loadings.

When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in NC-3111 other than pressure and temperature.

NC-3225 Flat Heads and Covers

The minimum thickness of unstayed flat heads, cover plates, and blind flanges shall conform to the requirements given in this paragraph. Some acceptable types of flat heads and covers are shown in Fig. NC-3225-2. The dimensions are exclusive of extra metal added for corrosion allowance.

⁸ The minimum thickness for all pipe materials is the nominal thickness listed in Table 2 of ANSI B36.10 less $12\frac{1}{2}\%$. For diameters other than those listed in the table, the minimum thickness shall be that of the next larger pipe size.

NC-3225.1 Nomenclature.

The notations used are defined as follows:

C	= a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in NC-3225.2, dimensionless (Figs. NC-3225-1 through NC-3225-3)
d	= diameter, in.
D	= bolt circle diameter, in.
h_G	= gasket moment arm, equal to the radial distance from the center line of the bolts to the line of the gasket reaction, in. (Fig. NC-3225-2)
L	= distance from center line of head to shell weld to tangent line on formed heads, in., as indicated in Fig. NC-3225-2 sketch (a)
m	= the ratio t_r/t_s , dimensionless
P	= Design Pressure, psi
r	= inside corner radius on a head formed by flanging or forging, in.
S	= design stress intensity S_m from Tables 2A, 2B, and 4, Section II, Part D, Subpart 1 multiplied by tabulated stress intensities, psi

Page 79

Page 80

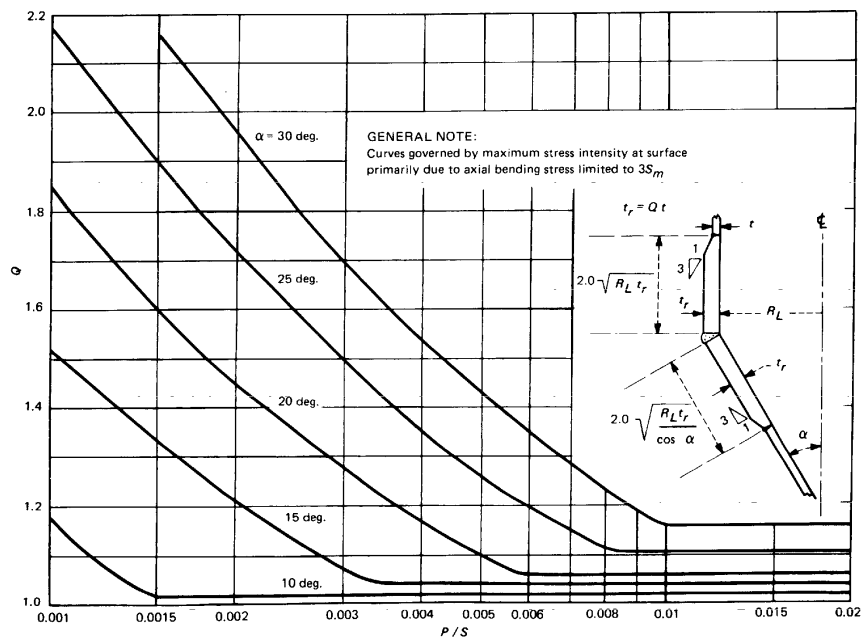


FIG. NC-3224.13(b)(6)(b)-1 VALUES FOR Q FOR SMALL END OF CONE-CYLINDER JUNCTION

FIG. NC-3224.13(b)(6)(b)-1 VALUES FOR Q FOR SMALL END OF CONE-CYLINDER JUNCTION

T	= minimum required thickness of flat head, cover, or flange, exclusive of corrosion allowance, in.
t_f	= actual thickness of the flange on a formed head, at the large end, exclusive of corrosion allowance, in.
t_p	= the smallest dimension from the face of the head to the edge of the weld preparation, in.
t_r	= required thickness of shell or nozzle for pressure, in.
t_s	= actual thickness of shell or nozzle, in.
W	= total bolt load, lb

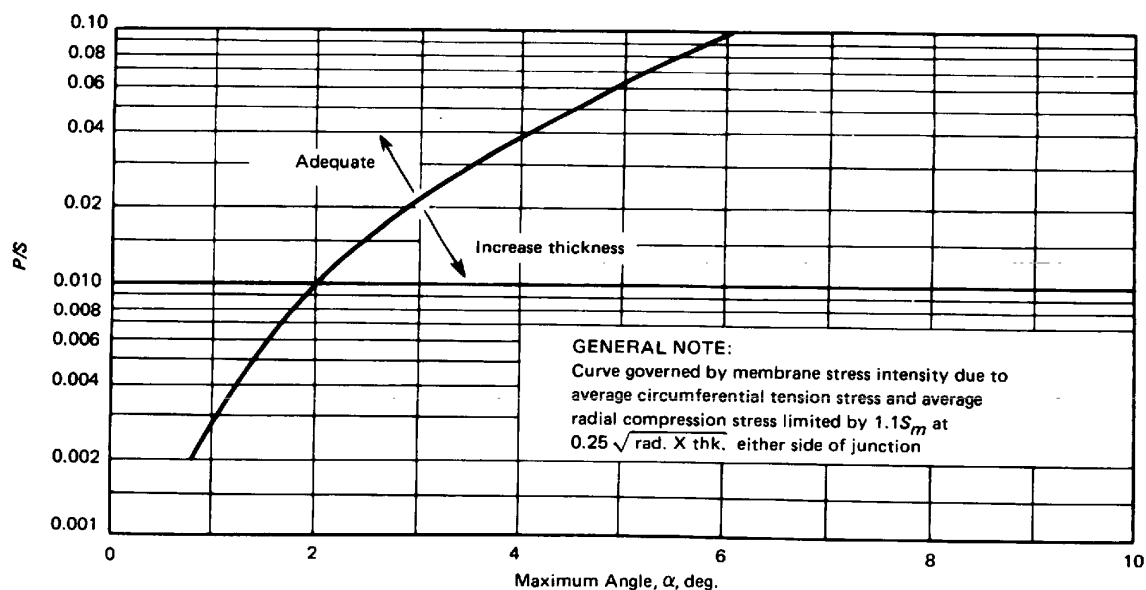


FIG. NC-3224.13(c)(6)(a)-1 INHERENT REINFORCEMENT FOR SMALL END OF CONE-CYLINDER JUNCTION

FIG. NC-3224.13(c)(6)(a)-1 INHERENT REINFORCEMENT FOR SMALL END OF CONE-CYLINDER JUNCTION

NC-3225.2 Formulas for Minimum Thickness⁹

(a) The thickness of flat heads, as shown in Figs. NC-3225-1 through NC-3225-3, shall be not less than that calculated by the following equation:

$$T = d\sqrt{CP/S}$$

(b) The thickness of cover plates and blind flanges attached by bolts causing an edge moment as shown in Fig. NC-3225-2 shall be not less than that calculated by the following equation:

⁹ The formulas provide safe construction as far as stress is concerned. Greater thicknesses may be necessary if deflection would cause leakage at threaded or gasketed joints.

$$T = d\sqrt{CP/S + 1.27 Wh/Sd^3}$$

NOTE: In some cases, the initial bolt load required to seat the gasket is larger than the service bolt load. The thickness should be checked for both the service condition and the initial bolt load required to seat the gasket.

NC-3227 Quick Actuating Closures

The requirements for quick actuating closures are given in NC-3327.

NC-3230 OPENINGS AND THEIR REINFORCEMENT

NC-3231 General Requirements

The rules contained in this Subarticle provide for a satisfactory design in the vicinity of openings in the pressure shell, under pressure loading only, on the basis of its opening shape, area replacement, and distribution, provided a fatigue analysis is not required. These rules do not include design requirements for piping loads that may be imposed on the nozzle or shell portion

Page 81

or both and that may be added to the pressure loadings. Such additional loadings shall be considered by the designer.

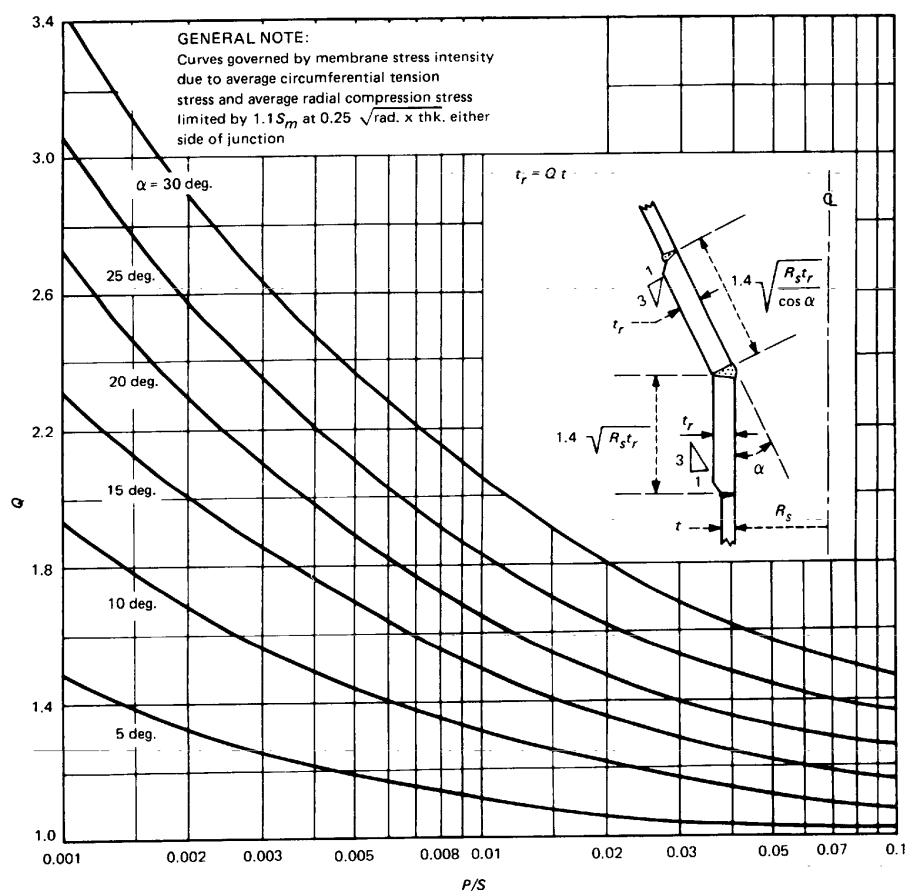


FIG. NC-3224.13(c)(6)(b)-1 VALUES FOR Q FOR SMALL END OF CONE-CYLINDER JUNCTION

FIG. NC-3224.13(c)(6)(b)-1 VALUES FOR Q FOR SMALL END OF CONE-CYLINDER JUNCTION

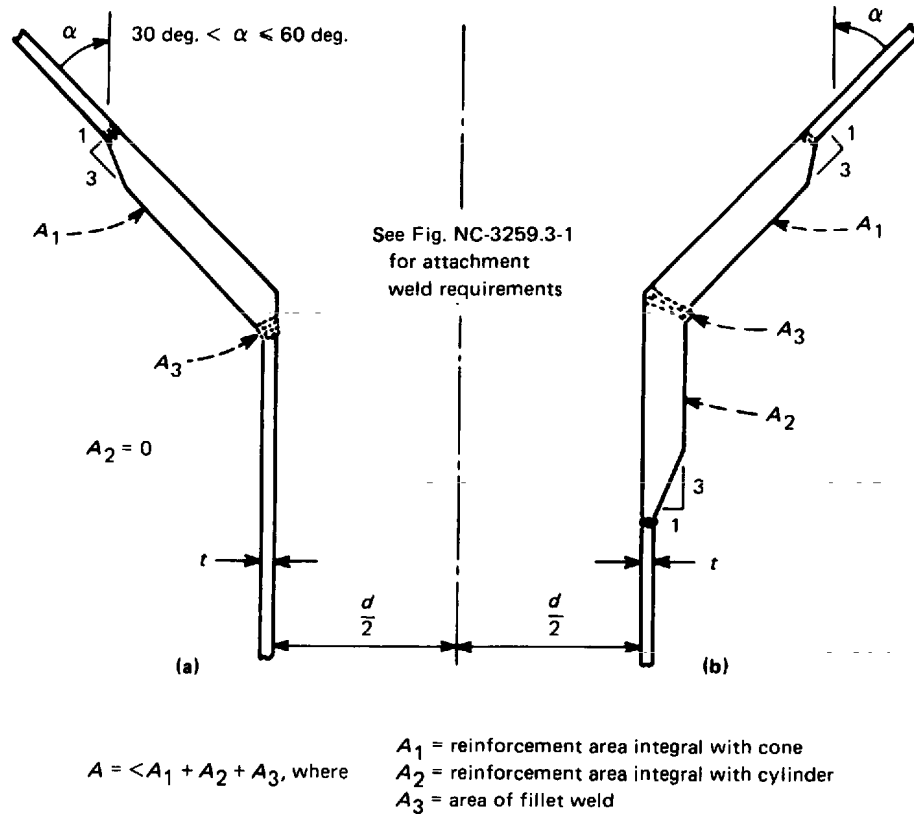


FIG. NC-3224.13(d)-1 CONE-CYLINDER JUNCTION AT SMALL END TREATED AS OPENING

FIG. NC-3224.13(d)-1 CONE-CYLINDER JUNCTION AT SMALL END TREATED AS OPENING

NC-3231.1 Dimensions and Shape of Openings

(a) Openings, except as permitted under (b), shall be circular, elliptical, or of any other shape which results from the intersection of a circular or elliptical cylinder with vessels of the shapes for which formulas are given in NC-3220, provided the requirements of (1) through (4) below are met.

(1) The ratio of the diameter along the major axis to the diameter along the minor axis of the finished opening is 1.5 or less.

(2) The ratio $d/D \leq 0.50$ where d is the largest inside diameter of the intersecting nozzle and D is the inside diameter of the vessel.

(3) The arc distance measured between the center lines of adjacent nozzles along the inside surface of the shell is not less than three times the sum of their inside radii for openings in a head or for openings along the longitudinal axis of a shell and is not less than two times the sum of their inside radii for openings along the circumference of a cylindrical shell. When two nozzles in a cylindrical shell are neither in a longitudinal line nor in a circumferential arc, their center line distance along the inside surface of the shell shall be such that $[(L_c/2)^2 + (L_c/3)^2]^{1/2}$ is not less than the sum of their inside radii, where L_c is the component of the center line distance in the circumferential direction and L is the

component of the center line distance in the longitudinal direction.

(4) Reinforcement is provided around the edge of the opening in amount and distribution such that the area requirements for reinforcement are satisfied for all planes through the center of the opening and normal to the vessel surface as stipulated in NC-3232.2.

(b) Openings of other shapes or dimensions may be used subject to the requirements of Appendix XIII or Appendix XIV.

(c) Any type of opening permitted by these rules may be located in a butt welded joint.

Page 83

Page 84

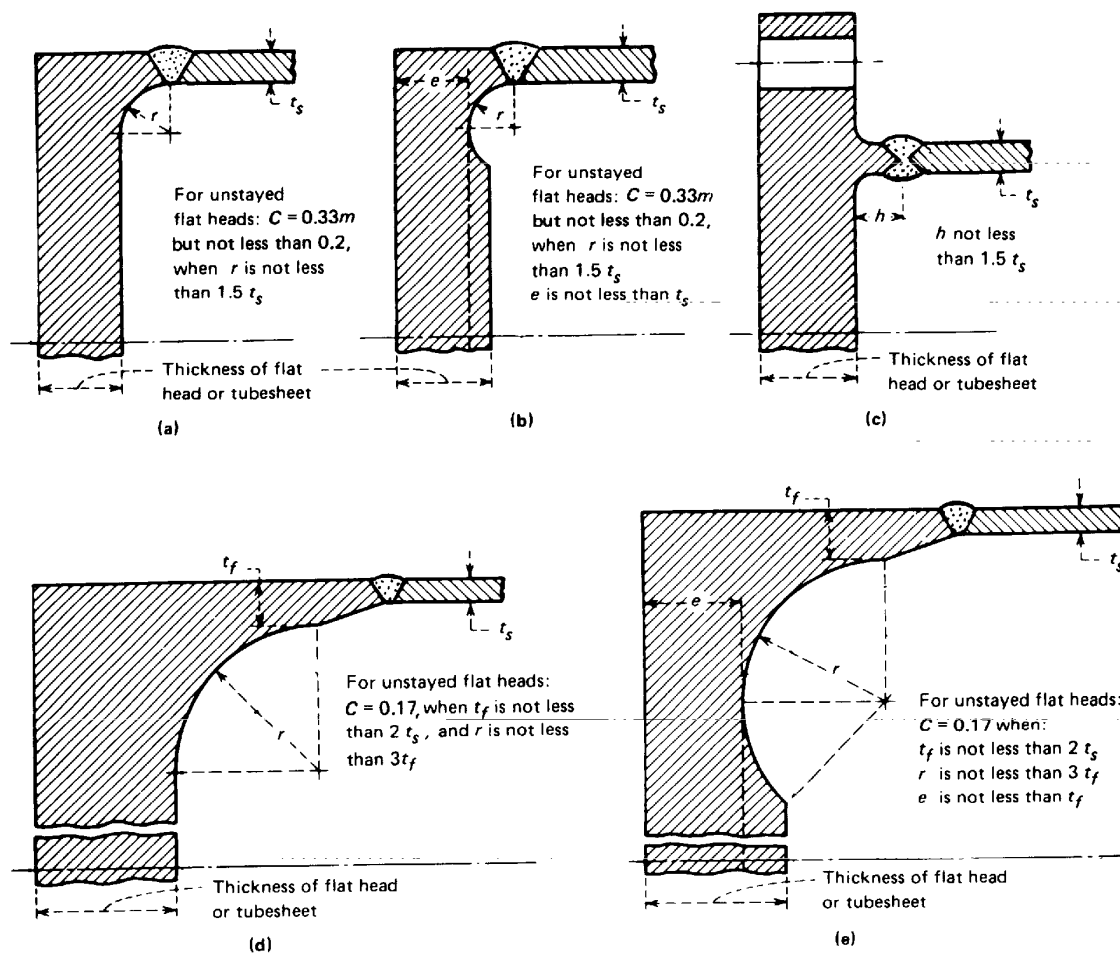


FIG. NC-3225-1 TYPICAL FLAT HEADS AND SUPPORTED AND UNSUPPORTED TUBESHEETS WITH HUBS

FIG. NC-3225-1 TYPICAL FLAT HEADS AND SUPPORTED AND UNSUPPORTED TUBESHEETS WITH HUBS

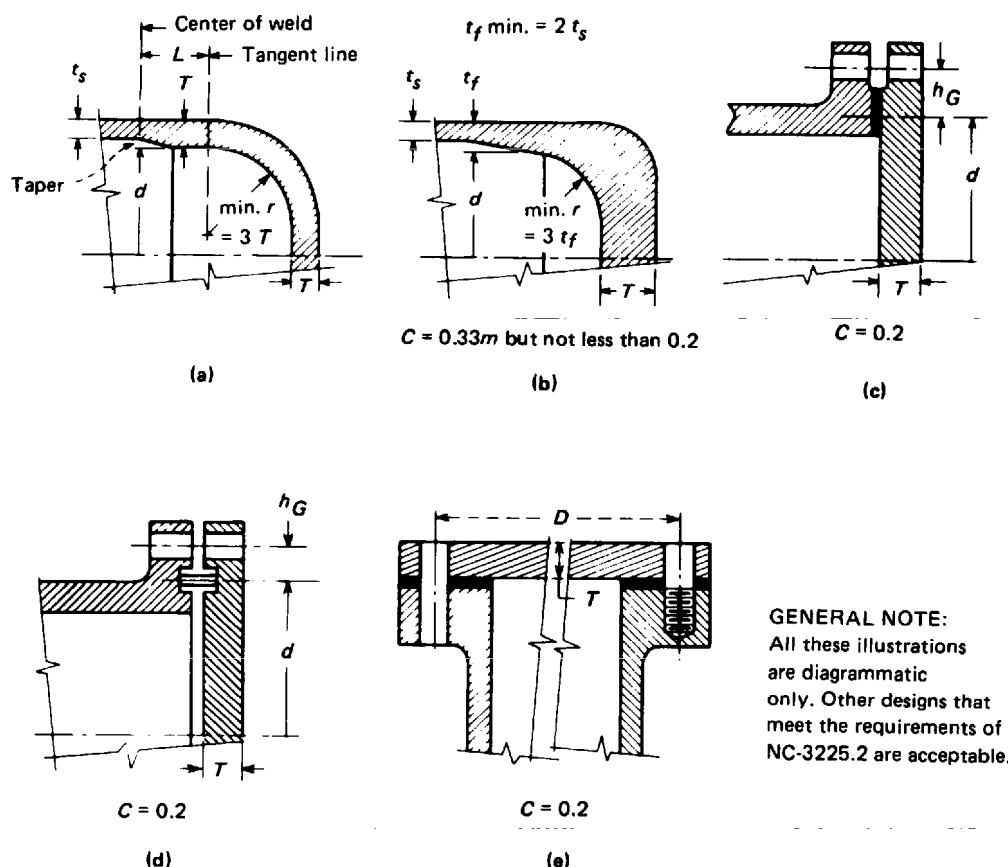


FIG. NC-3225-2 SOME ACCEPTABLE TYPES OF UNSTAYED FLAT HEADS AND COVERS

FIG. NC-3225-2 SOME ACCEPTABLE TYPES OF UNSTAYED FLAT HEADS AND COVERS

NC-3232 Reinforcement Requirements for Openings in Shells and Formed Heads

NC-3232.1 Circular Openings Not Requiring Reinforcement.

Circular openings need not be provided with reinforcement if all the requirements in (a), (b), and (c) below are satisfied.

(a) A single opening has a diameter not exceeding $0.2\sqrt{Rt}$, or if there are two or more openings within any circle of diameter, $2.5\sqrt{Rt}$, then the sum of the diameters of such unreinforced openings shall not exceed $0.25\sqrt{Rt}$.

(b) No two unreinforced openings shall have their centers closer to each other, measured on the inside of the vessel wall, than 1.5 times the sum of their diameters.

(c) No unreinforced opening shall have its center closer than $2.5\sqrt{Rt}$ to the edge of a locally stressed area in the shell where R is the mean radius and t is the nominal thickness of the vessel shell or head at the location of the openings and where locally stressed area means any area in the shell where the primary local membrane stress exceeds $1.1kS_m$, but excluding those areas where such primary local membrane stress is due to an unreinforced opening.

excluding those areas where such primary local membrane stress is due to an unreinforced opening.

NC-3232.2 Required Area of Reinforcement

(a) The total cross-sectional area of reinforcement A required in any given plane for a vessel under internal pressure shall be not less than

$$A = dt_r F$$

where

d

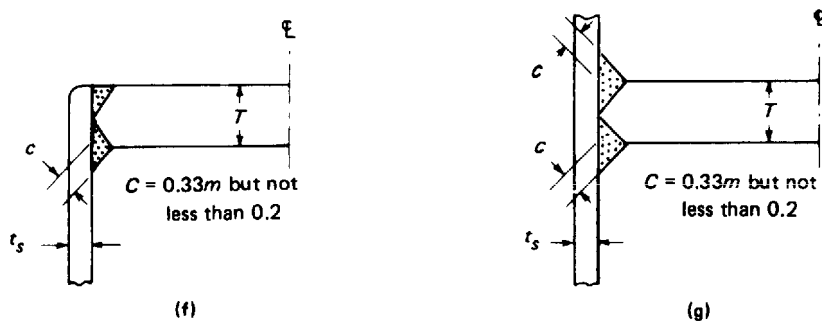
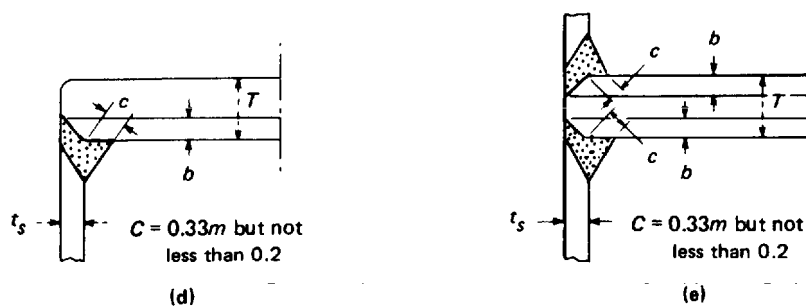
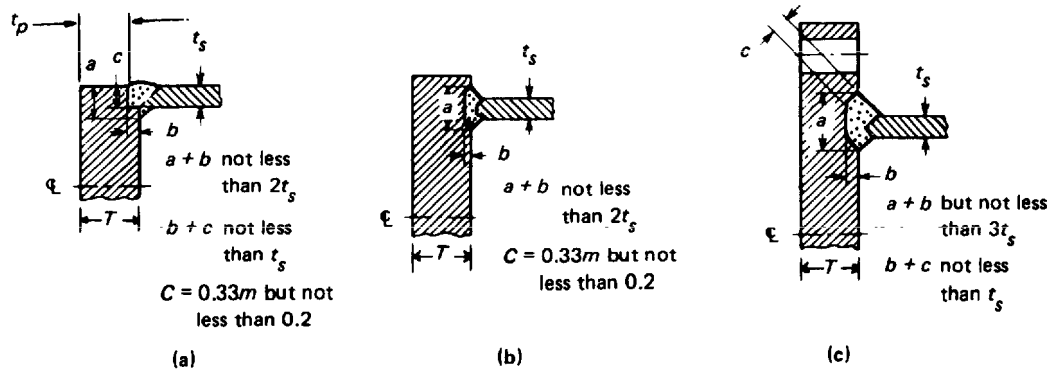
= finished diameter of a circular opening or finished dimension (chord length) of an opening on the plane being considered for elliptical and obround openings in corroded condition, in.

t_r

= the thickness which meets the requirements of NC-3220 in the absence of the opening, in.

F

= 1.00 when the plane under consideration is in the spherical portion of a head or when the given plane contains the longitudinal axis of a cylindrical shell. For other planes through a shell, use the value of F determined from Fig. NC-3332.2-1 except that, for reinforcing pads, $F = 1$.



$C \text{ min.} = 0.7 t_s \text{ or } 1/4 \text{ in., whichever is less}$
 $b = \text{the lesser of } t_s \text{ or } T/2$

FIG. NC-3225-3 ATTACHMENT OF PRESSURE PARTS TO PLATES TO FORM A CORNER JOINT

FIG. NC-3225-3 ATTACHMENT OF PRESSURE PARTS TO PLATES TO FORM A CORNER JOINT

(b) Not less than one-half the required material shall be on each side of the center line of the opening [NC-3234.1(c)].

NC-3233 Required Reinforcement for Openings in Flat Heads

(a) Flat heads that have an opening with a diameter that does not exceed one-half of the head diameter shall have a total cross-sectional area of reinforcement not less than that given by the formula

$$A = 0.5dt_r$$

where

d = the diameter of the finished opening in its corroded condition, in.

t_r = the thickness which meets the requirements of NC-3225.2 in the absence of the opening, in.

(b) Flat heads that have an opening with a diameter that exceeds one-half of the head diameter shall be designed according to Appendix XIX.

NC-3234 Limits of Reinforcement

The boundaries of the cross-sectional area in any plane normal to the vessel wall and passing through the center of the opening within which metal shall be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane and are as described in the following subparagraphs.

NC-3234.1 Limit of Reinforcement Along the Vessel Wall.

The limits of reinforcement, measured along the midsurface of the nominal wall thickness of the vessel, shall meet the following:

(a) 100% of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) the diameter of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus the sum of the thicknesses of the vessel wall and the nozzle wall;

(b) two-thirds of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) $r + 0.5\sqrt{Rt}$, where R is the mean radius of shell or head, t is the nominal vessel wall thickness, r is the radius of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus two-thirds the sum of the thicknesses of the vessel wall and the nozzle wall.

NC-3234.2 Limit of Reinforcement Normal to Vessel Wall.

The limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to the limits given in (a), (b), and (c) below.

(a) For Fig. NC-3234.2(a)-1 sketches (a) and (b), the limit is the larger of $(0.5\sqrt{r_m t_n} + k)$ or $(1.73x + 2.5t_p + k)$, but not to exceed either $2.5t$ or $(L + 2.5t_p)$.

Where

r = inside radius of nozzle

t_n	= nominal nozzle thickness
r_m	= mean nozzle radius = $r + 0.5t_n$
r_2	= transition radius between nozzle and wall
t_p	= nominal thickness of connecting pipe
t	= nominal vessel wall thickness
L	= length along nozzle with thickness of t_n plus transition length
k	= $0.73r_2$ when a transition radius (r_2) is used = the smaller of two legs of the fillet when a fillet transition is used
x	= $t_n - t_p$

(b) For Fig. NC-3234.2(a)-1 sketch (c), when $45 \geq \theta \geq 30$ deg., the limit is the larger of $(0.5\sqrt{r_m t_n})$ or $(L' + 2.5t_p)$, but not to exceed $2.5t$; when $\theta < 30$ deg., the limit is the larger $(0.5\sqrt{r_m t_n})$ or $(1.73x + 2.5t_p)$, but not to exceed $2.5t$. Where

t_n'	= $t_p + 0.667x$
x	= slope offset distance
θ	= angle between vertical and slope
L'	= length of tapered section along nozzle
r_m	= $r + 0.5t_n'$

Other terms are defined in (a) above.

(c) For Fig. NC-3234.2(a)-1 sketch (d), when reinforcing pads or insert plates are used, the limit is the larger of $(0.5\sqrt{r_m t_n} + t_e)$ or $(2.5t_n + t_e)$, but not to exceed $2.5t$. In no case can the thickness t_e used to establish the limit normal to the shell, exceed $1.5t$ or $1.73W$. Where

W	= width of added reinforcing element
t_e	= thickness of added reinforcing element

Other terms are defined in (a) above.

Page 87

Page 88

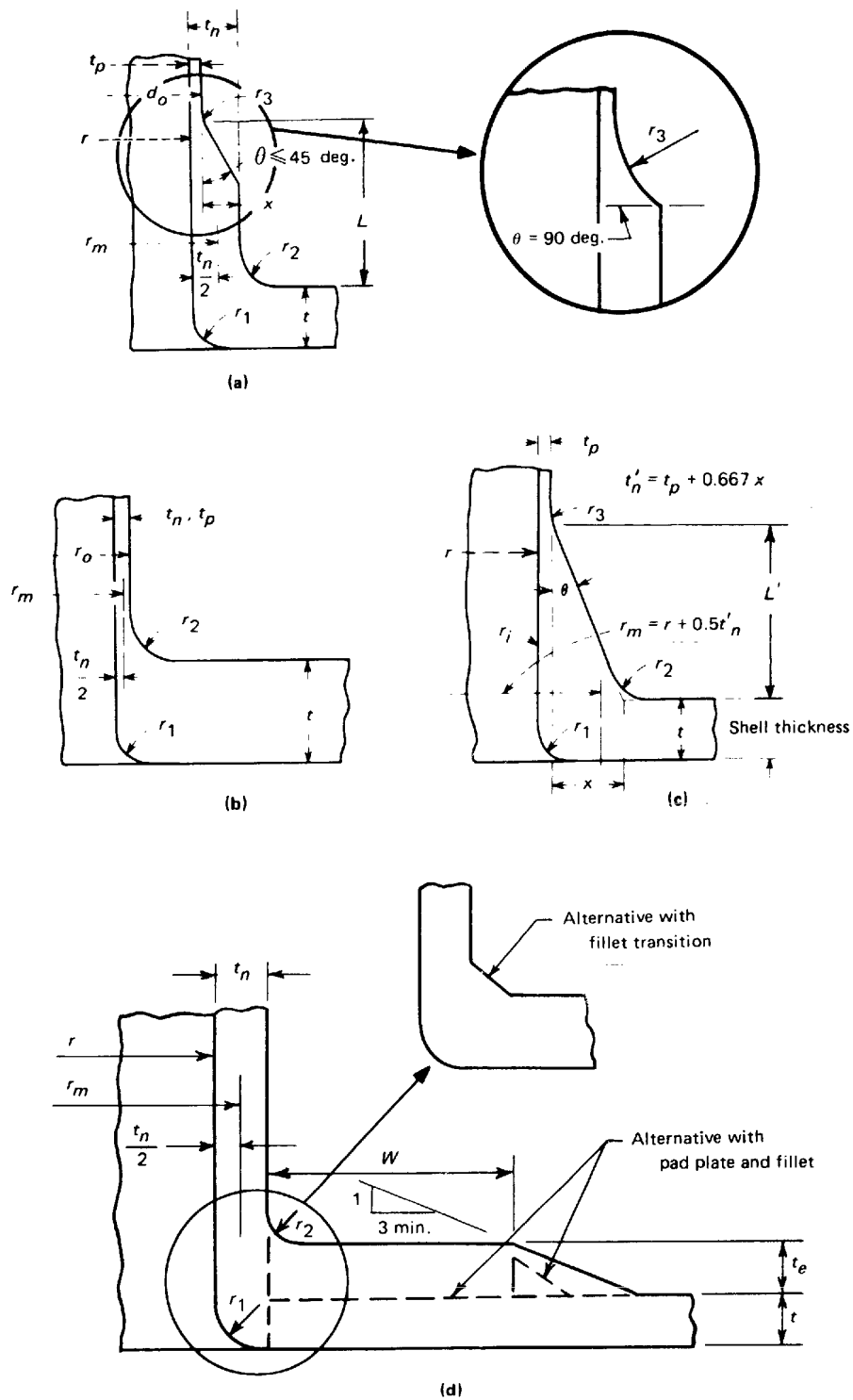


FIG. NC-3234.2(a)-1 NOZZLE NOMENCLATURE AND DIMENSIONS
Depicts Configuration Only

FIG. NC-3234.2(a)-1 NOZZLE NOMENCLATURE AND DIMENSIONS

NC-3234.3 Nozzle Piping Transitions.

The stress limits of NC-3200 shall apply to all portions of nozzles which lie within the limits of reinforcement given in NC-3234, except as noted in NC-3234.4. Stresses in the extension of any nozzle beyond the limits of reinforcement shall meet the stress limits of NC-3600.

NC-3234.4 Consideration of Standard Reinforcement.

Where a nozzle-to-shell juncture is reinforced in accordance with the rules of NC-3234, the stresses in this region due to internal pressure may be considered to satisfy the limits of NC-3217. Under these conditions, no analysis is required to demonstrate compliance for pressure induced stresses in the nozzle region. Where external piping loads are to be designed for, membrane plus bending stresses shall be calculated in the nozzle, and membrane stresses shall be calculated in the local nozzle-to-shell region. These stresses, in conjunction with pressure induced stresses, shall meet the limits of NC-3217 for $(P_m \text{ or } P_L) + P_b$. In this case, the pressure induced stresses in the $(P_m \text{ or } P_L) + P_b$ category may be assumed to be no greater than the limit specified for P_m in NC-3217 for a given condition.

NC-3235 Metal Available for Reinforcement

Metal may be counted as contributing to the area of reinforcement called for in NC-3232.2 and NC-3233, provided it lies within the area of reinforcement specified in NC-3234 and shall be limited to material which meets the requirements of (a) through (e) below:

- (a) metal forming a part of the vessel wall which is in excess of that required on the basis of primary stress intensity (NC-3221 through NC-3224 and NC-3225.2) and is exclusive of corrosion allowance;
- (b) similar excess metal in the nozzle wall, provided the nozzle is integral with the vessel wall or is joined to it by a full penetration weld;
- (c) weld metal which is fully continuous with the vessel wall;
- (d) metal not fully continuous with the shell, such as a pad continuously welded around its periphery, may be counted as reinforcement, provided the requirements of NC-4237 are met;
- (e) the mean coefficient of thermal expansion of metal to be included as reinforcement under (b), (c), and (d) above shall be within 15% of the value for the metal in the vessel wall.

NC-3235.1 Metal Not Available for Reinforcement.

Metal not fully continuous with the shell, as that in nozzles attached by partial penetration welds, shall not be counted as reinforcement.

NC-3235.2 Reinforcement Metal Limited to One Opening.

Metal available for reinforcement shall not be considered as applying to more than one opening.

NC-3236 Strength of Reinforcement Material

Material used for reinforcement shall preferably have the same design stress intensity value as that of the vessel wall. In no case shall material with an allowable design stress intensity value less than 80% of the value of the vessel wall material at the Design Temperature be used in determining area available for reinforcement. If the material of the nozzle wall or reinforcement has a lower design stress intensity value S_m than that for the vessel material, the amount of area provided by the nozzle wall or reinforcement in satisfying the requirements of NC-3232 shall be taken as the actual area provided multiplied by the ratio of the nozzle or reinforcement design stress intensity value to the vessel material design stress intensity value. No reduction in the reinforcement requirement may be made if the reinforcing material or weld metal has a design stress intensity value higher than that of the material of the vessel wall. The strength of the material at the point under consideration shall be used in fatigue analyses.

NC-3237 Requirements for Nozzles With Separate Reinforcing Plates

Except for nozzles at small ends of cones reinforced in accordance with the requirements of NC-3224.11(c), added reinforcement in the form of separate reinforcing plates may be used, provided the vessel and the nozzles meet all the conditions of (a) through (d) below.

- (a) The specified minimum tensile strengths of the materials do not exceed 80 ksi (552 MPa).
- (b) The minimum elongation of materials is 12% in 2 in.
- (c) The thickness of the added reinforcement does not exceed $1\frac{1}{2}$ times the shell thickness.
- (d) The requirements of NC-3219 for pads in cyclic service are met.

NC-3239 Alternative Rules for Opening Reinforcement

The requirements of this paragraph constitute an acceptable alternative to the rules of NC-3231 through NC-3237 and XIII-2000.

[98]

NC-3239.1 Limitations.

These rules are applicable only to openings utilizing nozzles in vessels within the limitations of (a) through (f) below.

Page 89

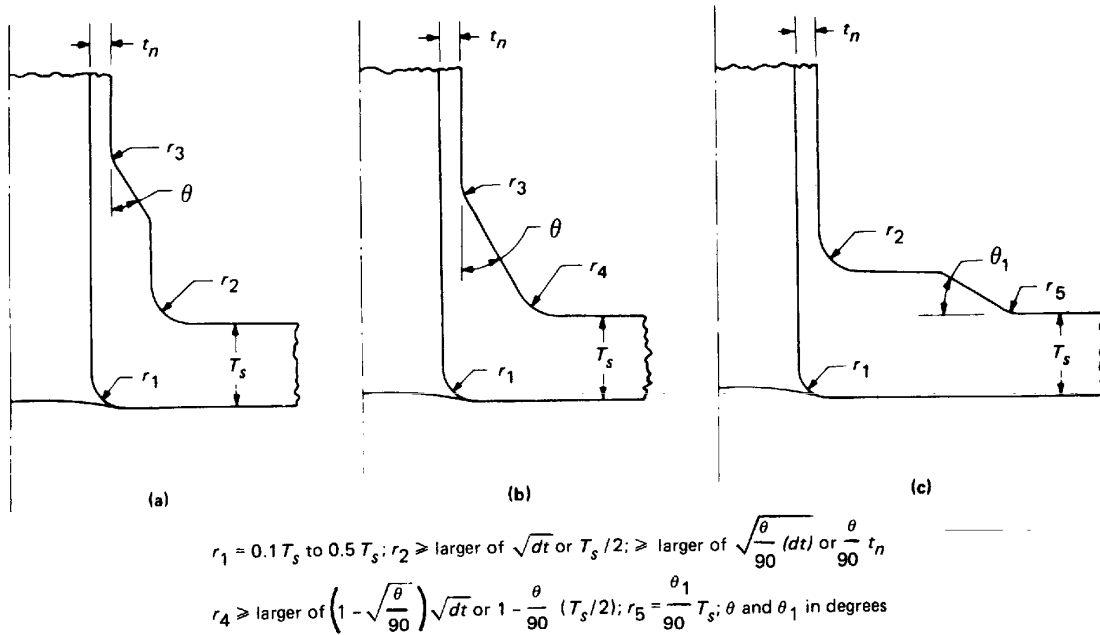


FIG. NC-3239.1(b)-1 EXAMPLES OF ACCEPTABLE TRANSITION DETAILS

FIG. NC-3239.1(b)-1 EXAMPLES OF ACCEPTABLE TRANSITION DETAILS

- (a) The nozzle is circular in cross section and its axis is perpendicular to the vessel or head.
- (b)

parts. Details such as those shown in Figs. NC-4266(a)-1, NC-4266(b)-1 sketches (a), (b), and (c), and NC-4266(c)-1 are acceptable. However, fillet welds must be ground to a radius in accordance with Fig. NC-3239.1(b)-1.

(c) In the case of spherical shells and formed heads, at least 40% of the total nozzle reinforcement area shall be located beyond the outside surface of the minimum required vessel wall thickness.

(d) The spacing between the edge of the opening and the nearest edge of any other opening is not less than the smaller of $1.25 (d_1 + d_2)$ and $2.5\sqrt{Rt_r}$, but in any case, not less than $1.0 (d_1 + d_2)$, where d_1 and d_2 are the inside diameters of the openings.

(e) The materials used in the nozzle reinforcement and vessel wall adjacent to the nozzle shall have a ratio of UTS/YS of not less than 1.5, where

UTS = specified minimum ultimate tensile strength

YS = specified minimum yield strength

(f) The following dimensional limitations are met:

	Nozzles in Cylindrical Vessels	Nozzles in Spherical Vessels or Heads
D/t	10 to 100	10 to 100
d/D	0.5 max.	0.5 max.
$d/\sqrt{Dt}$	...	0.8 max.
$d/\sqrt{Dt_n} \sqrt{t/t_n}$	1.5 max.	...

[98]

NC-3239.2 Nomenclature

D	= inside diameter, in corroded condition, of cylindrical vessel, spherical vessel, or spherical head, in.
d	= inside diameter of the nozzle in its corroded condition, in.
R	= inside radius, in corroded condition, of cylindrical vessel, spherical vessel, or spherical head, in.
r	= inside radius of the nozzle in its corroded condition, in.
t_r	= wall thickness of vessel or head, computed by the equation given in NC-3224.3 for cylindrical vessels; by NC-3224.4 for spherical vessels or spherical heads, in.
t_{rn}	= wall thickness of nozzle, computed by the equation given in NC-3224.3, in.

Page 90

t	= nominal wall thickness of vessel or head, less corrosion allowance, in.
t_n	= nominal wall thickness of nozzle, less corrosion allowance, in.
A_r	= required minimum reinforcing area, sq in.
A_a	= available reinforcing area, sq. in.

**TABLE NC-3239.3(a)-1
REQUIRED MINIMUM REINFORCING AREA A_r**

Required Minimum Reinforcing Area A_r		
Value of $d/\sqrt{Rt_r}$	Nozzles in Cylinders	Nozzles in Spherical Vessels or Heads
Less than 0.20 and	None [Note (1)]	None [Note (1)]
Greater than 0.20 and less than 0.40	$\{4.05 [d/\sqrt{Rt_r}]^{1/2} - 1.81\} dt_r$	$\{5.40 [d/\sqrt{Rt_r}]^{1/2} - 2.41\} dt_r$
Greater than 0.40	$0.75 dt_r$	$dt_r \cos \phi$ $\phi = \sin^{-1} (d/D)$

NOTE:

(1) The transition radius r_2 shown in Fig. NC-3239.1(b)-1, or equivalent, is required.

TABLE NC-3239.3(a)-1 REQUIRED MINIMUM REINFORCING AREA A_r

See Fig. NC-3239.1(b)-1 for $r_1, r_2, r_3, r_4, r_5, \theta, \theta_1$. See Fig. NC-3239.4-1 for L_c, L_n . See Fig. XIII-2122-1 and NC-3239.7 for $S, \sigma_p, \sigma_n, \sigma_r, \sigma$.

NC-3239.3 Required Reinforcement Area

- (a) The required minimum reinforcing area is related to the value of $d/\sqrt{Rt_r}$ shown in Table NC-3239.3(a)-1.
- (b) The required minimum reinforcing area shall be provided in all planes containing the nozzle axis.

NC-3239.4 Limits of Reinforcing Zone.

Reinforcing metal included in meeting the minimum reinforcing area specified in NC-3239.3 must be located within

the reinforcing zone boundary shown in Fig. NC-3239.4-1.

NC-3239.5 Strength of Reinforcing Material Requirements.

Material in the nozzle wall used for reinforcing should preferably be the same as that of the vessel wall. If material with a lower design stress intensity value S_m is used, the area provided by such material shall be increased in proportion to the inverse ratio of the stress values of the nozzle and the vessel wall material. No reduction in the reinforcing area requirement may be taken for the increased strength of nozzle material or weld metal which has a higher design stress value than that of the material of the vessel wall. The strength of the material at the point under consideration shall be used in fatigue analyses. The mean coefficient of thermal expansion of metal to be included as reinforcement shall be within 15% of the value for the metal of the vessel wall.

NC-3239.6 Transition Details.

Examples of acceptable transition tapers and radii are shown in Fig. NC-3239.1(b)-1. Other configurations which meet the reinforcing area requirements of NC-3239.3 and with equivalent or less severe transitions are also acceptable, such as larger radius-thickness ratios.

NC-3239.7 Stress Indices

(a) The term stress index is defined as the numerical ratio of the stress components σ_r , σ_n , and σ_t under consideration to the computed stress S . The symbols for the stress components are shown in Fig. XIII-2122-1 and are defined as follows:

S	= $P(2R + t)/4t$ for nozzles in spherical vessels or heads, psi
S	= $P(2R + t)/2t$ for nozzles in cylindrical vessels, psi
σ_t	= the stress component in the plane of the section under consideration and parallel to the boundary of the section, psi
σ_n	= the stress component normal to the plane of the section, ordinarily the circumferential stress around the hole in the shell, psi
σ_r	= the stress component normal to the boundary of the section, psi
σ	= the stress intensity, combined stress, at the point under consideration, psi
P	= service pressure, psi

(b) When the conditions of NC-3239.1 through NC-3239.6 are satisfied, the stress indices given in Table NC-3239.7-1 may be used. These stress indices deal only with the maximum stresses, at certain general locations, due to internal pressure. In the evaluation of stresses in or adjacent to vessel openings and connections, it is often necessary to consider the effect of stresses due to external loadings or thermal stresses. In such cases, the total stress at a given point may be determined by superposition. In the case of combined stresses due to internal pressure and nozzle loading, the maximum stresses should be considered as acting at the same point and added algebraically. If the stresses are otherwise determined by more accurate analytical techniques or by the experimental stress analysis procedure of Appendix II, the stresses are also to be added algebraically.

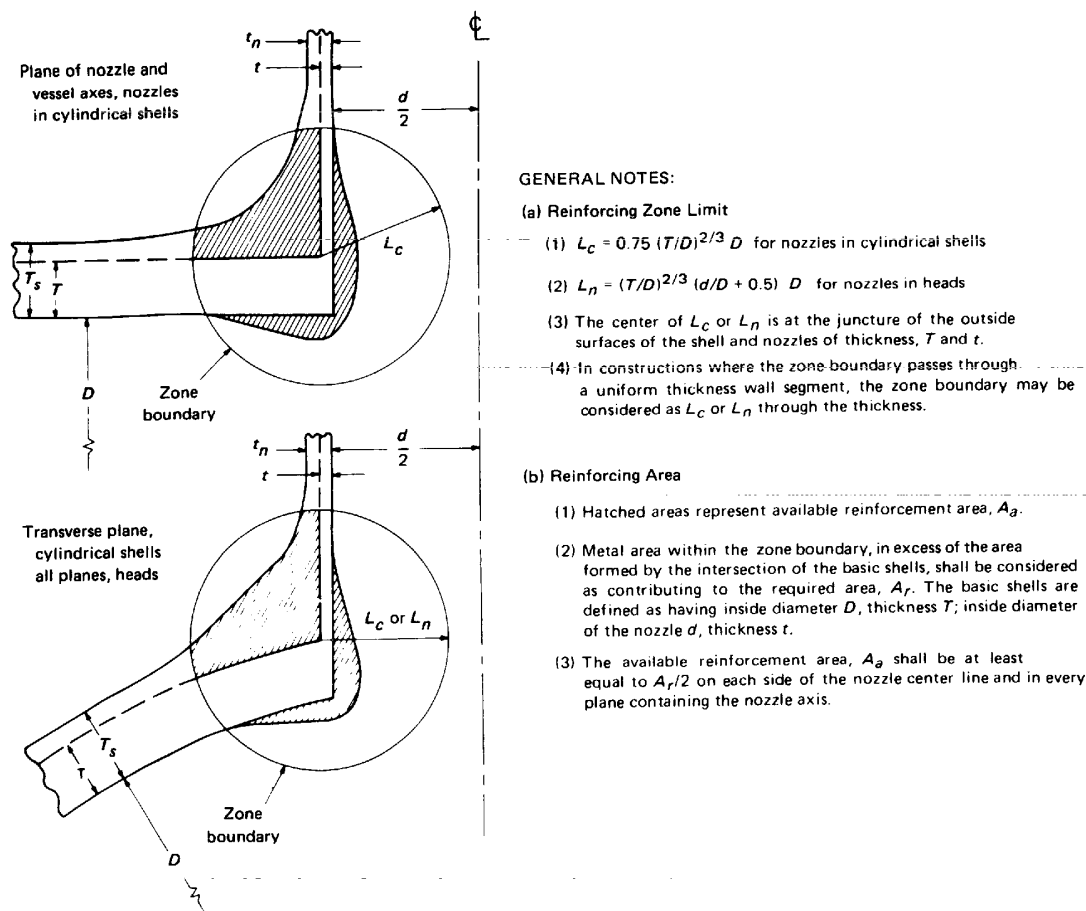


FIG. NC-3239.4-1 LIMITS OF REINFORCING ZONE

FIG. NC-3239.4-1 LIMITS OF REINFORCING ZONE

NC-3240 VESSELS UNDER EXTERNAL PRESSURE

NC-3241 General Requirements

These rules are applicable to spherical and cylindrical shells with or without stiffening rings and to formed heads and to tubular products (NC-4221.2). Charts for use in determining the thicknesses of these components are given in Section II, Part D, Subpart 3.

NC-3241.1 Nomenclature.

The symbols used in this Article are defined below. Except for the test condition, dimensions used or calculated shall be in the corroded condition.

T

= minimum required thickness of the cylindrical or spherical shell or tubular product, exclusive of corrosion allowance, in.

L

= design length of a vessel section, using the applicable

definition below: the distance between head bend lines plus one-third of the depth of each head if there are no stiffening rings; the greatest center to center distance between any two adjacent stiffening rings; or the distance from the center of the first stiffening ring to the head bend line plus one-third of the depth of the head, all measured parallel to the axis of the vessel, in.

R	= inside radius of spherical shells, in.
L_s	= one-half of the distance from the center line of the stiffening ring to the next line of support on one side, plus one-half of the centerline distance to the next line of support, if any, on the other side of the stiffening ring, both measured parallel to the axis of the vessel, in. (A line of support is a stiffening ring that meets the requirements of this paragraph; a circumferential line on a head at one-third the depth of the head from the head bend line; a circumferential connection to a jacket.)
D_o	= outside diameter of the cylindrical shell course under consideration, in.
P	= external Design Pressure, psi
I_s	= required moment of inertia of the combined ring shell section about its neutral axis parallel to the axis of the shell, in. ⁴ The width of shell which is taken as contributing to the combined moment of inertia shall not be greater than $1.10 \sqrt{D_o} \bar{T}$ and shall be taken as lying one-half on each side of the centroid of the ring. Portions of shell plates shall not be considered as contributing area to more than one stiffening ring.
A_s	= cross-sectional area of the stiffening ring, sq in.
A	= factor determined from the appropriate chart in Section II, Part D, Subpart 3 for the material used in the stiffening ring, corresponding to the factor B and the Design Temperature for the shell under consideration
B	= factor from the charts in Section II, Part D, Subpart 3, psi

**TABLE NC-3239.7-1
STRESS INDICES FOR INTERNAL
PRESSURE LOADING**

Nozzles in Spherical Shells and Spherical Heads		
Stress	Inside	Outside
σ_n	$2.0 - (r/R)$	$2.0 - (r/R)$
σ_t	-0.2	$2.0 - (r/R)$
σ_r	$-4t_p/(2R + t_p)$	0
σ	larger of: $2.2 - (r/R)$, or $2.0 + [4t_p/(2R + t_p)] - (r/R)$	$2.0 - (r/R)$

Nozzles in Cylindrical Shells				
Stress	Longitudinal Plane		Transverse Plane	
	Inside	Outside	Inside	Outside
σ_n	3.1	1.2	1.0	2.1
σ_t	-0.2	1.0	-0.2	2.6
σ_r	$-2t_p/(2R + t_p)$	0	$-2t_p/(2R + t_p)$	0
σ	3.3	1.2	1.2	2.6

TABLE NC-3239.7-1 STRESS INDICES FOR INTERNAL PRESSURE LOADING

NC-3242 Cylindrical Shells

NC-3242.1 For $D_o/T \geq 10$.

The minimum thickness of pipes or shell under external pressure¹⁰ having D_o/T values equal to or greater than 10 shall be determined by the procedure given in NC-3133.3.

NC-3242.2 For $D_o/T < 10$.

The minimum thickness of pipes or tubes under external pressure having D_o/T values less than 10 shall be determined by the procedure given in Steps 1 through 4 below:

Step 1: Compute a value for factor A from the equation

$$A = 1.1/(D_o/T)^2$$

Step 2: Enter the appropriate chart with the calculated value of A and move vertically to the material line for the Design Temperature or to the horizontal projection of the upper end of this material line where A falls to the right of the end of the material line. From this intersection, move horizontally to the right and read the value of B .

Step 3: Using this value of B , calculate the maximum allowable pressure by the following equation:

$$P_a = \left[\frac{2.167}{D_o/T} - 0.0833 \right] B$$

Step 4: If P_a is less than the external Design Pressure P , repeat the procedure using a larger value for T .

NC-3243 Spherical Shells

The minimum thickness of a spherical shell under external pressure shall be determined by the procedure given in NC-3133.4.

NC-3244 Stiffening Rings for Cylindrical Shells

NC-3244.1 Required Moment of Inertia for Circumferential Stiffening Rings.

The required moment of inertia of the combined ring shell section is given by the equation:

$$I_s = \frac{D_o^2 L_s (T + A_s / L_s) A}{10.9}$$

The moment of inertia for a stiffening ring shall be determined by the procedure given in Step 1 through Step 6 below.

Step 1: Assuming that the shell has been designed and $D_o L_s$, and T are known, select a member to be used for the

10 When axial compressive loadings occur in addition to the external pressure, the combined axial loading shall meet the requirements of NC-3245.

stiffening ring and determine its area A_s and the value of I_s . Calculate B by the equation:

$$B = \left[\frac{PD_o}{T + A_s / L_s} \right] \frac{3}{4}$$

Step 2: Enter the right hand side of the chart in Section II, Part D, Subpart 3 for the material under consideration at the value of B determined in Step 1.

Step 3: Move horizontally to the material line for the Design Temperature.

Step 4: From this intersection move vertically to the bottom of the chart and read the value of A .

Step 5: Compute the value of the required moment of inertia I_s from the formula given above.

Step 6: If the required I_s is greater than the computed moment of inertia for the combined ring shell section selected in Step 1, a new section with a larger moment of inertia must be selected and a new I_s determined. If the required I_s is less than the computed moment of inertia for the section selected in Step 1, that section should be satisfactory.

NC-3244.2 Permissible Methods of Attaching Stiffening Rings.

Stiffening rings shall be attached to either the outside or the inside of the vessel in accordance with NC-4267.

NC-3245 Cylinders Under Axial Compression

The maximum allowable compressive stress in cylindrical shells subjected to loadings that produce longitudinal compressive stresses shall be the smaller of the values determined by (a) and (b) below:

(a) the S_m value for the applicable material at Design Temperature given in Tables 2A, 2B, and 4, Section II, Part D, Subpart 1;

(b) the value of the factor B determined in accordance with NC-3133.6(b).

NC-3250 WELDED JOINTS

NC-3251 Welded Joint Categories

Welded joint categories are defined in NC-3351.

NC-3252 Permissible Types of Welded Joints

The design of the vessel shall meet the requirements for each category of joint. Butt joints are full penetration joints between plates or other elements that lie approximately in the same plane. Category B angle joints between plates or other elements that have an offset angle α not exceeding 30 deg. are considered as meeting the requirements for butt joints. Fig. NC-3352-1 shows typical butt welds for each category joint.

NC-3252.1 Joints of Category A.

All welded joints of Category A shall meet the fabrication requirements of NC-4263 and shall be capable of being examined in accordance with NC-5251.

NC-3252.2 Joints of Category B.

All welded joints of Category B shall meet the fabrication requirements of NC-4264 and shall be capable of being examined in accordance with NC-5252. When fatigue analysis of Type 2 joints is required and backing strips are not removed, stress concentration factors of 2.0 for membrane stresses and of 2.5 for bending stresses shall be applied in the design of the joints.

NC-3252.3 Joints of Category C.

All welded joints of Category C shall meet the fabrication requirements of NC-4265 and shall be capable of being examined in accordance with NC-5253. Minimum dimensions shall be as specified in NC-3258.3 and NC-3258.4.

NC-3252.4 Joints of Category D.

All welded joints of Category D shall be in accordance with the requirements of NC-3359 and one of (a) through (d) below.

(a) *Butt Welded Nozzles.* Nozzles shall meet the fabrication requirements of NC-4266(a) and shall be capable of being examined in accordance with NC-5254. The minimum dimensions and geometrical requirements of Fig. NC-4266(a)-1 shall be met where:

t	= nominal thickness of part penetrated, in.
t_n	= nominal thickness of penetrating part, in.
r_1	= $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2	= $\frac{1}{4}$ in. (6 mm) minimum

(b) *Full Penetration Corner Welded Nozzles.* Nozzles shall meet the fabrication requirements of NC-4266(b) and shall be capable of being examined as required in NC-5254. The minimum dimensions of Fig. NC-4266(b)-1 shall be met where:

t	= thickness of part penetrated, in.
t_n	= thickness of penetrating part, in.

Page 94

t_c	= $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
r_1	= $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2	= $\frac{1}{4}$ in. (6 mm) minimum
r_3	= $\frac{1}{4}t_n$ or $\frac{3}{8}$ in. (10 mm), whichever is less, or chamfer at 45 deg. to at least $\frac{5}{16}$ in. (8 mm).

(c) *Pad and Screwed Fitting Types of Welded Nozzles.* Nozzles and fittings shall meet the fabrication requirements of NC-4266(c) and shall be capable of being examined in accordance with NC-5254. The minimum dimensions and geometrical requirements of Fig. NC-4266(c)-1 shall be met, where:

t_e	= thickness of reinforcement element, in.
t_c	= $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less

t_n	= nominal thickness of neck, in.
t	= nominal thickness of shell, in.
r_1	= $\frac{1}{4}t_n$ or $\frac{3}{8}$ in., whichever is less
r_3	= $\frac{1}{4}t_g$ or $\frac{3}{8}$ in., whichever is less, or chamfer at 45 deg. to at least $\frac{5}{16}$ in.
c	= smaller of $0.7t_e$ or $0.7t$

(d) *Attachment of Nozzles Using Partial Penetration Welds.* Partial penetration welds shall meet the fabrication requirements of NC-4266(d) and shall be capable of being examined in accordance with NC-5254. They shall be used only for attachments such as instrumentation openings and inspection openings, which are subjected to essentially no external mechanical loadings and on which there will be no thermal stresses greater than in the vessel itself. Such attachments shall satisfy the rules for reinforcement of openings, except that no material in the neck shall be used for reinforcement in the attachment. The inside diameter of such openings shall not exceed 4 in. The minimum dimensions of Fig. NC-4266(d)-1 shall be met where:

t_n	= nominal thickness of neck, in.
t	= nominal thickness of vessel, in.
t_w	= depth of weld penetration, not less than $1\frac{1}{4}t_n$ in.
t_c	= $0.7t$ or $\frac{1}{4}$ in., whichever is less
r_1	= $\frac{1}{4}t_n$ or $\frac{3}{4}$ in., whichever is less
d	= outside diameter of nozzle, in.
C	= maximum diametral clearance between nozzle and vessel penetration, in.
	= 0.010 for $d \leq 1$ in.
	= 0.020 for 1 in. $< d \leq 4$ in.
	= 0.030 for $d > 4$ in., except that the above limits on maximum clearance need not be met for the full length of the opening, provided there is a region at the weld preparation and a region near the end of the opening opposite the weld which does meet the above limit on maximum clearance and the latter region is extensive enough (not necessarily continuous) to provide a positive stop for nozzle deflection

NC-3254 Structural Attachment Welds

Welds for structural attachments shall meet the requirements of NC-4267.

NC-3255 Welding Grooves

The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration, except as otherwise permitted in NC-3252.4.

NC-3257 Welded Joints Subject to Bending Stress

The requirements of NC-3357 shall be met.

NC-3258 Design Requirements for Head Attachments

NC-3258.1 Skirt Length of Formed Heads

(a) Ellipsoidal and other types of formed heads, concave or convex to the pressure, shall have a skirt length not less than that shown in Fig. NC-3358-1.

(b) A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections as shown in Fig. NC-3358-1 shall be provided at joints between formed heads and shells that differ in thickness by more than one-fourth the thickness of the thinner section or by more than $\frac{1}{8}$ in., whichever is less. When a taper is required on any formed head thicker than the shell and intended for butt welded attachment (Fig. NC-3358-1), the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.

NC-3258.2 Unstayed Flat Head Welded to Shells.

The requirements of welded unstayed flat heads to shells are given in NC-3225, NC-3258.3, and NC-3258.4.

NC-3258.3 Head Attachments Using Corner Joints.

When shells, heads, or other pressure parts are welded to a forged or rolled plate to form a corner joint, the welds shall meet the requirements given in (a) through (e) below.

(a) On the cross section through the welded joint, the line between the weld metal and the forged or rolled plate being attached shall be projected on planes both parallel to and perpendicular to the surface of the plate being attached, in order to determine the dimensions a and b , respectively.

(b) For flange rings of bolted flanged connections and for flat heads and supported and unsupported tube

Page 95

sheets with a projection for a bolted connection, the sum of a and b shall be not less than three times the nominal wall thickness of the abutting pressure parts.

(c) For other parts, the sum of a and b shall be not less than two times the nominal wall thickness of the abutting pressure parts. Examples of such parts are flat heads and supported and unsupported tubesheets without a projection for a bolted connection and the side plates of a rectangular vessel.

(d) Joint details that have a dimension through the joint less than the thickness of the shell, head, or other pressure part or that provide eccentric attachment are not permitted.

(e) The minimum dimensions in Figs. NC-4265-1 and NC-4265-2 are as follows:

(1) Fig. NC-4265-1

Sketch (a)

$a + b$ not less than $2t_s$

$b + c$ not less than t_s

t_p not less than t_s

Sketch (b)

$a + b$ not less than $2t_s$

Sketch (c)

$a + b$ not less than $3t_s$

$b + c$ not less than t_s

Sketches (d) and (e)

(a) For forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle not greater than 45 deg. measured from the face:

$c = 0.7t_s$ or $\frac{1}{4}$ in., whichever is less

b = the lesser of $t_s/2$ or $T/4$
 T, t_s = nominal thickness of welded parts

(b) For all other material forms and for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle greater than 45 deg. measured from the face:

c = $0.7t_s$ or $1/4$ in., whichever is less
 b = the lesser of t_s or $T/2$
 T, t_s = nominal thickness of welded parts sketches (f) and (g)
 c = $0.7t_s$ or $1/4$ in., whichever is less

(2) Fig. NC-4265-2

Sketch (a)

(a) For forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle not greater than 45 deg. measured from the face:

t_c = $0.7t_n$ or $1/4$ in., whichever is less
 t_w = the lesser of $t_n/2$ or $t/4$
 t, t_n = nominal thickness of welded parts, in.

(b) For all other material forms and for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle greater than 45 deg. measured from the face:

t_c = $0.7t_n$ or $1/4$ in., whichever is less
 t_w = the lesser of t_n or $t/2$
 t, t_n = nominal thicknesses of welded parts, in.

Sketch (b)

t and t_n = nominal thickness of welded parts, in.
 h or g_1 = $0.25t_n$ but not less than $1/4$ in.

Sketch (c)

t_n = nominal thickness of neck, in.

$a + b$ not less than $3t_n$

c not less than t_n

NC-3258.4 Head Attachments Using Butt Welds.

When flat heads are attached using butt welds, as shown in Fig. NC-4243.1-1, the minimum dimensions are as follows:

(a) Sketch (a)

r not less than $1.5t_s$

(b) Sketch (b)

r not less than $1.5t_s$

e not less than t_s

- (c) *Sketch (c)*
 h not less than $1.5t_s$
- (d) *Sketch (d)*
 t_f not less than $2t_s$
 r not less than $3t_f$
- (e) *Sketch (e)*
 t_f not less than $2t_s$
 r not less than $3t_f$
 e not less than t_f

NC-3259 Design Requirements for Nozzle Attachment Welds and Other Connections

The minimum design requirements for nozzle attachment welds and other connections are set forth in (a) through (c) below.

(a) *Permitted Types of Nozzles and Other Connections.* Nozzles and other connections may be any of the types for which rules are given in this Subarticle, provided the requirements of (1) through (7) below are met.

- (1) Nozzles shall meet requirements regarding location.
- (2) The attachment weld shall meet the requirements of NC-3252.4.
- (3) The requirements of NC-3230 shall be met.
- (4) Type No. 1 full penetration joints shall be used when the openings are in shells $2\frac{1}{2}$ in. (64 mm) or more in thickness.
- (5) The welded joints shall be examined by the methods stipulated in NC-5250.

Page 96

- (6) Studded connections shall meet the requirements of NC-3262.4.
- (7) Threaded connections shall meet the requirements of NC-3270.

(b) *Provision of Telltale Holes for Air Testing.* Reinforcing plates and saddles attached to the outside of a vessel shall be provided with at least one telltale hole, of maximum size $\frac{1}{4}$ in. pipe tap, that may be tapped for a preliminary compressed air and soap solution or equivalent test for tightness of welds that seal off the inside of the vessel. These telltale holes may be left open or may be plugged when the vessel is in service. If the holes are plugged, the plugging material used shall not be capable of sustaining pressure between the reinforcing plate and the vessel wall. Telltale holes shall not be plugged during heat treatment.

(c) *Attachments.* Typical attachments are shown in Fig. NC-4267-1. The minimum dimensions in this figure are as follows:

$$a \geq t/4; b \geq t/2; C \geq t$$

t	= thickness of attached member, in.
c	= minimum thickness of weld metal from the root to the face of the weld, in.

NC-3260 SPECIAL VESSEL REQUIREMENTS

NC-3261 Transition Joints Between Sections of Unequal Thickness

Unless the requirements of Appendix XIII, XIV, or II are shown to be satisfied, a tapered transition as shown in Figs.

NC-3358-1 and NC-3361-1 shall be provided at joints of Categories A and B between sections that differ in thickness by more than one-fourth of the thickness of the thinner section or by more than $\frac{1}{8}$ in. The transition may be formed by any process that will provide a uniform taper. The weld may be partly or entirely in the tapered section. When Appendix XIII, XIV, or II are not used, the following requirements of (a) through (e) below shall also apply.

(a) The length of taper shall be not less than three times the offset between adjacent surfaces.

(b) Figure NC-3361-1 shall apply to all joints of categories A and B except joints connecting formed heads to main shells, for which case Fig. NC-3358-1 shall apply.

(c) When a taper is required on any formed head intended for butt welded attachment, the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.

(d) An ellipsoidal or hemispherical head which has a greater thickness than a cylinder of the same inside diameter may be machined to the outside diameter of the cylinder, provided the remaining thickness is at least as great as that required for a shell of the same diameter.

(e) The requirements of this paragraph are not applicable to flange hubs.

NC-3262 Bolted Flanged Connections

NC-3262.1 Flanges and Flanged Fittings Conforming to ANSI B16.5.

Except as provided in NC-3262.3, the dimensional requirements of flanges used in bolted flange connections to external piping shall conform to ANSI B16.5, Steel Pipe Flanges and Flanged Fittings. Flanges and flanged fittings conforming to ANSI B16.5 and listed in Tables 13 through 33 of that Standard, with the exception of threaded and socket welding types, may be used at the pressure-temperature ratings specified in that Standard. Flanges within the size and pressure range of ANSI B16.5, Tables 13 through 33, may be designed by interpolation.

NC-3262.2 Slip-On Flanges Conforming to ANSI B16.5.

Slip-on flanges conforming to ANSI B16.5 may be used, provided all the conditions of (a) through (e) below are met.

(a) The specified minimum tensile strengths of materials do not exceed 80.0 ksi (552 MPa).

(b) The minimum elongation of materials is 12% in 2 in. (51 mm).

(c) The thickness of the materials to which the flange is welded does not exceed $1\frac{1}{4}$ in. (32 mm).

(d) The throat thickness, taken as the minimum thickness in any direction through the attaching fillet welds, is at least 0.7 times the thickness of the material to which the flange is welded.

(e) The fatigue analysis required for nozzles with separate reinforcement and nonintegral attachments, as set forth in NC-3219.3, is applied to the design.

NC-3262.3 Flanges Not Conforming to ANSI B16.5.

Flanges which do not conform to ANSI B16.5 shall be designed in accordance with the Rules for Bolted Flange Connections, Appendix XI, or by the rules of Appendices II, XIII, and XIV.

NC-3262.4 Studded Connections.

Where tapped holes are provided for studs, the threads shall be full and clean and shall engage the stud for a length not less than the larger of d or

$$(0.75d_s) \times \frac{\text{Design stress intensity value of stud material at Design Temperature}}{\text{Design stress intensity value of tapped material at Design Temperature}}$$

in which d is the root diameter of the stud, except that the thread engagement need not exceed $1\frac{1}{2}d_s$.

NC-3263 Access and Inspection Openings

The requirements for access and inspection openings are given in NC-3363.

NC-3264 Attachments and Supports

NC-3264.1 General Requirements.

Supports, lugs, brackets, stiffeners, and other attachments may be welded or stud bolted to detailed fatigue analysis in accordance with the requirements of Appendices XIII and XIV unless the conditions of NC-3219 are met. Attachments shall conform reasonably to the curvature of the shell to which they are to be attached. The fabrication requirements of NC-4267 and the examination requirements of NC-5250 shall be met.

NC-3264.2 Attachment Materials.

Materials welded directly to pressure parts shall meet the requirements of NC-2190.

NC-3264.3 Design of Attachments.

The effects of attachments, including external and internal piping connections, shall be taken into account in the design. Attachments shall meet the requirements of NC-3135.

NC-3264.4 Design of Supports

(a) All vessels shall be so supported and the supporting members so arranged and attached to the vessel as to provide for the maximum imposed loadings. Wind and earthquake loads need not be assumed to occur simultaneously.

(b) All supports should be designed to prevent excessive localized stresses due to temperature changes in the vessel or deformations produced by the internal pressure.

(c) Horizontal vessels supported by saddles shall provide bearing extending over at least one-third of the shell circumference.

(d) Additional requirements for the design of supports are given in NCA-3240 and Subsection NF.

NC-3264.5 Types of Attachment Welds.

Welds attaching nonpressure parts or stiffeners to pressure parts shall meet the requirements of NC-4267.

NC-3264.6 Stress Values for Weld Material.

Attachment weld strength shall be based on the nominal weld area and the design stress intensity values in Tables 2A,

2B, and 4, Section II, Part D, Subpart 1 and stress criteria in NC-3200 for the weaker of the two materials joined, or, where weaker weld metal is permitted, the design stress intensity values of the weld metal multiplied by the following reduction factors: 0.5 for fillet welds NC-3264.5; 0.75 for partial penetration groove or partial penetration groove plus fillet welds NC-3264.5; 1.0 for complete weld penetration. The nominal weld area for fillet welds is the throat area; for groove welds, the depth of penetration times the length of weld; and for groove welds with fillet welds, the combined throat and depth of penetration, exclusive of reinforcement, times the length of weld.

(a) *Attachment Welds - Evaluation of Need for Fatigue Analysis.* In applying Condition AP or BP of NC-3219.3, fillet welds and partial penetration welds are considered nonintegral attachments, except that the following welds need not be considered:

(1) welds for minor attachments

(2) welds for supports which may be considered integral as covered by Conditions A and B of NC-3219.2

NC-3266 Threaded Connections

(a) Threads

(1) Pipes, tubes, and other threaded connections that conform to the ANSI B2.1, Standard for Pipe Threads, may be screwed into a threaded hole in a vessel wall, provided the pipe engages the minimum number of threads specified in Table NC-3266-1 after allowance has been made for curvature of the vessel wall. A built-up pad or a properly attached plate or fitting shall be used to provide the metal thickness and number of threads required in Table NC-3266-1 or to furnish reinforcement when required.

(2) Straight threaded connections may be employed as provided for in NC-3266(b)(2).

(b) Restrictions on the Use of Threaded Connections

(1) *Taper Threaded Connections.* Internal taper pipe thread connections larger than 2 in. (51 mm) shall not be used.

(2) Straight Threaded Connections

(a) Threaded connections employing straight threads shall provide for mechanical seating of the assembly by a shoulder or similar means. Straight thread center openings in vessel heads shall meet the requirements of NC-3230. The length of the thread shall be calculated for the opening design and they shall not exceed the smaller of one-half the vessel

Page 98

diameter or 8 in. nominal pipe size. In addition, they shall be placed at a point where the calculated stress without a hole, due to any combination of design pressure and mechanical loadings expected to occur simultaneously, is not more than $0.5S_m$.

**TABLE NC-3266-1
MINIMUM NUMBER OF PIPE THREADS
FOR CONNECTIONS**

Size of Pipe Connection, in.	Threads Engaged	Min. Plate Thickness Required, in.
$\frac{1}{2}$	6	0.43
$\frac{3}{4}$	6	0.43
1	6	0.61
$1\frac{1}{4}$	6	0.61
$1\frac{1}{2}$	6	0.61
2	8	0.70

TABLE NC-3266-1 MINIMUM NUMBER OF PIPE THREADS FOR CONNECTIONS

(b) Threaded connections above $2\frac{3}{4}$ in. (70 mm) in diameter may be used only if they meet the requirements of NC-3219, or, if these requirements are not met, a detailed fatigue analysis shall be made in accordance with the rules of Appendices XIII and XIV.

NC-3300 VESSEL DESIGN

NC-3310 GENERAL REQUIREMENTS

Class 2 vessel requirements as stipulated in the Design Specifications (NCA-3250) shall conform to the design requirements of this Article.

NC-3320 DESIGN CONSIDERATIONS

NC-3321 Stress Limits for Design and Service Loadings

Stress¹¹ limits for Design and Service Loadings are specified in Table NC-3321-1. The symbols used in Table NC-3321-1 are defined as follows:

σ_m	= general membrane stress, psi. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.
σ_L	= local membrane stress, psi. This stress is the same as σ_m .

except that it includes the effect of discontinuities.

11 Stress means the maximum normal stress.

σ_b

= bending stress, psi. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

S

= allowable stress value given in Table 1A, 1B, and 3, Section II, Part D, Subpart 1, psi. The allowable stress shall correspond to the highest metal temperature at the section under consideration during the condition under consideration.

**TABLE NC-3321-1
STRESS LIMITS FOR DESIGN AND SERVICE
LOADINGS¹**

Service Limit	Stress Limits [Note (2)]
Design and Level A	$\sigma_m \leq 1.0 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5 S$
Level B	$\sigma_m \leq 1.10 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65 S$
Level C	$\sigma_m \leq 1.5 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8 S$
Level D	$\sigma_m \leq 2.0 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4 S$

NOTES:

(1) See NC-3321.1 for definitions of symbols.

(2) These limits do not take into account either local or general buckling which might occur in thin-wall vessels.

TABLE NC-3321-1 STRESS LIMITS FOR DESIGN AND SERVICE LOADINGS¹

Typical examples of locations for which σ_m , σ_L , σ_b are applicable are shown in Table NC-3321-2.

NC-3322 Special Considerations

The provisions of NC-3120 apply.

NC-3323 General Design Rules

The provisions of NC-3130 apply except as modified by the rules of this Subarticle. In case of conflict, this Subarticle governs the design of vessels.

NC-3324 Vessels Under Internal Pressure

NC-3324.1 General Requirements.

Equations are given for determining the minimum thicknesses under internal pressure loading in cylindrical and spherical shells and ellipsoidal, torispherical, toriconical, conical, and hemispherical heads. Provision shall be made for

Page 99

any of the other loadings listed in NC-3111 when such loadings are specified. Pages 100-100

TABLE NC-3321-2
CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES¹

Vessel Part	Location	Origin of Stress	Type of Stress	Classification
Cylindrical or spherical shell	Shell plate remote from discontinuities	Internal pressure	General membrane Gradient through plate thickness	σ_m Q
		Axial thermal gradient	Membrane Bending	Q Q
	Junction with head or flange	Internal pressure	Membrane Bending	σ_L Q [Note (2)]
Any shell or head	Any section across entire vessel	External load or moment, or internal pressure	General membrane averaged across full section; stress component perpendicular to cross section.	σ_m
		External load or moment	Bending across full section; stress component perpendicular to cross section.	σ_m
	Near nozzle or other opening	External load or moment, or internal pressure	Local membrane Bending Peak (fillet or corner)	σ_L Q F
	Any location	Temperature difference between shell and head	Membrane Bending	Q Q
Dished head or conical head	Crown	Internal pressure	Membrane Bending	σ_m σ_b
	Knuckle or junction to shell	Internal pressure	Membrane Bending	σ_L [Note (3)] Q
Flat head	Center region	Internal pressure	Membrane Bending	σ_m σ_b
	Junction to shell	Internal pressure	Membrane Bending	σ_L Q [Note (2)]
Perforated head or shell	Typical ligament in a uniform pattern	Pressure	Membrane (averaged through cross section) Bending (averaged through width of ligament, but gradient through plate) Peak	σ_m σ_b F
	Isolated or atypical ligament	Pressure	Membrane Bending Peak	Q F F

Table continues on next page

TABLE NC-3321-2 (CONT'D)
CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES¹

Vessel Part	Location	Origin of Stress	Type of Stress	Classification
Nozzle	Within the limits of reinforcement defined by NC-3334	Pressure and external loads and moments, including those attributable to restrained free end displacements of attached piping	General membrane Bending (other than gross structural discontinuity stresses) averaged through nozzle thickness	σ_m σ_m
		Pressure and external axial, shear, and torsional loads other than those attributable to restrained free end displacements of attached piping	General membrane stresses	σ_m
	Outside the limits of reinforcement defined by NC-3334	Pressure and external loads and moments other than those attributable to restrained free end displacements of the attached piping	Membrane Bending	σ_L σ_b
		Pressure and all external loads and moments	Membrane Bending Peak	σ_L Q F
	Nozzle wall	Gross structural discontinuities	Local membrane Bending Peak	σ_L Q F
		Differential expansion	Membrane Bending Peak	Q Q F
Cladding	Any	Differential expansion	Membrane Bending	F F
Any	Any	Radial temperature distribution [Note (4)]	Equivalent linear stress [Note (5)]	Q
			Nonlinear portion of stress distribution	F
Any	Any	Any	Stress concentration (notch effect)	F

NOTES:

- (1) Q and F classifications of stresses refers to other than Design Condition.
- (2) If the bending moment at the edge is required to maintain the bending stress in the middle within acceptable limits, the edge bending is classified as σ_b . Otherwise, it is classified as Q .
- (3) Consideration must also be given to the possibility of wrinkling and excessive deformation in vessels with large diameter-to-thickness ratio.
- (4) Consider possibility of thermal stress ratchet.
- (5) *Equivalent linear stress* is defined as the linear distribution which has the same net bending moment as the actual stress distribution.

TABLE NC-3321-2 (CONT'D) CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES¹

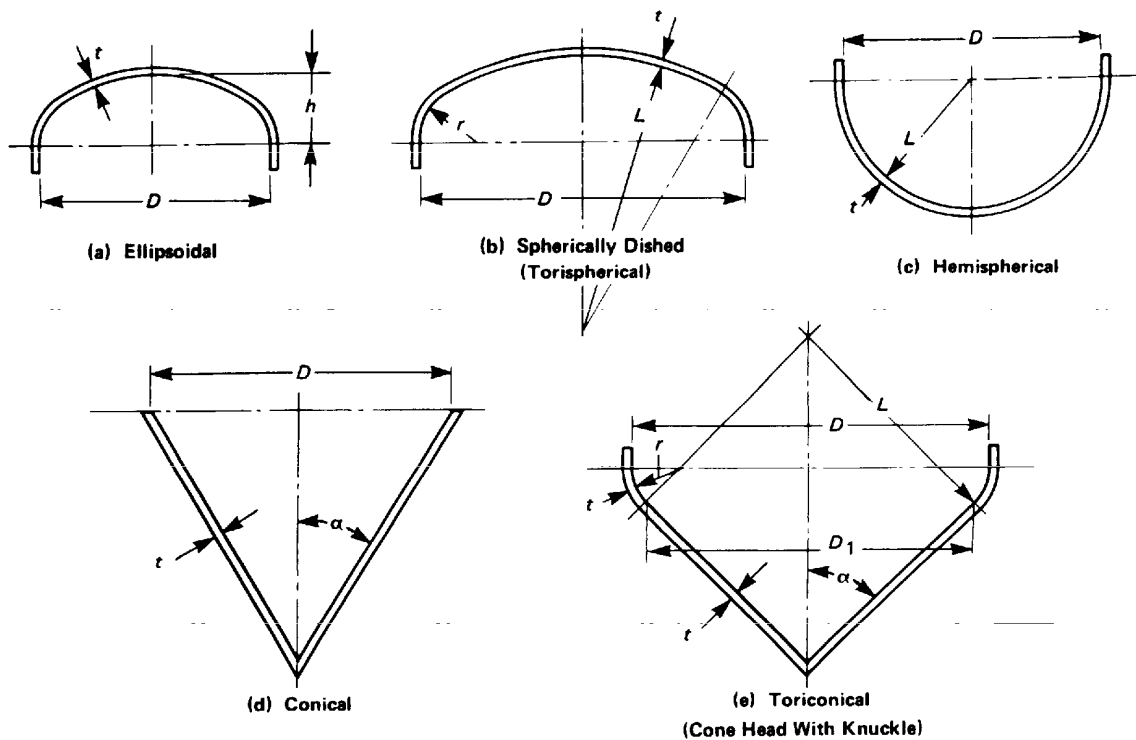


FIG. NC-3324.2-1 PRINCIPAL DIMENSIONS OF TYPICAL HEADS

FIG. NC-3324.2-1 PRINCIPAL DIMENSIONS OF TYPICAL HEADS

NC-3324.2 Nomenclature.

The symbols used in this paragraph and Fig. NC-3324.2-1 are defined as follows:

t	= minimum required thickness of shell or head after forming, exclusive of corrosion allowance, in.
P	= Design Pressure, psi
R	= inside radius of the shell course under consideration before corrosion allowance is added, in.
R_o	= outside radius of the shell course under consideration, in.
S	= maximum allowable stress value, psi (Tables 1A, 1B, and 3, Section II, Part D, Subpart 1)
D	= inside diameter of the head skirt; or inside length of the major axis of an ellipsoidal head; or inside diameter of a conical head at the point under consideration, measured perpendicular to the longitudinal axis, in.
D_o	= outside diameter of the head skirt; or outside length of the major axis of an ellipsoidal head; or outside diameter of a

	conical head at the point under consideration, measured perpendicular to the longitudinal axis, in.
D_I	= inside diameter of the conical portion of a toriconical head at its point of tangency to the knuckle, measured perpendicular to the axis of the cone, in.
L	= inside spherical or crown radius for torispherical and hemispherical heads, in.
L	= $K_1 D$ for ellipsoidal heads in which K_1 is obtained from Table NC-3332.2-1, in.
L_o	= outside spherical or crown radius, in.
r	= inside knuckle radius, in.
h	= one-half of the length of the minor axis of the ellipsoidal head or the inside depth of the ellipsoidal head measured from the tangent line, head bend line, in.
K	= a factor in the formulas for ellipsoidal heads depending on the head proportion, $D/2h$ (Table NC-3324.2-1)
$D/2h$	= ratio of the major to the minor axis of ellipsoidal heads, which equals the inside diameter of the skirt of the head divided by twice the inside height of the head and is used in Table NC-3324.2-1

Page 102

α	= one-half of the included apex angle of the cone at the centerline of the head
----------	---

TABLE NC-3324.2-1
VALUES OF FACTOR K
 Use Nearest Value of $D/2h$; Interpolation Unnecessary

$D/2h$	3.0	2.9	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.0
K	1.83	1.73	1.64	1.55	1.46	1.37	1.29	1.21	1.14	1.07	1.00
$K/2h$	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	...
K	0.93	0.87	0.81	0.76	0.71	0.66	0.61	0.57	0.53	0.50	...

TABLE NC-3324.2-1 VALUES OF FACTOR K

NC-3324.3 Cylindrical Shells.

The minimum thickness of cylindrical shells shall be the greater thickness as given by (a) through (d) below.

(a) *Circumferential Stress (Longitudinal Joints)*. When the thickness does not exceed one-half of the inside radius, or P does not exceed 0.385 S , the following equations shall apply:

$$t = \frac{PR}{S - 0.6P} \quad \text{or} \quad P = \frac{St}{R + 0.6t}$$

(b) *Longitudinal Stress (Circumferential Joints)*. When the thickness does not exceed one-half of the inside radius, or P does not exceed $1.25S$, the following equations shall apply:

$$t = \frac{PR}{2S + 0.4P} \quad \text{or} \quad P = \frac{2St}{R - 0.4t}$$

(c) *Thickness of Cylindrical Shells*. The following formulas, in terms of the outside radius, are equivalent to and may be used instead of those given in (a) above:

$$t = \frac{PR_o}{S + 0.4P} \quad \text{or} \quad P = \frac{St}{R_o - 0.4t}$$

(d) *Thick Cylindrical Shells*

(1) *Circumferential Stress (Longitudinal Joints)*. When the thickness of the cylindrical shell under internal pressure exceeds one-half of the inside radius, or when P exceeds $0.385S$, the following equations shall apply.

When P is known and t is desired:

$$t = R (Z^{1/2} - 1) = R_o \frac{(Z^{1/2} - 1)}{Z^{1/2}}$$

where

$$Z = \frac{S + P}{S - P}$$

When t is known and P is desired:

$$P = S \left(\frac{Z - 1}{Z + 1} \right)$$

where

$$Z = \left(\frac{R + t}{R} \right)^2 = \left(\frac{R_o}{R} \right)^2 = \left(\frac{R_o}{R_o - t} \right)^2$$

(2) *Longitudinal Stress (Circumferential Joints)*. When the thickness of the cylindrical shell under internal pressure exceeds one-half of the inside radius, or when P exceeds 1.25S, the following equations shall apply.

When P is known and t is desired:

$$t = R (Z^{1/2} - 1) = R_o \frac{(Z^{1/2} - 1)}{Z^{1/2}}$$

where

$$Z = \left(\frac{P}{S} + 1 \right)$$

When t is known and P is desired:

$$P = S(Z - 1)$$

where

$$Z = \left(\frac{R + t}{R} \right)^2 = \left(\frac{R_o}{R} \right)^2 = \left(\frac{R_o}{R_o - t} \right)^2$$

NC-3324.4 Spherical Shells

(a) When the thickness of the shell of a spherical vessel does not exceed $0.356R$, or P does not exceed $0.665S$, the following equations shall apply. Any reduction

Page 103

in thickness within a shell course of a spherical shell shall be in accordance with NC-3361.

$$t = \frac{PR}{2S - 0.2P} \quad \text{or} \quad P = \frac{2St}{R + 0.2t}$$

(b) The following equations, in terms of the outside radius, are equivalent to and may be used instead of those given in (a) above.

$$t = \frac{PR_o}{2S + 0.8P}$$

$$P = \frac{2St}{R_o - 0.8t}$$

(c) When the thickness of the shell of a spherical vessel or of a hemispherical head under internal pressure exceeds $0.356R$, or when P exceeds $0.665S$, the following equations shall apply.

When P is known and t is desired:

$$t = R (Y^{1/3} - 1) = R_o \left(\frac{Y^{1/3} - 1}{Y^{1/3}} \right)$$

where

$$Y = \frac{2(S + P)}{2S - P}$$

When t is known and P is desired:

$$P = 2S \left(\frac{Y - 1}{Y + 2} \right)$$

where

$$Y = \left(\frac{R + t}{R} \right)^3 = \left(\frac{R_o}{R_o - t} \right)^3$$

NC-3324.5 Formed Heads, General Requirements.

Formed heads shall meet the requirements of (a) through (g) below.

(a) All formed heads, thicker than the shell and concave to pressure, for butt welded attachment, shall have a skirt length sufficient to meet the requirements of Fig. NC-3358.1(a)-1 when a tapered transition is required.

(b) Any taper at a welded joint within a formed head shall be in accordance with NC-3361. The taper at a circumferential welded joint connecting a formed head to a main shell shall meet the requirements of NC-3358 for the respective type of joint shown therein.

(c) All formed heads concave to pressure and for butt welded attachment need not have an integral skirt when the thickness of the head is equal to or less than the thickness of the shell. When a skirt is provided, its thickness shall be at least that required for a seamless shell of the same diameter.

(d) The inside crown radius to which an unstayed head is dished shall be not greater than the outside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall be not less than 6% of the outside diameter of the skirt of the head but in no case less than three times the head thickness.

(e) When an ellipsoidal, torispherical, hemispherical, conical, or toriconical head is of a lesser thickness than required by the rules of this paragraph, it shall be stayed as a flat surface according to the rules of NC-3329.

(f) If a torispherical, ellipsoidal, or hemispherical head is formed with a flattened spot or surface, the diameter of the flat spot shall not exceed that permitted for flat heads as given by Eq. (1) or (2) of NC-3325.2 using $C = 0.25$.

(g) Openings in formed heads under internal pressure shall comply with the requirements of NC-3330.

NC-3324.6 Ellipsoidal Heads

(a) *Ellipsoidal Heads.* The required thickness of a dished head of semiellipsoidal form, in which one-half the minor axis, inside depth of the head minus the skirt, equals one-fourth the inside diameter of the head skirt, shall be determined by:

$$t = \frac{PD}{2S - 0.2P} \quad \text{or} \quad P = \frac{2St}{D + 0.2t}$$

(b) *Ellipsoidal Heads of Other Ratios.* The minimum required thickness of an ellipsoidal head of other than a 2:1 ratio shall be determined by:

$$t = \frac{PDK}{2S - 0.2P} \quad \text{or} \quad P = \frac{2St}{KD + 0.2t}$$

$$t = \frac{PD_o K}{2S + 2P(K - 0.1)}$$

$$P = \frac{2St}{KD_o - 2t(K - 0.1)}$$

where

$$K = \frac{1}{6} \left[2 + \left(\frac{D}{2h} \right)^2 \right]$$

Numerical values of the factor K are given in Table NC-3324.2-1.

NC-3324.7 Hemispherical Heads

(a) When the thickness of a hemispherical head does not exceed $0.356L$ or P does not exceed $0.665S$, the following equations shall apply:

$$t = \frac{PL}{2S - 0.2P} \quad \text{or} \quad P = \frac{2St}{L + 0.2t}$$

(b) When the thickness of the hemispherical head under internal pressure exceeds $0.356L$, or when P exceeds $0.665S$, the following equations shall apply:

$$t = L (Y^{1/3} - 1) = L_o \left(\frac{Y^{1/3} - 1}{Y^{1/3}} \right)$$

where

$$Y = \frac{2(S + P)}{2S - P}$$

or

$$P = 2S \left(\frac{Y - 1}{Y + 2} \right)$$

where

$$Y = \left(\frac{L + t}{L} \right)^3 = \left(\frac{L_o}{L_o - t} \right)^3$$

NC-3324.8 Torispherical Heads

(a) *Torispherical Heads With a 6% Knuckle Radius.* The required thickness of a torispherical head in which the knuckle radius is 6% of the inside crown radius shall be determined by:

$$t = \frac{0.885PL}{S - 0.1P} \quad \text{or} \quad P = \frac{St}{0.885L + 0.1t}$$

(b) *Torispherical Heads of Other Proportions.* The required thickness of a torispherical head in which the knuckle radius is other than 6% of the crown radius shall be determined by:

$$t = \frac{PLM}{2S - 0.2P} \quad \text{or} \quad P = \frac{2St}{LM + 0.2t}$$

$$t = \frac{PL_oM}{2S + P(M - 0.2)}$$

or

$$P = \frac{2St}{ML_o - t(M - 0.2)}$$

where

$$M = \frac{1}{4} \left(3 + \sqrt{\frac{L}{r}} \right)$$

Numerical values of the factor M are given in Table NC-3324.8(b)-1.

(c) Torispherical heads made of materials having a specified minimum tensile strength exceeding 80 ksi shall be designed using a value of S equal to 20 ksi at room temperature and reduced in proportion to the reduction in maximum allowable stress values at temperature for the material as shown in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1.

NC-3324.9 Conical Heads Without Transition Knuckle.

The required thickness of conical heads or conical shell sections that have a half apex angle α not greater than 30 deg. shall be determined by:

$$t = \frac{PD}{2 \cos \alpha (S - 0.6P)} \quad \text{or} \quad P = \frac{2St \cos \alpha}{D + 1.2t \cos \alpha}$$

For α greater than 30 deg., see NC-3324.11(b)(5). A compression ring shall be provided when required by the rule in NC-3324.11(b).

NC-3324.10 Toriconical Heads.

Toriconical heads in which the inside knuckle radius is neither less than 6% of the outside diameter of the head skirt nor less than three times the knuckle thickness shall be used

Page 105

when the angle α exceeds 30 deg., except when the design complies with NC-3324.11. The required thickness of the knuckle shall be determined by the first equation of NC-3324.8(b) in which

$$L = \frac{D_1}{2 \cos \alpha}$$

TABLE NC-3324.8(b)-1
VALUES OF FACTOR M
Use Nearest Value of L/r ; Interpolation Unnecessary

L/r	1.0	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50
M	1.00	1.03	1.06	1.08	1.10	1.13	1.15	1.17	1.18	1.20	1.22
L/r	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
M	1.25	1.28	1.31	1.34	1.36	1.39	1.41	1.44	1.46	1.48	1.50
L/r	9.5	10.00	10.5	11.0	11.5	12.0	13.0	14.0	15.0	16.0	16.67
M	1.52	1.54	1.56	1.58	1.60	1.62	1.65	1.69	1.72	1.75	1.77

NOTE:

(1) Maximum ratio allowed by NC-3324.5(d) when L equals the outside diameter of the skirt of the head.

TABLE NC-3324.8(b)-1

The required thickness of the conical portion shall be determined by the equation in NC-3324.9, using D_1 in place of D .

NC-3324.11 Reducer Sections

(a) General Requirements

(1) The rules of NC-3324.11(a) apply to concentric reducer sections.

(2) The symbols used are defined as follows:

D_1	= inside diameter of reducer section at point of tangency to the knuckle or reverse curve, in.
A	= required area of reinforcement, sq in.
A_e	= effective area of reinforcement, due to excess metal thickness, sq in.
Δ	= value to indicate need for reinforcement at cone-to-cylinder intersection having a half-apex angle $\alpha \leq 30$ deg. When $\Delta \geq \alpha$, no reinforcement at the junction is required [Tables NC-3324.11(b)(2)-1 and NC-3324.11(b)(3)-1].
m	= the lesser of

$$\left[\frac{t_s}{t} \cos (\alpha - \Delta) \right] \text{ or}$$

$$\left[\frac{t_c \cos \alpha \cos (\alpha - \Delta)}{t} \right]$$

R_L	= inside radius of larger cylinder, in.
R_s	= inside radius of smaller cylinder, in.

**TABLE NC-3324.11(b)(2)-1
VALUES OF Δ FOR JUNCTIONS AT THE
LARGE CYLINDER FOR $\alpha \leq 30$ DEG.**

<i>P/S</i>	0.001	0.002	0.003	0.004	0.005
Δ , deg.	11	15	18	21	23
<i>P/S</i>	0.006	0.007	0.008	0.009	...
				[Note (1)]	
Δ , deg.	25	27	28.5	30	...

NOTE:

(1) $\Delta = 30$ deg. for greater values of *P/S*.

TABLE NC-3324.11(b)(2)-1 VALUES OF Δ FOR JUNCTIONS AT THE LARGE CYLINDER FOR $\alpha \leq 30$ DEG.

r_L	= inside radius of knuckle at larger cylinder, in.
r_s	= radius to the inside surface of flare at the small end, in.
t_s	= nominal thickness of cylinder at cone-to-cylinder junction, exclusive of corrosion allowance, in.
t_c	= nominal thickness of cone at cone-to-cylinder junction, exclusive of corrosion allowance, in.
t_e	= the smaller of $(t_s - t)$ or $[t_c - (t/\cos \alpha)]$, in.

**TABLE NC-3324.11(b)(3)-1
VALUES OF Δ FOR JUNCTIONS AT THE
SMALL CYLINDER FOR $\alpha \leq 30$ DEG.**

<i>P/S</i>	0.002	0.005	0.010	0.02
Δ , deg.	4	6	9	12.5
<i>P/S</i>	0.04	0.08	0.10	0.125
				[Note (1)]
Δ , deg.	17.5	24	27	30

NOTE:

(1) $\Delta = 30$ deg. for greater values of *P/S*.

TABLE NC-3324.11(b)(3)-1 VALUES OF Δ FOR JUNCTIONS AT THE SMALL CYLINDER FOR $\alpha \leq 30$ DEG.

(3) The thickness of each element of a reducer, as defined in (4) below, under internal pressure shall not be less than that computed by the applicable equation. In addition, provisions shall be made for any of the other loadings listed in NC-3111 when such loadings are expected.

(4) A transition section reducer consisting of one or more elements may be used to join two cylindrical shell sections of different diameters but with a common axis, provided the requirements of (a) and (b) below are met.

(a) *Conical Shell Section.* The required thickness of a conical shell section or the allowable pressure for such a section of given thickness shall be determined by the equations given in NC-3324.9.

(b) *Knuckle Tangent to the Larger Cylinder.* Where a knuckle is used at the large end of a reducer section, its shape shall be that of a portion of an ellipsoidal, hemispherical, or torispherical head. The thickness and other dimensions shall satisfy the requirements.

(5) When elements of (4) above having different thicknesses are combined to form a reducer, the joints including the plate taper required by NC-3361 shall lie entirely within the limits of the thinner element being joined.

(6) A reducer may be a simple conical shell section [Fig. NC-3324.11(a)(6)-1 sketch (a)] without knuckle, provided the half apex angle, α , is not greater than 30 deg. except as provided for in (b) below. A reinforcement ring shall be provided at either or both ends of the reducer when required by (b) below.

(7) A toriconical reducer [Fig. NC-3324.11(a)(6)-1 sketch (b)] may be shaped as a portion of a toriconical shell, a portion of a hemispherical head plus a conical section, or a portion of an ellipsoidal head plus a conical section, provided the half apex angle, α , is not greater than 30 deg., except as provided for in (b) below. A reinforcement ring shall be provided at the small end of a conical reducer element when required by (b) below.

(8) Reverse curve reducers [Fig. NC- 3324.11(a)(6)-1 sketches (c) and (d)] may be shaped of elements other than those illustrated.

(b) Supplementary Requirements for Reducer Sections and Conical Heads Under Internal Pressure

(1) The equations of (2) and (3) below provide for the design of reinforcement, if needed, at the cone to cylinder junctions for reducer sections and conical heads where all the elements have a common axis and the half apex angle $\alpha \leq 30$ deg. In (5) below, provision is made for special analysis in the design of cone to cylinder intersections with or without reinforcing rings where α is greater than 30 deg.

(2) Reinforcement shall be provided at the junction of the cone with the large cylinder for conical heads and reducers without knuckles when the value of Δ , obtained from Table NC-3324.11(b)(2)-1, using the appropriate ratio P/S , is less than α . Interpolation may be made in the table.

(a) The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following equation:

$$A = \frac{PR_L^2}{2S} \left(1 - \frac{\Delta}{\alpha} \right) \tan \alpha \quad (1)$$

(1)

(b) When the thickness, less corrosion allowance, of both the reducer and cylinder exceeds that required by the applicable design equations, the minimum excess thickness may be considered to contribute to the required reinforcement ring in accordance with the following equation:

$$(2) A_e = 4t_e \sqrt{R_L t_s}$$

(c) Any additional area of reinforcement which is required shall be situated within a distance of $\sqrt{R_L t_s}$ from the junction of the reducer and the cylinder. The centroid of the added area shall be within a distance of $0.5\sqrt{R_L t_s}$ from the junction.

(3) Reinforcement shall be provided at the junction of the conical shell of a reducer without a flare and the small cylinder when the value of Δ obtained from Table NC-3324.11(b)(3)-1, using the appropriate ratio P/S , is less than α .

(a) The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following formula:

$$A = \frac{PR_s^2}{2S} \left(1 - \frac{\Delta}{\alpha} \right) \tan \alpha \quad (3)$$

(3)

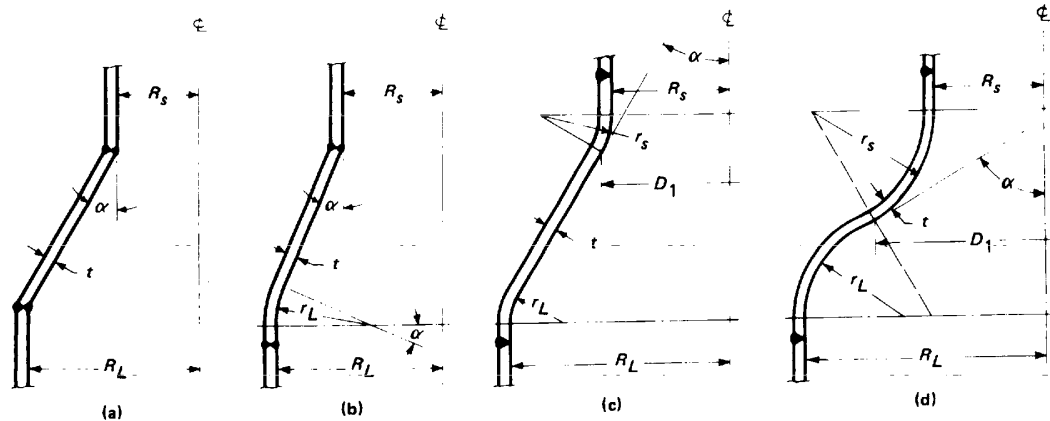
(b) When the thickness, less corrosion allowance, of either the reducer or cylinder exceeds that required by the applicable design equation, the excess thickness may be considered to contribute to the required reinforcement ring in accordance with the following equation:

$$(4) A_e = m \sqrt{R_s t} [(t_c - (t/\cos \alpha) + (t_s - t)]$$

(c) Any additional area of reinforcement which is required shall be situated within a distance of

Page 107

$\sqrt{R_s t}$ from the junction, and the centroid of the added area shall be within a distance of $0.5\sqrt{R_s t}$ from the junction.



GENERAL NOTES:

- (1) r_L shall not be less than the smaller of $0.12 (R_L + t)$ or $3t$.
- (2) r_s has no dimensional requirement.

FIG. 3324.11(a)(6)-1 LARGE HEAD OPENINGS, REVERSE CURVE, AND CONICAL SHELL REDUCER SECTIONS

FIG. 3324.11(a)(6)-1 LARGE HEAD OPENINGS, REVERSE CURVE, AND CONICAL SHELL REDUCER SECTIONS

(4) Reducers not described in NC-3324.11(a)(3), such as those made up of two or more conical frustums having different slopes, may be designed in accordance with (5) below.

(5) When the half apex angle α is greater than 30 deg., cone-to-cylinder junctions without a knuckle may be used, with or without reinforcing rings, if the design is based on stress analysis. When a stress analysis is made, the calculated localized stresses at the discontinuity shall not exceed the following values:

(a) membrane hoop stress plus average discontinuity hoop stress shall not be greater than $1.5S$;

(b) membrane longitudinal stress plus discontinuity longitudinal stress due to bending shall not be greater than $4S$, where the average discontinuity hoop stress is the average hoop stress across the wall thickness due to the discontinuity at the junction, disregarding the effect of Poisson's ratio times the longitudinal stress at the surfaces;

(c) the angle joint between the cone and cylinder shall be designed equivalent to a double butt welded joint and, because of the high bending stress, there shall be no weak zones around the angle joint. The thickness of the cylinder may have to be increased to limit the difference in thickness so that the angle joint has a smooth contour.

NC-3324.12 Nozzles

(a) The wall thickness of a nozzle or other connection shall not be less than the nominal thickness of the connecting piping. In addition, the wall thickness shall not be less than the thickness computed for the applicable loadings in NC-3111 plus the thickness added for corrosion. Except for access openings and openings for inspection only, the wall thickness shall not be less than the smaller of (1) and (2) below:

(1) the required thickness of the shell or head to which the connection is attached plus the corrosion allowance provided in the shell or head adjacent to the connection;

(2) the minimum thickness¹² of standard wall pipe plus the corrosion allowance on the connection; for nozzles larger than the largest pipe size included in ANSI B36.10, the wall thickness of that largest size, plus corrosion allowance.

12 The minimum thickness for all pipe materials is the nominal wall thickness listed in Table 2 of ANSI B36.10 less $12\frac{1}{2}\%$. For diameters other than those listed in the table, this shall be based on the next larger pipe size.

Page 108

(b) The allowable stress value for shear in a nozzle neck shall be 70% of the allowable tensile stress for the vessel material.

NC-3324.13 Nozzle Piping Transitions.

The stress limits of Table NC-3321-1 shall apply to all portions of nozzles which lie within the limits of reinforcement given in NC-3334, except as provided for in NC-3324.14. Stresses in the extension of any nozzle beyond the limits of reinforcement shall be subject to the stress limits of NC-3600.

NC-3324.14 Consideration of Standard Reinforcement

(a) Where a nozzle-to-shell junction is reinforced in accordance with the rules of NC-3334, the stresses in this region due to internal pressure may be considered to satisfy the limits of Table NC-3321-1. Under these conditions, no analysis is required to demonstrate compliance for pressure induced stresses in the nozzle region.

(b) Where external piping loads are specified, membrane plus bending stresses due to these loads shall be calculated in the nozzle, and membrane stresses shall be calculated in the local nozzle-to-shell region. These stresses, in conjunction with pressure induced stresses, shall meet the limits of Table NC-3321-1 for $(\sigma_m \text{ or } \sigma_L) + \sigma_b$. In this case, the pressure induced stresses in the $(\sigma_m \text{ or } \sigma_L) + \sigma_b$ category may be assumed to be no greater than the limit for σ_m in Table NC-3321-1 for a given condition.

NC-3324.15 Other Loadings.

When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in NC-3111 other than pressure and temperature.

NC-3325 Flat Heads and Covers

The minimum thickness of unstayed flat heads, cover plates, and blind flanges shall conform to the requirements given in this paragraph. These requirements apply to circular heads and covers. Some acceptable types of flat heads and covers are shown in Fig. NC-3325-1. In this figure, the dimensions of the component parts and the dimensions of the welds are exclusive of extra metal required for corrosion allowance.

NC-3325.1 Nomenclature.

The symbols used are defined as follows:

C	= a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in NC-3325.3, dimensionless
d	= diameter, measured as indicated in Fig. NC-3325-1, in.
h_G	= gasket moment arm, equal to the radial distance from the centerline of the bolts to the line of the gasket reaction, as shown in Table XI-3221.1-2, in.
l	= length of flange of flanged heads, measured from the tangent line of knuckle, as indicated in Fig. NC-3325-1 sketch (a), in.

	(a), in.
m	= the ratio of t_f/t_s , dimensionless
P	= Design Pressure, psi
r	= inside corner radius on a head formed by flanging or forging, in.
S	= maximum allowable stress value, psi, from Tables 1A, 1B, and 3 Section II, Part D, Subpart 1 of Appendix I
t	= minimum required thickness of flat head or cover, exclusive of corrosion allowance, in.
t_f	= actual thickness of the flange on a forged head, at the large end, exclusive of corrosion allowance, as indicated in Fig. NC-3325-1 sketches (b-1) and (b-2), in.
t_h	= actual thickness of flat head or cover, exclusive of corrosion allowance, in.
t_r	= required thickness of shell, for pressure, in.
t_s	= actual thickness of shell, exclusive of corrosion allowance, in.
W	= total bolt load, lb, given for circular heads for Eqs. (3) and (4), XI-3223

NC-3325.2 Thickness.

The thickness of flat unstayed heads, covers, and blind flanges shall conform to one of the following two requirements.
13

(a) Circular blind flanges of ferrous materials conforming to ANSI B16.5 shall be acceptable for the diameters and pressure-temperature ratings in Tables 2 to 8 of that Standard, when of the types shown in Fig. NC-3325-1 sketches (d) and (e).

13 The formulas provide safe construction as far as stress is concerned. Greater thicknesses may be necessary if deflection would cause leakage at threaded or gasketed joints.

(b) The minimum required thickness of flat unstayed circular heads, covers, and blind flanges shall be calculated by the equation

$$(5) t = d \sqrt{CP/S}$$

except when the head, cover, or blind flange is attached by bolts causing an edge moment [Fig. NC-3325-1 sketches (d) and (e)], in which case the thickness shall be calculated by

$$(6) t = d \sqrt{CP/S + 1.27Wh_c/Sd^3}$$

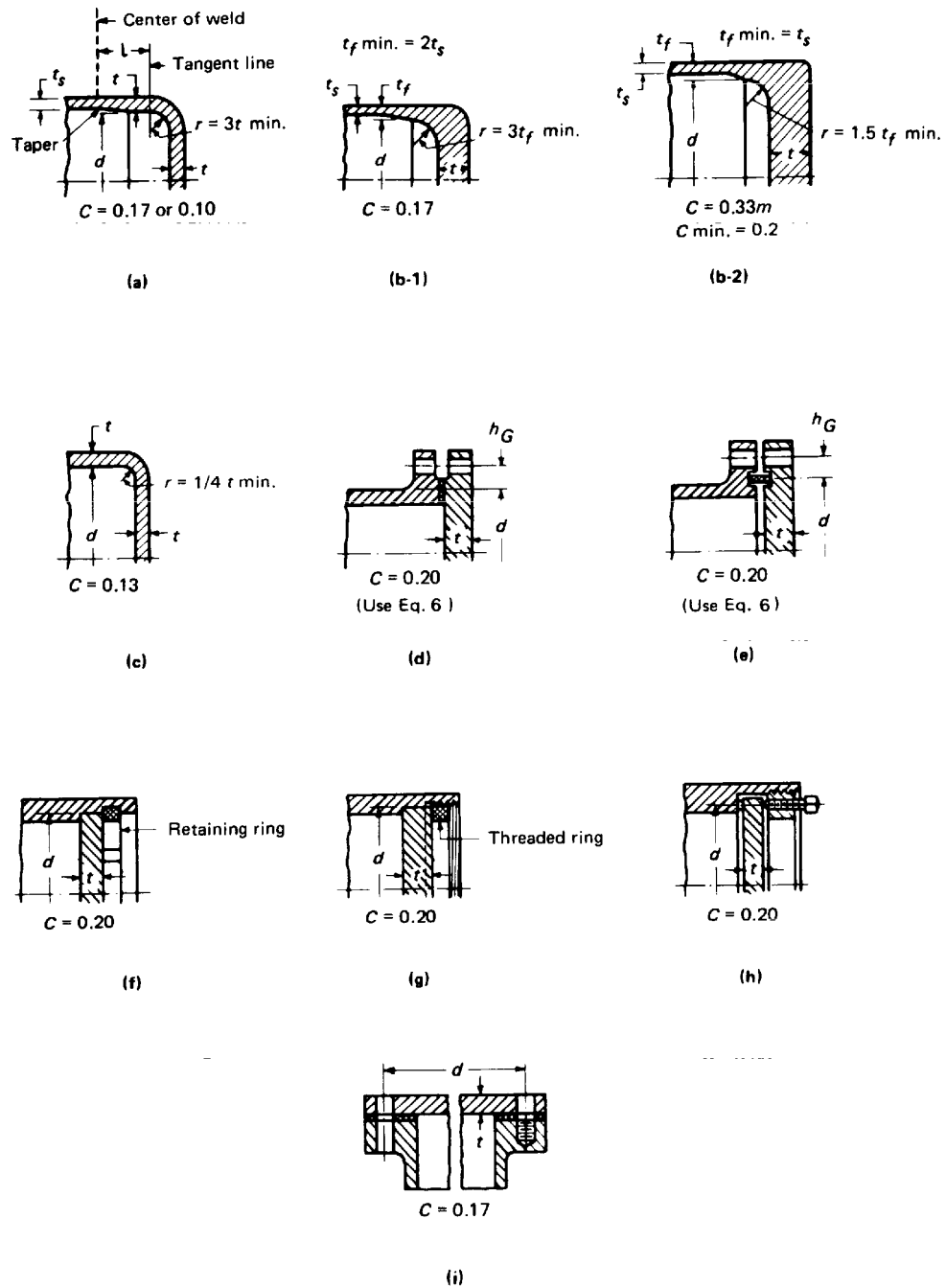


FIG. NC-3325-1 SOME ACCEPTABLE TYPES OF UNSTAYED FLAT HEADS AND COVERS

FIG. NC-3325-1 SOME ACCEPTABLE TYPES OF UNSTAYED FLAT HEADS AND COVERS

When using Eq. (6), the thickness t shall be calculated for both service loadings and gasket seating, and the greater of the

two values shall be used. For service loadings, the value of P shall be the Design Pressure, and the values of S at the Design Temperature and W from Eq. (3) of XI-3223 shall be used. For gasket seating, P equals zero, and the values of S at atmospheric temperature and W from Eq. (4) of XI-3223 shall be used.

NC-3325.3 Values of C .

For the types of construction shown in Figs. NC-3325-1, NC-4243-1, NC-4243-2, and NC-4243.1-1, the minimum values of C to be used in Eqs. (5) and (6) shall be as given in (a) through (g) for Fig. NC-3325-1 and in (h) for Figs. NC-4243.1-1 and NC-4243-1, in (i) for Fig. NC-4243-2, and in (j) for Fig. NC-4243.1-1.

(a) In sketch (a), $C = 0.17$ for flanged circular heads forged integral with or butt welded to the vessel with an inside corner radius not less than three times the required head thickness, with no special requirement with regard to length of flange.

(1) $C = 0.10$ for circular heads, when the flange length for heads of the above design is not less than

$$l = \left(1.1 - 0.8 \frac{t_s^2}{t_h^2} \right) \sqrt{d t_h} \quad (7)$$

(7)

(2) $C = 0.10$ for circular heads, when the flange length l is less than the requirement in (1) above but the shell thickness is not less than

$$t_s = 1.12 t_h \sqrt{1.1 - l / \sqrt{d t_h}} \quad (8)$$

(8) for a length of at least $2\sqrt{d t_s}$.

(3) When $C = 0.10$ is used, the taper shall be 1:4.

(b) In sketch (b-1), $C = 0.17$ for forged circular heads integral with or butt welded to the vessel, where the flange thickness is not less than two times the shell thickness, the corner radius on the inside is not less than three times the flange thickness, and the welding meets all the requirements of NC-4000.

(c) In sketch (b-2), $C = 0.33m$ but not less than 0.2 for forged circular heads integral with or butt welded to the vessel, where the flange thickness is not less than the shell thickness and the corner radius on the inside is not less than 1.5 times the flange thickness. See Fig. NC-4243.1-1 sketches (a) and (b) for the special cases where $t_f = t_s$.

(d) In sketch (c), $C = 0.13$ for integral flat circular heads when the dimension d does not exceed 24 in. (610 mm), the ratio of thickness of the head to the dimension d is not less than 0.05 nor greater than 0.25, the head thickness t_h is not

less than the shell thickness t_s , the inside corner radius is not less than $0.25t$, and the construction is obtained by special techniques of upsetting and spinning the end of the shell, such as employed in closing header ends.

(e) In sketches (d) and (e), $C = 0.2$ for circular heads and covers bolted to the vessel as indicated in the figures. Note that Eq. (6) shall be used because of the extra moment applied to the cover by the bolting. When the cover plate is grooved for a peripheral gasket as shown in sketch (e), the net cover plate thickness under the groove or between the groove and the outer edge of the cover plate shall be not less than $d\sqrt{1.27Wh_C/Sd^3}$ for circular heads and covers.

(f) In sketches (f), (g), and (h), $C = 0.2$ for a circular plate inserted into the end of a vessel and held in place by a positive mechanical locking arrangement, and when all possible means of failure (by shear, tension, compression, or radial deformation, including flaring) resulting from pressure and differential thermal expansion are resisted using stresses consistent with this Article. Seal welding may be used, if desired.

(g) In sketch (i), $C = 0.17$ for circular covers, bolted with a full-face gasket, to shells, flanges, or side plates.

(h) In Fig. NC-4243-1 sketches (b), (c), (e), and (f), $C = 0.33m$ but not less than 0.3 when the dimensional requirements of NC-3358.3 are met.

(i) In Fig. NC-4243.1-1, $C = 0.33m$ but not less than 0.3 when the dimensional requirements of NC-3358.4 are met.

(j) In Fig. NC-4243-2 sketches (a) and (b), $C = 0.33m$ but not less than 0.2 when the dimensional requirements of NC-3358.3 are met.

NC-3326 Spherically Dished Covers With Bolting Flanges

NC-3326.1 Nomenclature.

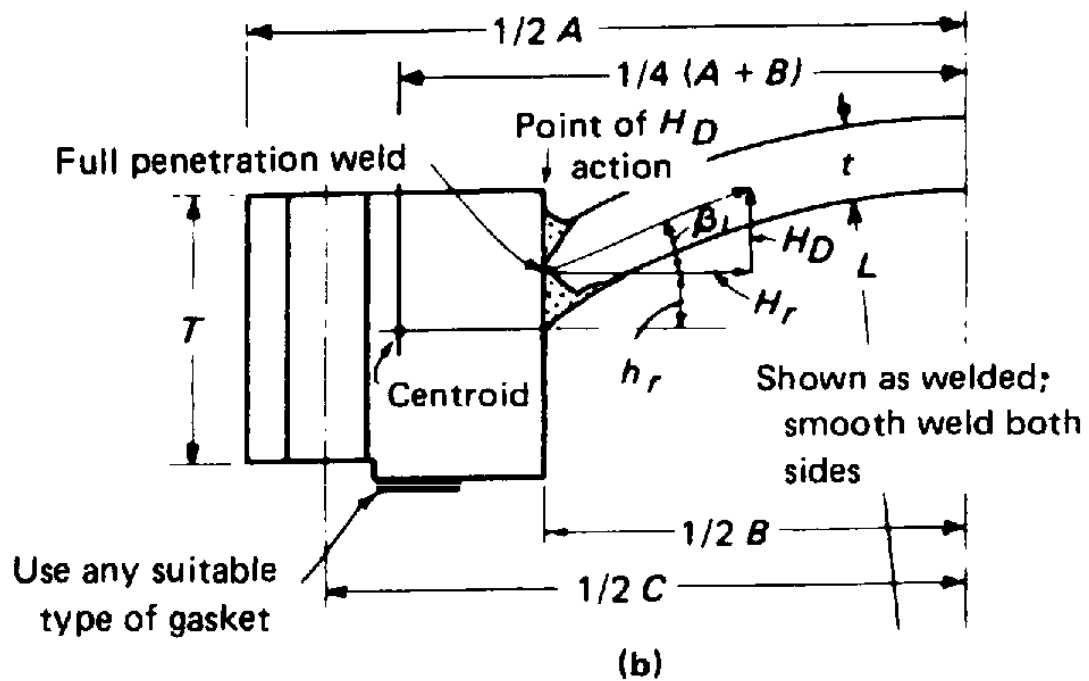
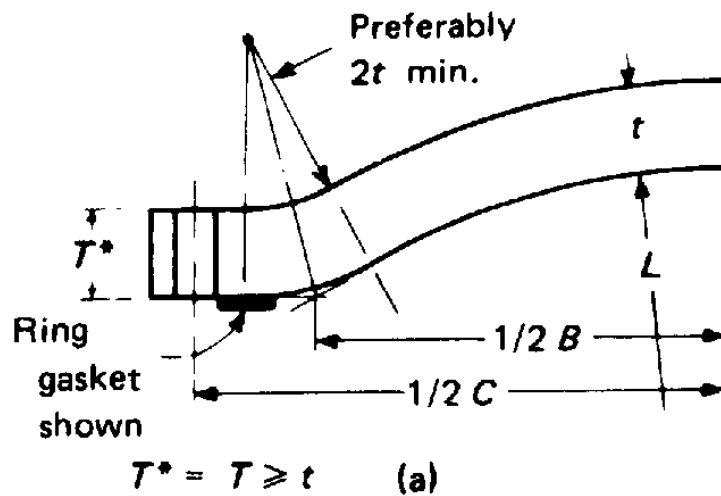
The symbols used are defined as follows:

t	= minimum required thickness of head plate after forming, in.
L	= inside spherical or crown radius, in.
r	= inside knuckle radius, in.
P	= Design Pressure, psi
S	= maximum allowable stress value, psi
T	= flange thickness, in.

Page 111

M_o	= the total moment, in. lb, determined as in XI-3230 for heads concave to pressure, and XI-3260 for heads convex to pressure; except that for heads of the type shown in Fig. NC-3326.1-1 sketch (b), H_D and h_D shall be as defined below, and an additional moment, $H_r h_r^{14}$ shall be included:
H_r	= radial component of the membrane load in the spherical segment = $H_D \cot \beta_1$, lb, acting at the intersection of the inside of the flange ring with the center line of the dished cover thickness
h_r	= lever arm of H_r about centroid of flange ring, in.
H_D	= axial component of the membrane load in the spherical segment, lb, acting at the inside of the flange ring = $0.785 B^2 P$
h_D	= radial distance from the bolt circle to the inside of the flange

ring, in.



**FIG. NC-3326.1-1 SPHERICALLY DISHED
COVERS WITH BOLTING FLANGES**

FIG. NC-3326.1-1 SPHERICALLY DISHED COVERS WITH BOLTING FLANGES

14 Since Hh in some cases will subtract from the total moment, the moment in the flange ring when the internal pressure is zero may be the determining loading for the flange design.

β_1

= angle formed by the tangent to the center line of the dished cover thickness at its point of intersection with the flange ring, and a line perpendicular to the axis of the dished cover, where

$$\beta_1 = \arcsin \left(\frac{B}{2L + t} \right)$$

A

= outside diameter of flange, in.

B

= inside diameter of flange, in.

C

= bolt circle diameter, in.

NC-3326.2 Spherically Dished Heads With Bolting Flanges.

Circular spherically dished heads with bolting flanges, both concave and convex to the pressure, and conforming to the several types illustrated in Fig. NC-3326.1-1, shall be designed in accordance with the requirements of (a) and (b) below. For heads convex to pressure, the spherical segments shall be thickened, if necessary, to meet the requirements of NC-3133. The actual value of the total moment M_o may calculate to be either plus or minus for both the heads concave to pressure and the heads convex to pressure. However, for use in all of the formulas which follow, the absolute values for both P and M_o shall be used.

(a) Heads of the type shown in Fig. NC-3326.1-1 sketch (a):

(1) head thickness:

$$(9) t = 5PL/6S$$

(2) flange thickness, T :

for ring gasket:

$$T = Q + \sqrt{\frac{1.875M_o(C + B)}{SB(7C - 5B)}} \quad (10)$$

(10)

for full face gasket:

$$T = Q + \sqrt{Q^2 + \frac{3BQ(C - B)}{L}} \quad (11)$$

(11)

where

$$Q = \frac{PL}{4S} \left(\frac{C + B}{7C - 5B} \right) \quad (12)$$

(12)

for heads with round bolting holes or where

$$Q = \frac{PL}{4S} \left(\frac{C + B}{3C - B} \right) \quad (13)$$

(13)

for heads with bolting holes slotted through edge of head;

Page 112

(3) the larger of the values of t given by (1) and (2) above shall be used.

(b) Heads of the type shown in Fig. NC-3326.1-1 sketch (b):

(1) head thickness:

$$(14) t = 5PL/6S$$

(2) flange thickness for ring gaskets shall be calculated as follows:

(a) for heads with round bolting holes:

$$T = Q + \sqrt{\frac{1.875M_o(C + B)}{SB(7C - 5B)}} \quad (15)$$

(15)

where

$$Q = \frac{PL}{4S} \left(\frac{C + B}{7C - 5B} \right) \quad (16)$$

(16)

(b) for heads with bolting holes slotted through the edge of the head:

$$T = Q + \sqrt{\frac{1.875M_o(C + B)}{SB(3C - B)}} \quad (17)$$

(17)

where

$$Q = \frac{PL}{4S} \left(\frac{C + B}{3C - B} \right) \quad (18)$$

(18)

(3) flange thickness for full face gaskets shall be calculated by the following equation:

$$T = Q + \sqrt{Q^2 + \frac{3BQ(C - B)}{L}} \quad (19)$$

(19)

The value of Q in Eq. (19) is calculated by Eq. (16) for round bolting holes or by Eq. (18) for bolting holes slotted through the edge of the head [see (2) above].

(4) the required flange thickness shall be T as calculated in (2) or (3) above, but in no case less than the value of t calculated in (1).

NOTE: These equations are approximate in that they do not take into account continuity between the flange ring and the dished head. A more exact method of analysis which takes this into account may be used. Such a method may parallel the method of analysis and allowable stresses for flange design in Appendix XI. The dished portion of a cover designed under this rule may, if welded, require evaluation of any welded joint.

NC-3327 Quick Actuating Closures

Closures other than the multibolted type designed to provide access to the contents space of a component shall have the locking mechanism or locking device so designed that failure of any one locking element or component in the locking mechanism cannot result in the failure of all other locking elements and the release of the closure. Quick actuating closures shall be so designed and installed that it may be determined by visual external observation that the holding elements are in good condition and that their locking elements, when the closure is in the closed position, are in full engagement.

NC-3327.1 Positive Locking Devices.

Quick actuating closures that are held in position by positive locking devices and that are fully released by partial rotation or limited movement of the closure itself or the locking mechanism and any closure that is other than manually operated shall be so designed that when the vessel is installed the conditions of (a) through (c) below are met.

(a) The closure and its holding elements are fully engaged in their intended operating position before pressure can be built up in the vessel.

(b) Pressure tending to force the closure clear of the vessel will be released before the closure can be fully opened for access.

(c) In the event that compliance with (a) and (b) is not inherent in the design of the closure and its holding elements, provision shall be made so that devices to accomplish this can be added when the vessel is installed.

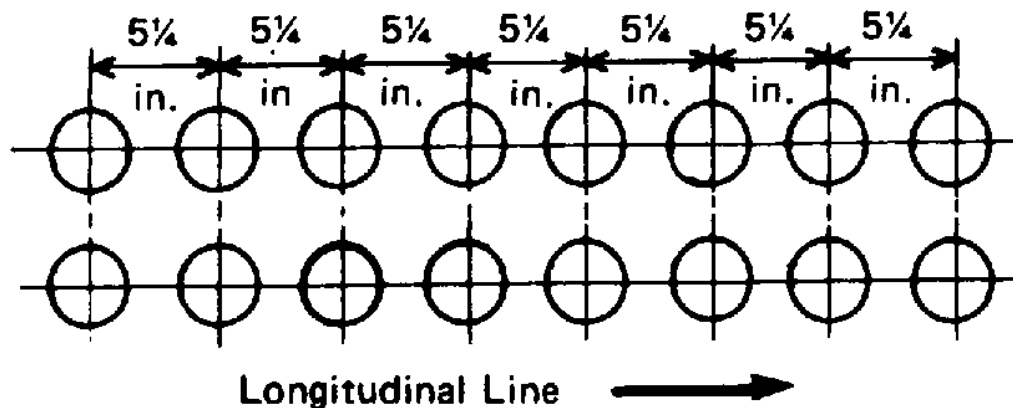
NC-3327.2 Manual Operation.

Quick actuating closures that are held in position by a locking device or mechanism that requires manual operation and are so designed that there will be leakage of the contents of the vessel prior to disengagement of the locking elements and release of closure need not satisfy NC-3327.1, but such closures shall be equipped with an audible or visible warning device that will serve to warn the operator if pressure is applied to the vessel before the closure and its holding elements are fully engaged in their intended position and further will serve to warn the operator if an attempt is made to operate the locking mechanism or device before the pressure within the vessel is released.

NC-3327.3 Pressure Indicating Device.

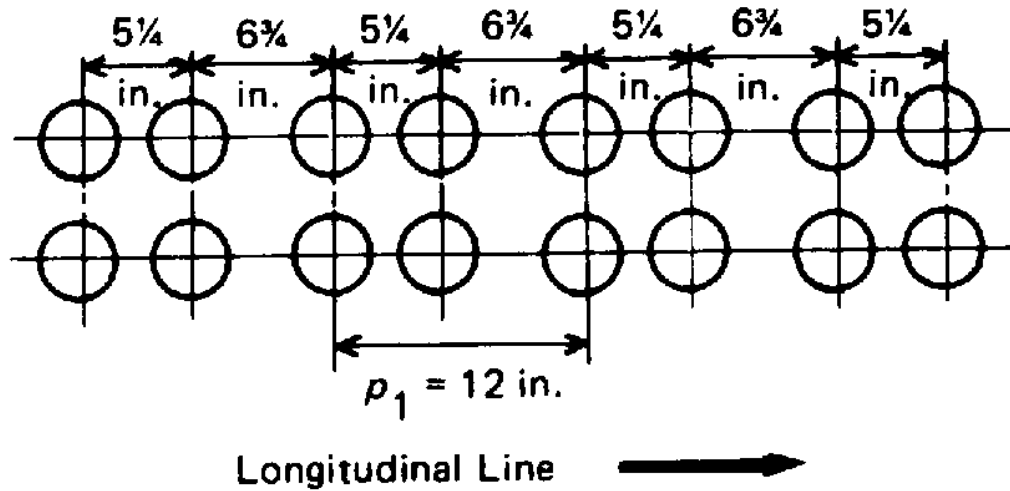
When installed, all vessels having quick actuating closures shall be provided with a pressure indicating device visible from the operating area.

Page 113



**FIG. NC-3329(b)-1 EXAMPLE OF
TUBE SPACING WITH PITCH OF HOLES
EQUAL IN EVERY ROW**

FIG. NC-3329(b)-1 EXAMPLE OF TUBE SPACING WITH PITCH OF HOLES EQUAL IN EVERY ROW



**FIG. NC-3329(b)-2 EXAMPLE OF
TUBE SPACING WITH PITCH OF HOLES
UNEQUAL IN EVERY SECOND ROW**

FIG. NC-3329(b)-2 EXAMPLE OF TUBE SPACING WITH PITCH OF HOLES UNEQUAL IN EVERY SECOND ROW

NC-3329 Ligaments

(a) The symbols used are defined as follows:

p	= longitudinal pitch of tube holes, in.
p_1	= unit length of ligament, in.
p'	= diagonal pitch of tube holes, in.
d	= diameter of tube holes, in.
n	= number of tube holes in length p_1

(b) When a cylindrical shell is drilled for tubes in a line parallel to the axis of the shell for substantially the full length of the shell as shown in Figs. NC-3329(b)-1 through NC-3329(b)-3, the efficiency of the ligaments between the tube holes shall be determined by (1) or (2) below:

(1) when the pitch of the tube holes on every row is equal [Fig. NC-3329(b)-1], the equation is:

$$\frac{p - d}{p} = \text{efficiency of ligament}$$

(2) when the pitch of tube holes on any one row is unequal [Figs. NC-3329(b)-2 and NC-3329(b)-3], the formula is:

$$\frac{p_1 - nd}{p_1} = \text{efficiency of ligament}$$

(c) The strength of ligaments between tube holes measured circumferentially shall be at least 50% of the strength of ligaments of similar dimensions taken in a line parallel to the axis of the cylindrical shell.

(d) When a cylindrical shell is drilled for tube holes so as to form diagonal ligaments, as shown in Fig. NC-3329(d)-1, the efficiency of these ligaments shall be that given by the diagram in Fig. NC-3329(d)-2. The pitch of tube holes shall be measured either on the flat plate before rolling or on the middle line of the plate after rolling. To use the diagram in Fig. NC-3329(d)-2, compute the value of p'/p_1 and also the efficiency of the longitudinal ligament. Next, find in the diagram the vertical line corresponding to the longitudinal efficiency of the ligament and follow this line vertically to the point where it intersects the diagonal line representing the ratio of p'/p_1 . Then project this point horizontally to the left and read the diagonal efficiency of the ligament on the scale at the edge of the diagram. The shell thickness and the maximum allowable pressure shall be based on the ligament that has the lower efficiency.

(e) When tube holes in a cylindrical shell are arranged in symmetrical groups which extend a distance greater than the inside diameter of the shell along lines parallel to the axis and the same spacing is used for each group, the efficiency for one of the groups shall be not less than the efficiency on which the maximum allowable pressure is based.

(f) The average ligament efficiency in a cylindrical shell, in which the tube holes are arranged along lines parallel to the axis with either uniform or nonuniform spacing, shall be computed by the following rules and shall satisfy the requirements of both (1) and (2) below.¹⁵

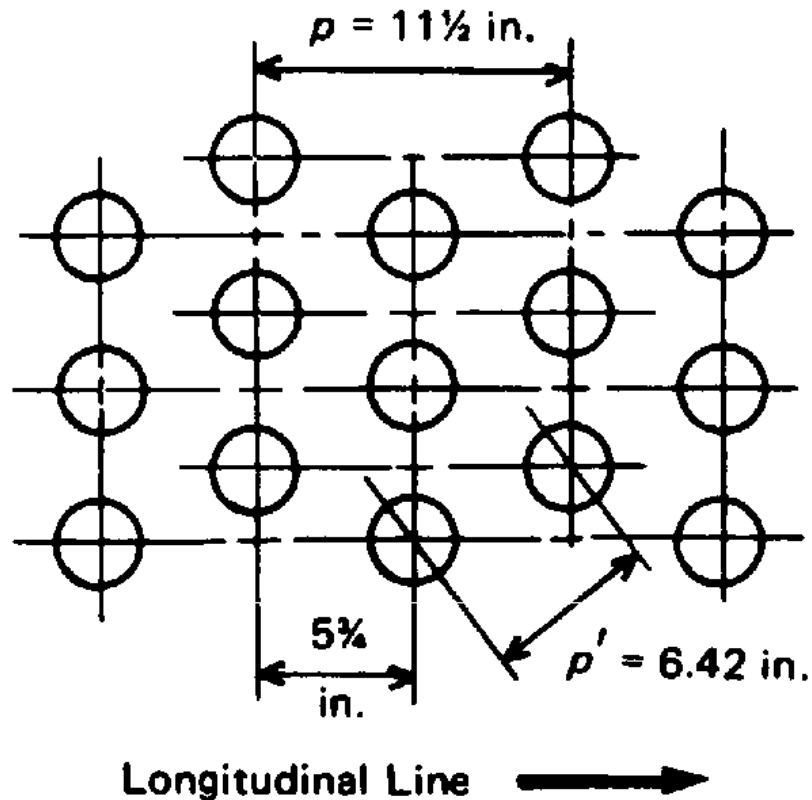
(1) For a length equal to the inside diameter of the shell for the position which gives the minimum efficiency, the efficiency shall not be less than that on which the maximum allowable pressure is based. When the diameter of the shell exceeds 60 in. (1520 mm), the length shall be taken as 60 in. (1520 mm) in applying this rule.

¹⁵ The rules in this paragraph apply to ligaments between tube holes and not to single openings. They may give lower efficiencies in some cases than those for symmetrical groups which extend a distance greater than the inside diameter of the shell as covered in (c). When this occurs, the efficiencies computed by the rules under (b) shall govern.

(2) For a length equal to the inside radius of the shell for the position which gives the minimum efficiency,

the efficiency shall be not less than 80% of that on which the maximum allowable pressure is based. When the radius of the shell exceeds 30 in. (762 mm), the length shall be taken as 30 in. (762 mm) in applying this rule.

FIG. NC-3329(b)-3 EXAMPLE OF TUBE SPACING WITH PITCH HOLES VARYING IN EVERY SECOND AND THIRD ROW



**FIG. NC-3329(d)-1 EXAMPLE OF
TUBE SPACING WITH TUBE HOLES
ON DIAGONAL LINES**

FIG. NC-3329(d)-1 EXAMPLE OF TUBE SPACING WITH TUBE HOLES ON DIAGONAL LINES

(g) For holes which are not in line, placed longitudinally along a cylindrical shell, the rules in (f) above for calculating efficiency shall hold, except that the equivalent longitudinal width of a diagonal ligament shall be used. To obtain the equivalent width, the longitudinal pitch of the two holes having a diagonal ligament shall be multiplied by the efficiency of the diagonal ligament. The efficiency to be used for the diagonal ligaments is given in Fig. NC-3329(g)-1.

NC-3330 OPENINGS AND REINFORCEMENT

NC-3331 General Requirements for Openings

(a) Openings in cylindrical or conical portions of vessels or in formed heads shall preferably be circular, elliptical, or obround. When the long dimension of an elliptical, or obround, opening exceeds twice the short dimensions, the reinforcement across the short dimensions shall be increased as necessary to provide against excessive distortion due to twisting moment.

(b) Openings may be of other shapes than those given in (a) and all corners shall be provided with a suitable radius.

(c)(1) The rules for reinforcement of openings given in NC-3330 are intended to apply to openings not exceeding the following:

(a) for vessels 60 in. (1520 mm) diameter and less, one half the vessel diameter but not to exceed 20 in. (508 mm);

(b) for vessels over 60 in. (1520 mm) diameter, one-third the vessel diameter but not to exceed 40 in. (1000 mm).

(2) Larger openings shall be given special attention. Two-thirds of the required reinforcement shall be within $\frac{1}{2}r$ parallel to the vessel surface and measured from the edge of the opening, where r is the radius of the finished opening. The limit normal to the vessel wall is the smaller of the limits specified in NC-3334.2. Special consideration shall be given to the fabrication details used and examination employed. Reinforcement often may be advantageously obtained by use of heavier shell plate for a vessel course or inserted locally around the opening. Welds may be ground to concave contour and the inside corners of the opening rounded to a generous radius to reduce stress concentrations.

Page 115

Page 116

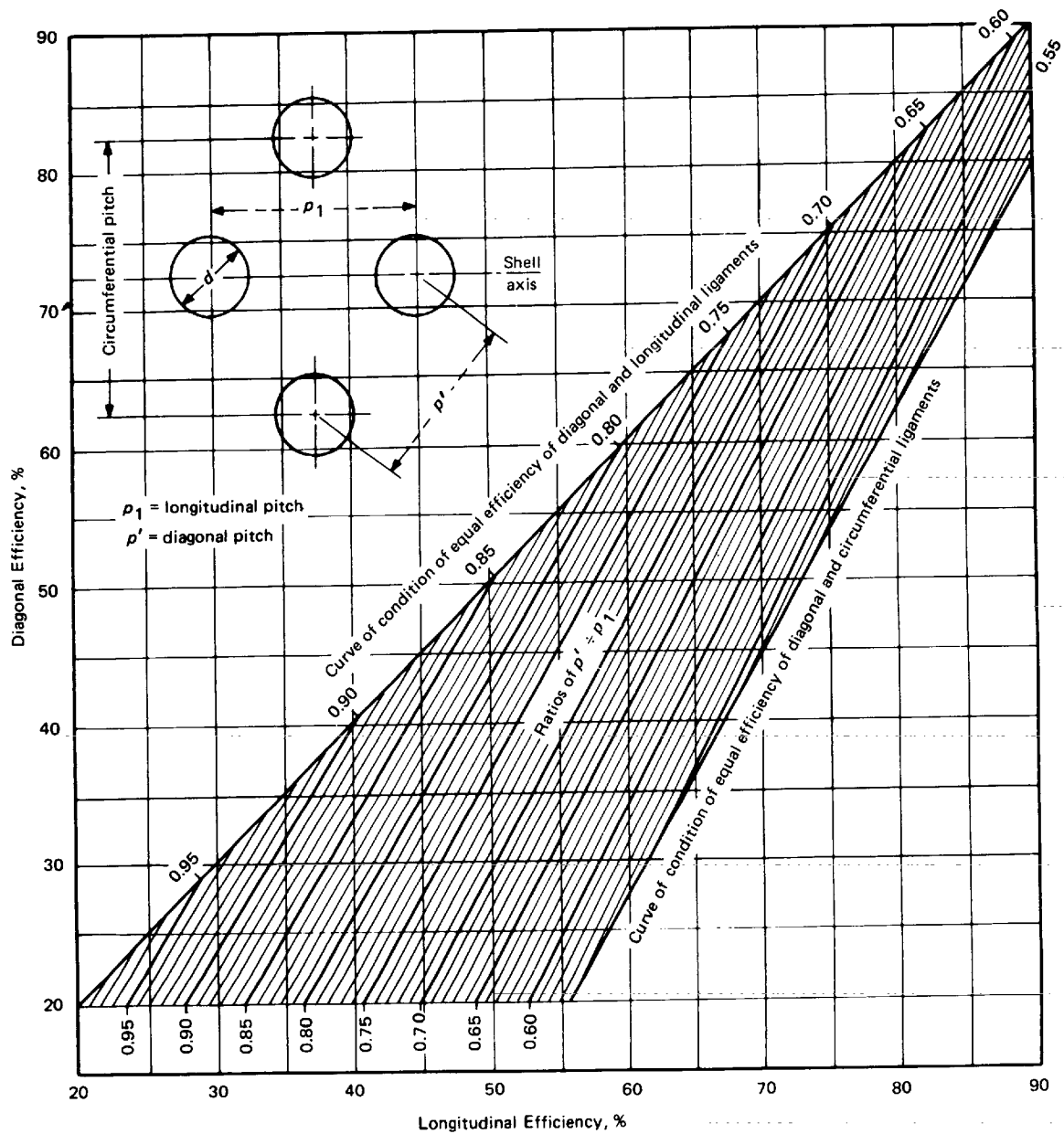


FIG. NC-3329(d)-2 DIAGRAM FOR DETERMINING THE EFFICIENCY OF LONGITUDINAL AND DIAGONAL LIGAMENTS BETWEEN OPENINGS IN CYLINDRICAL SHELLS

FIG. NC-3329(d)-2 DIAGRAM FOR DETERMINING THE EFFICIENCY OF LONGITUDINAL AND DIAGONAL LIGAMENTS BETWEEN OPENINGS IN CYLINDRICAL SHELLS

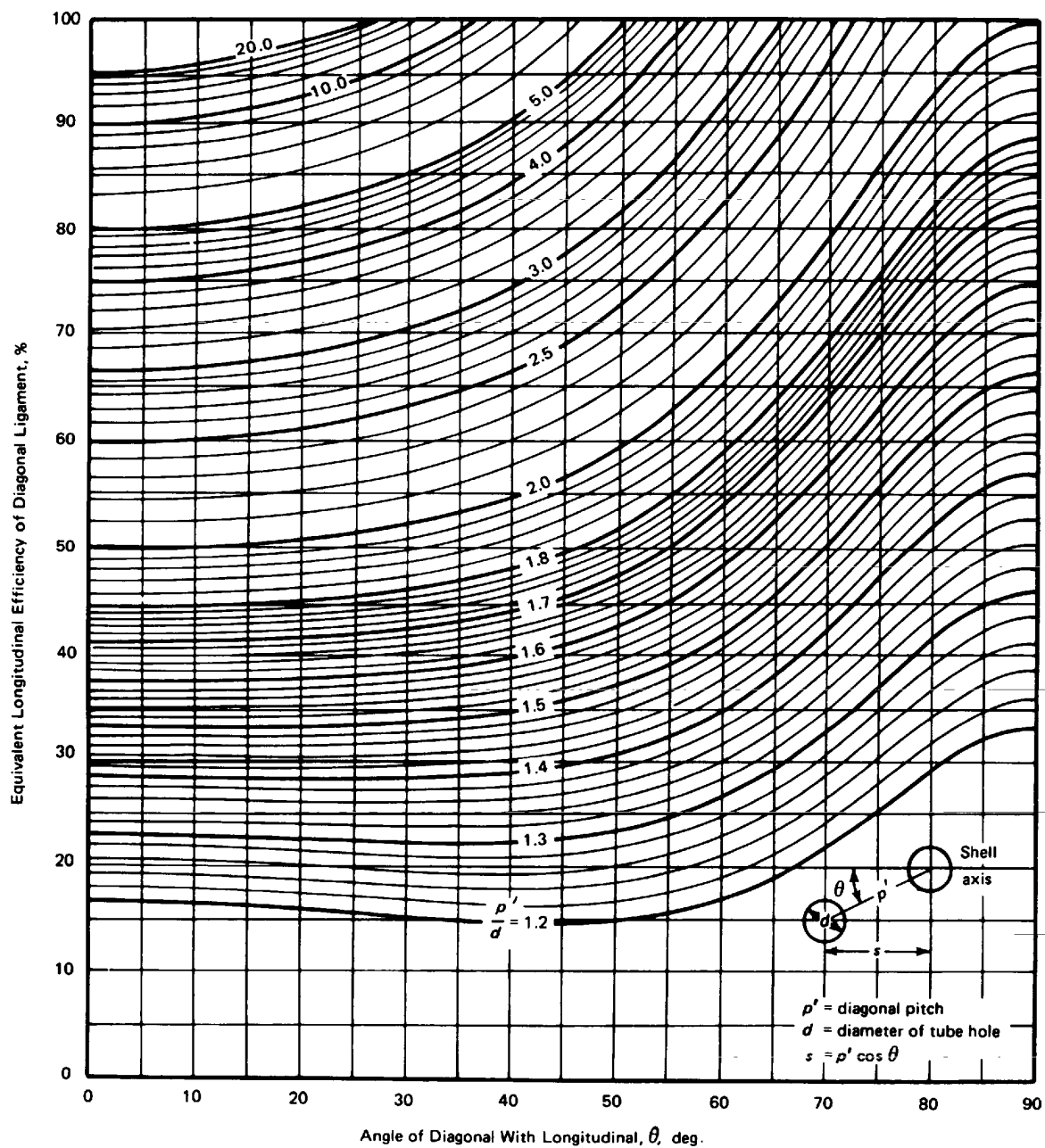


FIG. NC-3329(g)-1 DIAGRAM FOR DETERMINING EQUIVALENT LONGITUDINAL EFFICIENCY OF DIAGONAL LIGAMENTS

FIG. NC-3329(g)-1 DIAGRAM FOR DETERMINING EQUIVALENT LONGITUDINAL EFFICIENCY OF DIAGONAL LIGAMENTS

(d)

allowance.

(e) Any type of opening may be located in a welded joint.

NC-3332 Reinforcement Requirements for Openings in Shells and Formed Heads

NC-3332.1 Openings Not Requiring Reinforcement.

Reinforcement shall be provided in amount and distribution such that the requirements for area of reinforcement are satisfied for all planes through the center of the opening and normal to the surface of the vessel, except that single circular openings need not be provided with reinforcement if the openings have diameters equal to or less than 2 in. nominal pipe size (DN 50).

NC-3332.2 Required Area of Reinforcement.

The total cross-sectional area of reinforcement A required in any given plane for a vessel under internal pressure shall not be less than

$$A = dt_r F$$

where

d

= finished diameter of a circular opening or finished dimension (chord length) of an opening on the plane being considered for elliptical and obround openings in corroded condition, in.

F

= a correction factor which compensates for the variation in pressure stresses on different planes with respect to the axis of a vessel. A value of 1.00 shall be used for all configurations except that Fig. NC-3332.2-1 may be used for integrally reinforced openings in cylindrical shells and cones.

t_r

= the required thickness of a shell or head computed by the rules of this Article for the Design Pressure, in., except that:

(a) when the opening and its reinforcement are entirely within the spherical portion of a torispherical head, t_r is the thickness required by NC-3324.8(b) using $M = 1$;

(b) when the opening is in a cone, t_r is the thickness required for a seamless cone of diameter D measured where the nozzle axis pierces the inside wall of the cone;

(c) when the opening and its reinforcement are in an ellipsoidal head and are located entirely within a circle, the center of which coincides with the center of the head and the diameter of which is equal to 80% of the shell diameter, t_r is the thickness required for a seamless sphere of radius $K_1 D$, where D is the shell diameter and K_1 is given by Table NC-3332.2-1.

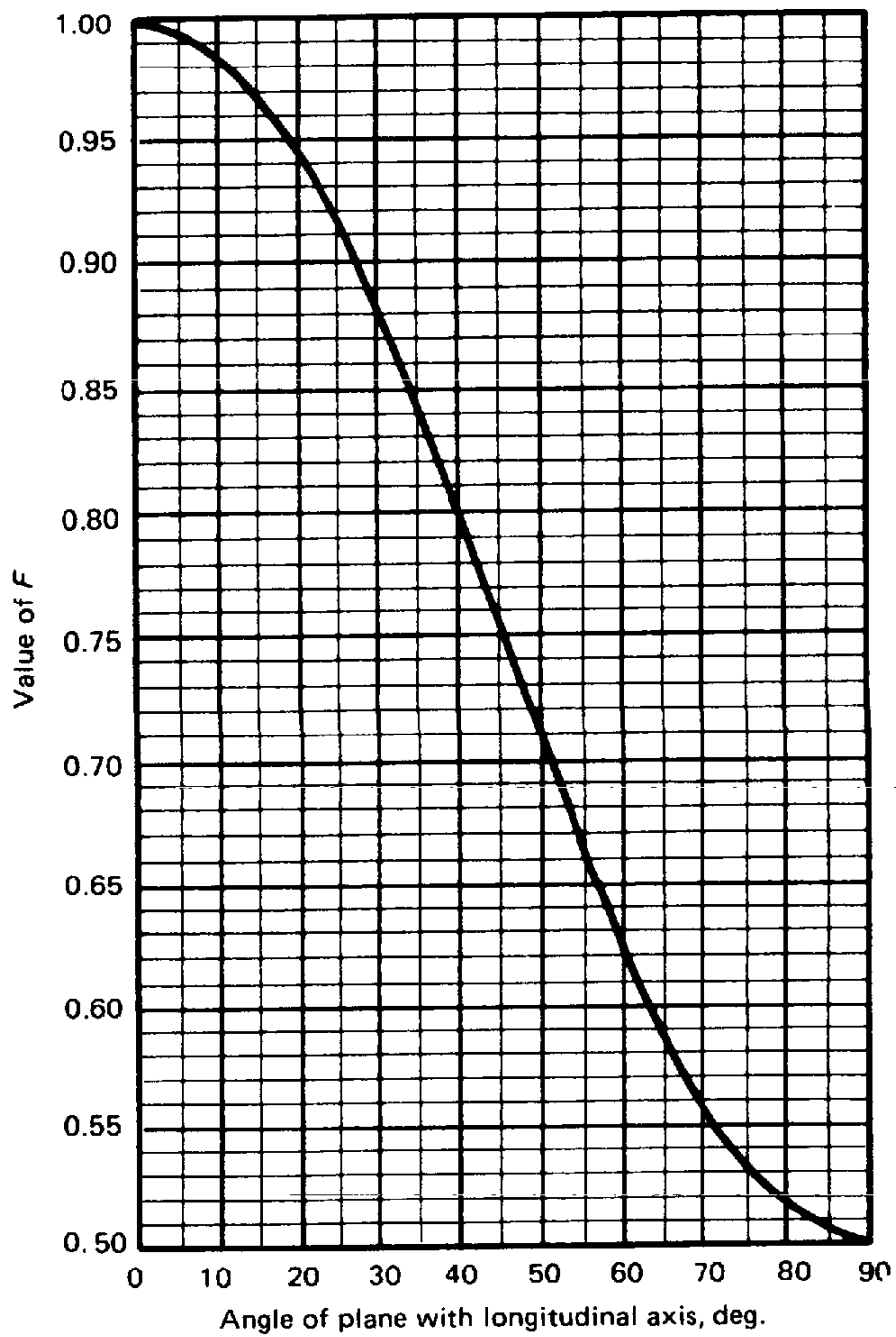


FIG. NC-3332.2-1 CHART FOR DETERMINING
THE VALUE OF F

FIG. NC-3332.2-1 CHART FOR DETERMINING THE VALUE OF F

At least one-half of the required reinforcing shall be on each side of the center line of the opening.

NC-3332.3 Reinforcement for External Pressure.

The reinforcement required for openings in vessels designed for external pressure need only be 50% of that required in the formula for area in NC-3332.2, except that t_r is the wall thickness required by the rules for vessels under external pressure.

NC-3332.4 Reinforcement for Both Internal and External Pressure.

Reinforcement of vessels subject to both internal and external pressures shall meet the

Page 118

requirements of NC-3332.2 for internal pressure and of NC-3332.3 for external pressure.

TABLE NC-3332.2-1
VALUES OF SPHERICAL RADIUS FACTOR K_1
Equivalent Spherical Radius = $K_1 D$; $D/2h$ = Axis Ratio;
Interpolation Permitted for Intermediate Values

$D/2h$	...	3.0	2.8	2.6	2.4	2.2
K_1	...	1.36	1.27	1.18	1.08	0.99
$K/2h$	2.0	1.8	1.6	1.4	1.2	1.0
K_1	0.90	0.81	0.73	0.65	0.57	0.50

TABLE NC-3332.2-1 VALUES OF SPHERICAL RADIUS FACTOR K_1

NC-3333 Reinforcement Required for Openings in Flat Heads

(a) Flat heads that have an opening with a diameter that does not exceed one-half of the head diameter shall have a total cross-sectional area of reinforcement not less than that given by the equation

$$A = 0.5dt_r$$

where d is defined in NC-3332.2 and t_r is the thickness in inches which meets the requirements of NC-3325 in the absence of the opening.

(b) As an alternative to (a) above, the thickness of flat heads may be increased to provide the necessary opening reinforcement as follows:

(1) in Eq. (5) of NC-3325.2 by using $2C$ or 0.75 in place of C , whichever is less;

(2) in Eq. (6) of NC-3325.2, by doubling the quantity under the square root sign.

(c) Flat heads that have an opening with a diameter that exceeds one-half of the head diameter or shortest span, as defined in NC-3325.1, shall be designed as follows.

(1) When the opening is a single, circular, centrally located opening and when the shell-head juncture is integrally formed or integrally attached by a full penetration weld similar to those shown in Fig. NC-3325-1 sketch (a), (b-1), (b-2), or (c), the head shall be designed according to Appendix XIX and related parts of Appendix XI. The required head thickness does not have to be calculated according to NC-3325, since the head thickness which satisfies all the requirements of Appendix XIX also satisfies the intent of NC-3325. The opening in the head may have a nozzle which is integrally formed or integrally attached by a full penetration weld, or it may be an opening without an attached nozzle or hub.

(2) When the opening is of any other type than that described in (1) above, no specific rules are given. Consequently, the requirements of NC-1100(c) shall be met.

NC-3334 Limits of Reinforcement

The boundaries of the cross-sectional area in any plane normal to the vessel wall and passing through the center of the opening and within which metal shall be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane and are given in the following subparagraphs.

NC-3334.1 Limits of Reinforcement Along the Vessel Wall.

The limits of reinforcement, measured along the midsurface of the nominal wall thickness, shall meet the following:

(a) 100% of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) the diameter of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus the sum of the thicknesses of the vessel wall and the nozzle wall;

(b) two-thirds of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) $r + 0.5\sqrt{Rt}$, where R is the mean radius of shell or head, t is the nominal vessel wall thickness, r is the radius of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus two-thirds the sum of the thicknesses of the vessel wall and the nozzle wall.

NC-3334.2 Limits of Reinforcement Normal to the Vessel Wall.

The limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to the lesser of (a) or (b) below:

(a) $2\frac{1}{2}$ times the nominal shell thickness less corrosion allowance;

(b) $2\frac{1}{2}$ times the nozzle wall thickness less corrosion allowance, plus the thickness of any added reinforcement exclusive of weld metal on the side of the shell under consideration.

NC-3335 Metal Available for Reinforcement

NC-3335.1 Openings.

Metal within the limits of reinforcement that may be considered to have reinforcing value shall be that given in (a) through (d) below:

(a) metal in the vessel wall over and above the thickness required to resist pressure and the thickness specified as

corrosion allowance. The area in the vessel wall available as reinforcement is the larger of the values of A_1 given by:

$$A_1 = (t - Ft_r)d$$

or

$$A_1 = 2(t - Ft_r)(t + t_n)$$

(b) metal over and above the thickness required to resist pressure and the thickness specified as corrosion allowance in that part of a nozzle wall extending outside the vessel wall. The maximum area in the nozzle wall available as reinforcement is the lesser of the values of A_2 given by:

$$A_2 = (t_n - t_{rn})5t$$

or

$$A_2 = (t_n - t_{rn})(5t_n + 2t_e)$$

(c) all metal in the nozzle wall extending inside the vessel wall may be included after proper deduction for corrosion allowance on all the exposed surface is made. No allowance shall be taken for the fact that a differential pressure on an inwardly extending nozzle may cause opposing stress to that of the stress in the shell around the opening where

A_1	= area in excess thickness in the vessel wall available for reinforcement, sq in. (NC-3334)
A_2	= area in excess thickness in the nozzle wall available for reinforcement, sq in. (NC-3334)
F	= a correction factor which compensates for the variation in pressure stresses on different planes with respect to the axis of a vessel. A value of 1.00 shall be used for all configurations, except that Fig. NC-3332.2-1 may be used for integrally reinforced openings in cylindrical shells and cones.
t_e	= thickness of attached reinforcing pad or height of the largest 60 deg. right triangle supported by the vessel and nozzle outside diameter projected surfaces and lying completely within the area of integral reinforcement, in. [Fig. NC-3335(b)-1]
t	= nominal thickness of the vessel wall, less corrosion allowance, in.
t_r	= required thickness of a seamless shell or head as defined in NC-3332.2, in.
t_n	= nominal thickness of nozzle wall, less corrosion allowance, in.
t_{rn}	= required thickness of a seamless nozzle wall, in.
d	= diameter in the plane under consideration of the finished opening in its corroded condition, in. (NC-3332.2)

(d) metal added as reinforcement and metal in attachment welds.

NC-3335.2 Reinforcement of Multiple Openings

(a) When any two openings in a group of two or more openings are spaced at less than two times their average diameter so that their limits of reinforcement overlap, the two openings shall be reinforced in the plane connecting the centers (Fig. NC-3335.2-1) in accordance with NC-3330 through NC-3336, with a combined reinforcement that has an area equal to the combined area of the reinforcement required for separate openings. No portion of the cross section is to be considered as applying to more than one opening, or to be evaluated more than once in a combined area. The

following additional requirements shall also apply.

(1) When the distance between the centers of the openings is greater than $1\frac{1}{3}$ times their average diameter, the area of reinforcement between them shall not be less than 50% of the total required for these openings.

(2) When the distance between the centers of the openings is less than $1\frac{1}{3}$ times their average diameter, no credit for reinforcement shall be taken for any of the material between these openings, and the openings shall be reinforced as described in (b) below.

(b) Any number of adjacent openings, in any arrangement, may be reinforced for an assumed opening of a diameter enclosing all such openings. The diameter of the assumed opening shall not exceed the following:

(1) for vessels 60 in. in diameter and less, one-half the vessel diameter, but not to exceed 20 in. (508 mm);

(2) for vessels over 60 in. in diameter, one-third the vessel diameter, but not to exceed 40 in.

(c) When a group of openings is reinforced by a thicker section butt welded into the shell or head, the edges of the inserted section shall be tapered as prescribed in NC-3361.

(d) When a series of two or more openings in a pressure vessel is arranged in a regular pattern,

Page 120

reinforcement of the openings may be provided in accordance with the requirements of NC-3329.

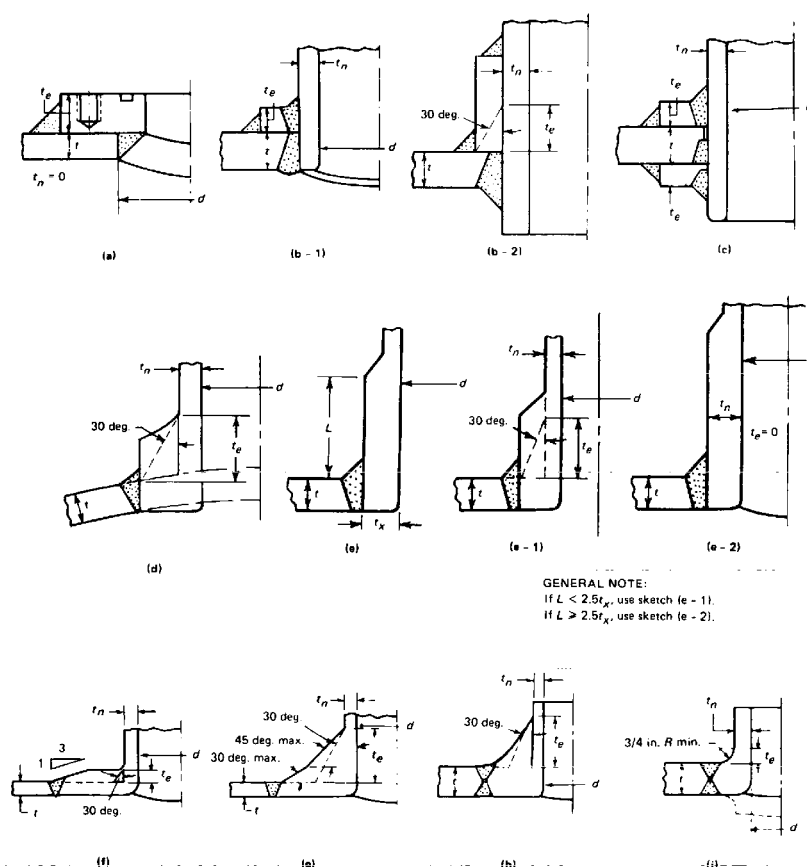
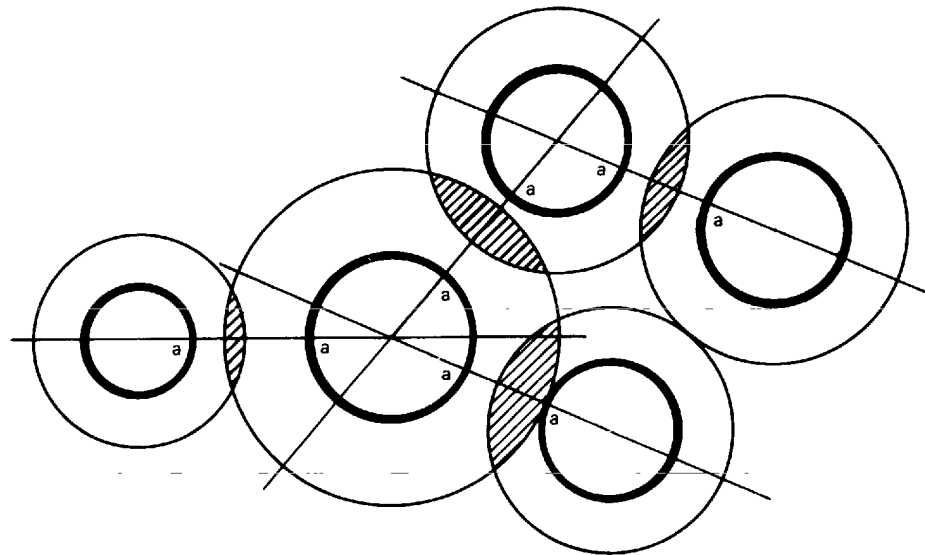


FIG. NC-3335(b)-1 SOME REPRESENTATIVE CONFIGURATIONS DESCRIBING THE t_e REINFORCEMENT DIMENSION

FIG. NC-3335(b)-1 SOME REPRESENTATIVE CONFIGURATIONS DESCRIBING THE t_e REINFORCEMENT DIMENSION



GENERAL NOTES:

- (1) Hatched area represents overlapping of the reinforcement limits.
- (2) Each cross section indicated by a straight line a-a must be investigated for adequacy of reinforcement.
- (3) Heavy circles represent openings, and light circles represent limits of reinforcement.

FIG. NC-3335.2-1 ARRANGEMENT OF MULTIPLE OPENINGS

FIG. NC-3335.2-1 ARRANGEMENT OF MULTIPLE OPENINGS

NC-3335.3 Flued Openings in Formed Heads

(a) Flued openings in formed heads made by inward or outward forming of the head plate shall meet the requirements for reinforcement in NC-3332.

(b) The minimum depth of flange of a flued opening exceeding 6 in. in any inside dimension, when not stayed by an attached pipe or flue, shall equal $3t_r$ or $(t_r + 3)$ in., whichever is less, where t_r is the required head thickness. The depth of flange shall be determined by placing a straight edge across the side opposite the flued opening along the major axis and measuring from the straight edge to the edge of the flanged opening [Fig. NC-3335.3(b)-1].

(c) The minimum width of bearing surface for a gasket on a self-sealing flued opening shall be in accordance with NC-3363.7.

NC-3336 Strength of Reinforcing Material

Material used for reinforcement shall preferably be the same as that of the vessel wall. If the material of the nozzle wall or reinforcement has a lower design stress value S than that for the vessel material, the

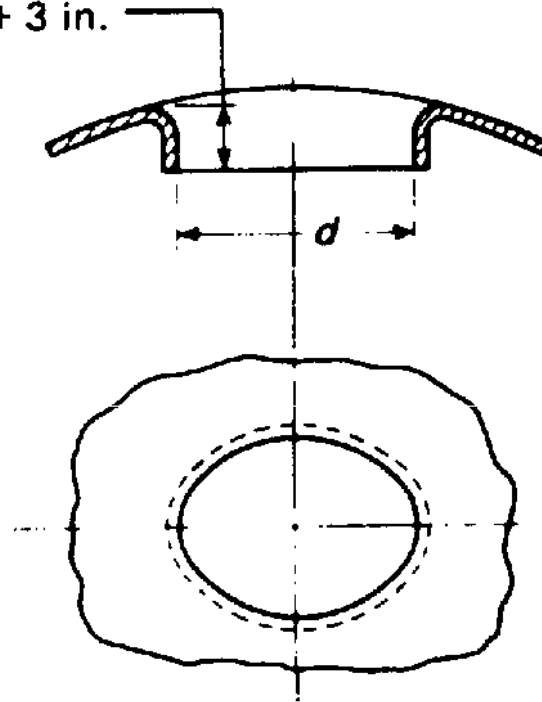
Page 122

amount of area provided by the nozzle wall or reinforcement in satisfying the requirements of NC-3332 shall be taken as the actual area provided multiplied by the ratio of the nozzle or reinforcement material design stress value to the vessel material design stress value. No reduction in the reinforcing required shall be taken for the increased strength of

reinforcing material and weld metal having higher design stress values than that of the material of the vessel wall. Deposited weld metal outside of either the vessel wall or any reinforcing pad used as reinforcement shall be credited with an allowable stress value equivalent to the weaker of the materials connected by the weld. Vessel-to-nozzle or pad-to-nozzle attachment weld metal within the vessel wall or within the pad may be credited with a stress value equal to that of the vessel wall or pad, respectively.

Maximum depth of flange:

the smaller of $3t_r$ or $t_r + 3$ in.
when d exceeds 6 in.



**FIG. NC-3335.3(b)-1 MINIMUM DEPTH FOR
FLANGE OF FLUED OPENINGS**

FIG. NC-3335.3(b)-1 MINIMUM DEPTH FOR FLANGE OF FLUED OPENINGS

NC-3336.1 Strength of Weld.

On each side of the plane defined in NC-3334, the strength of the attachment joining the vessel wall and reinforcement or any two parts of the attached reinforcement shall be at least equal to the lesser of (a) or (b) below:

(a) the strength in tension of the cross section of the element of reinforcement being considered;

(b) the strength in tension of the area defined in NC-3332 less the strength in tension of the reinforcing area which is integral in the vessel wall.

NC-3336.2 Strength of Attachment.

The strength of the attachment joint shall be considered for its entire length on each side of the plane of the area of reinforcement defined in NC-3334. For obround openings, consideration shall also be given to the strength of the attachment joint on one side of the plane transverse to the parallel sides of the opening which passes through the center of the semicircular end of the opening.

NC-3350 DESIGN OF WELDED CONSTRUCTION

NC-3351 Welded Joint Categories

The term *category* defines the location of a joint in a vessel but not the type of joint. The categories are for use in specifying special requirements regarding joint type and method of examination for certain welded joints. Since these special requirements, which are based on service, material, and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in the categories. The special requirements apply to joints of a given category only when specifically stated. The joints included in each category are designated as joints of Categories A, B, C, and D. Figure NC-3351-1 illustrates typical joint locations included in each category.

NC-3351.1 Category A.

Category A comprises longitudinal welded joints within the main shell, communicating chambers,¹⁶ transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head, or within the side plates¹⁷ of a flat-sided vessel; circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameters, to nozzles, or to communicating chambers.

NC-3351.2 Category B.

Category B comprises circumferential welded joints within the main shell, communicating chambers,¹⁴ nozzles, or transitions in diameter including joints between the transition and a cylinder at either the large or small end; circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers.

NC-3351.3 Category C.

Category C comprises welded joints connecting flanges, Van Stone laps, tubesheets, or flat heads to main shell, to formed heads, to transitions in diameter, to nozzles, or to communicating chambers¹⁴ and any welded joint connecting one side plate¹⁵ to another side plate of a flat-sided vessel.

NC-3351.4 Category D.

Category D comprises welded joints connecting communicating chambers¹⁴ or nozzles to main shells, to spheres, to transitions in diameter, to heads, or to flat-sided vessels and those joints connecting nozzles to communicating chambers. For nozzles at the small end of a transition in diameter, see Category B.

NC-3352 Permissible Types of Welded Joints

The design of the vessel shall meet the requirements for each category of joint. Butt joints are full penetration joints

between plates or other elements that lie approximately in the same plane. Category B angle joints between plates or other elements that have an offset angle α not exceeding 30 deg. are considered as meeting the requirements for butt joints. Figure NC-3352-1 shows typical butt welds for each category joint.

16 Communicating chambers are defined as appurtenances to the vessel which intersect the shell or heads of a vessel and form an integral part of the pressure retaining enclosure, such as sumps.

17 Side plates of a flat-sided vessel are defined as any of the flat plates forming an integral part of the pressure retaining enclosure.

NC-3352.1 Joints of Category A.

All welded joints of Category A shall meet the fabrication requirements

Page 123

of NC-4241 and shall be capable of being examined in accordance with NC-5210.

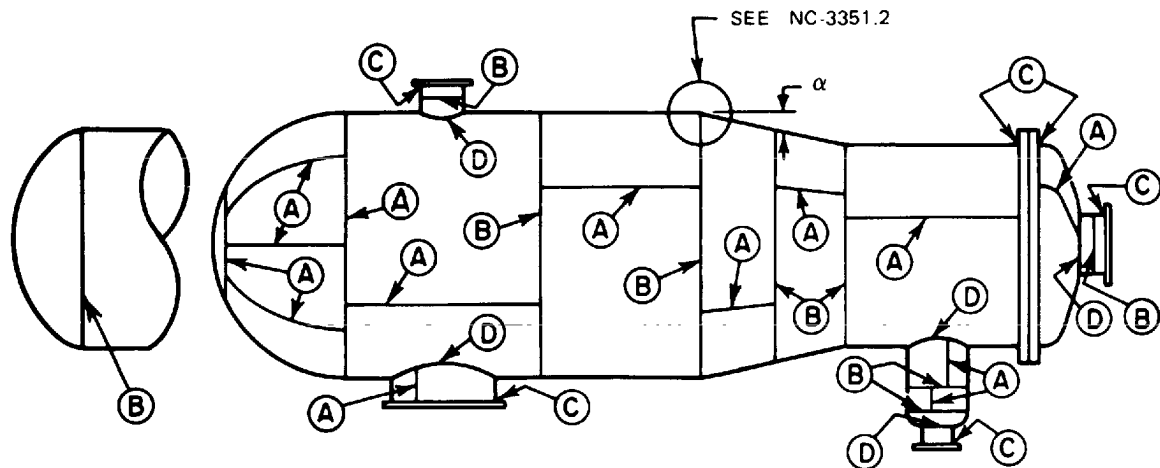


FIG. NC-3351-1 WELDED JOINT LOCATIONS TYPICAL OF CATEGORIES A, B, C, AND D

FIG. NC-3351-1 WELDED JOINT LOCATIONS TYPICAL OF CATEGORIES A, B, C, AND D

NC-3352.2 Joints of Category B.

All welded joints of Category B shall meet the fabrication requirements of NC-4242 and shall be capable of being examined in accordance with NC-5220.

NC-3352.3 Joints of Category C.

All welded joints of Category C shall meet the fabrication requirements of NC-4243 and shall be capable of being examined in accordance with NC-5230.

NC-3352.4 Joints of Category D.

All welded joints of Category D shall be in accordance with the requirements of NC-3359 and one of (a) through (e) below.

(a) *Butt Welded Nozzles.* Nozzles shall meet the fabrication requirements of NC-4244(a) and shall be capable of being examined in accordance with NC-5241. The minimum dimensions and geometrical requirements of Fig. NC-4244(a)-1 shall be met where:

t	= nominal thickness of part penetrated, in.
t_n	= nominal thickness of penetrating part, in.
r_1	= $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2	= $\frac{1}{4}$ in. (6 mm), minimum

(b) *Full Penetration Corner Welded Nozzles.* Nozzles shall meet the fabrication requirements of NC-4244(b) and shall be capable of being examined as required in NC-5241. Inserted type necks having added reinforcement in the form of a separate reinforcing plate shall be attached by welds at the outer edge of the reinforcement plate and at the nozzle periphery. The weld at the outer edge of the reinforcement shall be a fillet weld with a minimum throat dimension of $\frac{1}{2}t_{\min}$. The minimum dimensions of Fig. NC-4244(b)-1 shall be met where:

$t_{\min}$	= the lesser of $\frac{3}{4}$ in. or the thickness of the thinner of the parts joined
t	= nominal thickness of part penetrated, in.
t_n	= nominal thickness of penetrating part, in.
t_c	= $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
r_1	= $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2	= $\frac{1}{4}$ in. (6 mm), minimum
t_e	= thickness of reinforcing element, in.

(c) *Use of Deposited Weld Metal for Openings and Nozzles*

(1) Nozzles shall meet the requirements of NC-4244(c) and shall be capable of being examined in accordance with NC-5241.

(2) When the deposited weld metal is used as reinforcement, the coefficients of thermal expansion of the base metal, the weld metal, and the nozzle shall not differ by more than 15% of the lowest coefficient involved.

(3) The minimum dimensions of Fig. NC-4244(c)-1 shall be met where:

t	= nominal thickness of part penetrated, in.
t_n	= nominal thickness of penetrating part, in.
t_c	= $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
r_1	= $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less

(4) The corners of the end of each nozzle, extending less than $\sqrt{d}t_n$ beyond the inner surface of the part penetrated, shall be rounded to a radius of one-half the thickness t_n of the nozzle or $\frac{3}{4}$ in., whichever is less.

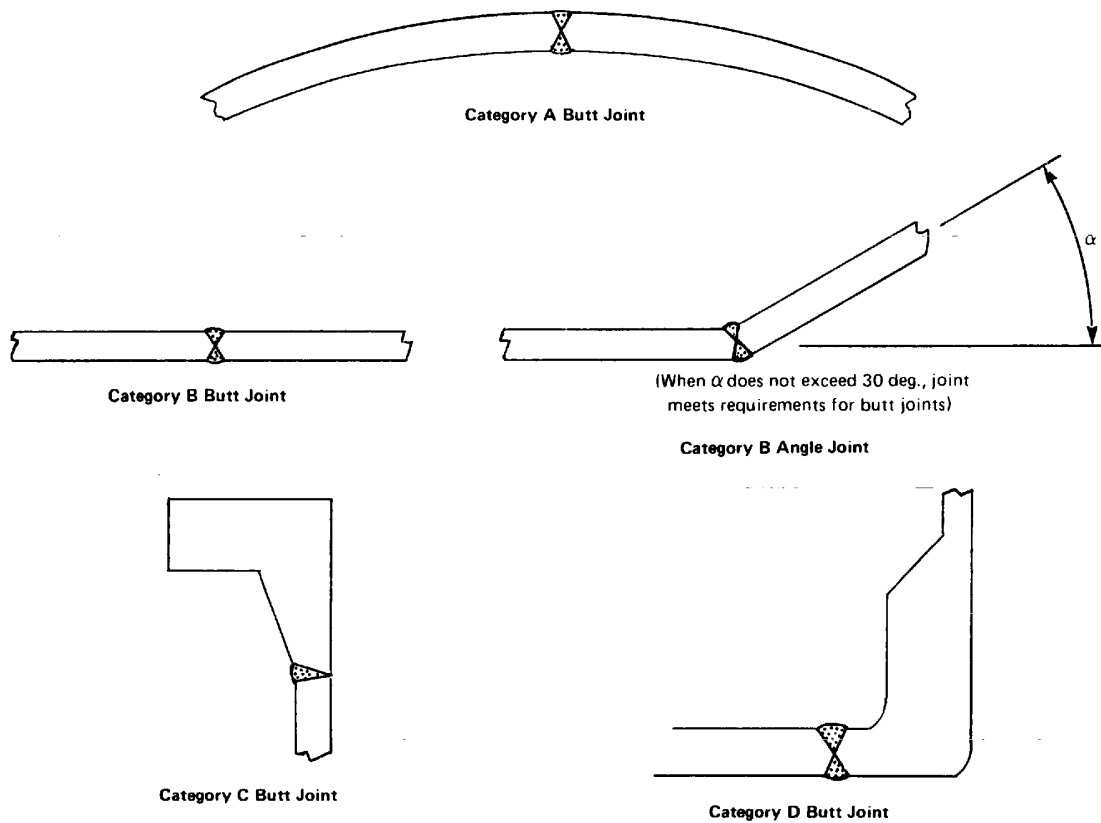


FIG. NC-3352-1 TYPICAL BUTT JOINTS

FIG. NC-3352-1 TYPICAL BUTT JOINTS

(d) Attachment of Nozzles Using Partial Penetration Welds

(1) Partial penetration welds shall meet the requirements of NC-4244(d) and are limited to those used to connect nozzles 2 in. nominal pipe size or less, as shown in Fig. NC-4244(d)-1. For inserted nozzles without reinforcing elements, two partial penetration welds may be used of any desired combination of fillet, single bevel, and single J-welds. Inserted-type nozzles having added reinforcement in the form of a separate reinforcing plate shall be attached by welds at the outer edge of the reinforcement plate and at the nozzle periphery. The weld at the outer edge of the reinforcement shall be a fillet weld with a minimum throat dimension of $\frac{1}{2}t_{\min}$. The welds attaching the nozzle to the vessel wall and to the reinforcement shall consist of one of the combinations given in (a) through (c) below:

(a) a single bevel or single J-weld in the shell plate and a single bevel and single J-weld in each reinforcement plate. The dimension t_w of each weld shall be not less than $0.7t_{\min}$ [Fig. NC-4244(d)-1 sketch (g)].

(b) a full penetration groove weld in the shell plate and a fillet, single bevel, or single J-weld with a weld dimension t_w not less than $0.7t_{\min}$ in each reinforcement plate [Fig. NC-4244(d)-1 sketch (f)];

(c) a full penetration groove weld in each reinforcement plate and a fillet, single bevel, or single J-weld with a weld dimension t_w not less than $0.7t_{\min}$ in the shell plate [Fig. NC-4244(d)-1 sketch (e)]. These welds shall be capable of being examined in accordance with the requirements of NC-5241.

(2) The minimum dimensions of Fig. NC-4244(d)-1 shall be met where:

$t_1 + t_2$	$= 1/4 t_{\min}; t_1 \text{ or } t_2 \text{ not less than the lesser of } 1/4 \text{ in. or } 0.7t_{\min}$
$t_{\min}$	$= \text{the lesser of } 3/4 \text{ in. or the thickness of the thinner of the parts joined}$
t_e	$= \text{thickness of reinforcement element, in.}$

Page 125

t	$= \text{nominal thickness of part penetrated, in.}$
t_n	$= \text{nominal thickness of penetrating part, in.}$
t_c	$= 0.7t_n \text{ or } 1/4 \text{ in., whichever is less}$
c	$= 1/2 t_{\min}$
t_w	$= 0.7t_n \text{ except } t_w = 0.7t_{\min} \text{ for sketch (e)}$

(e) *Attachment of Fittings With Internal Threads.*¹⁸ The attachment of internally threaded fittings shall meet the requirements of (1) through (3) below:

(1) except as provided for in (2) and (3), the provisions of NC-4244(e) shall be met. The minimum weld dimensions shall be as shown in Fig. NC-4244(d)-1 where:

$t_{\min}$	$= \text{lesser of } 3/4 \text{ in. or the thickness of the parts joined}$
t_c	$= 1/4 \text{ in., minimum}$

sketches (a) and (b)

$$t_1 + t_2 = 1/4 t_{\min}$$

sketch (c)

$$t_w = \text{thickness of Sch. 160 pipe (ANSI B36.10)} \quad t_1 + t_2 \text{ not less than the lesser of } 1/4 \text{ in. or } 0.7t_{\min}$$

sketch (d)

$$t_w = 0.7t_{\min}$$

(2) fittings shown in Fig. NC-4244(d)-1 sketches (a-2), (b-2), (c-2), and (d) not exceeding 2 in. nominal pipe size may be attached by welds that are exempt from size requirements other than those specified in NC-3359;

(3)(a) when internally threaded fittings and bolting pads not exceeding 3 in. nominal pipe size (DN 80) are attached to vessels having a wall thickness not greater than $3/8$ in. (76 mm) by a fillet weld deposited from the outside only, the welds shall comply with the dimensions shown in Fig. NC-4244(e)-2. These openings do not require reinforcement other than that inherent in the construction as permitted in NC-3332.1.

(b) if the opening exceeds $5/8$ in. (136 mm) in any direction or is greater than one-half the vessel diameter, the opening shall be reinforced in accordance with NC-3332 with the nozzle or other connections attached, using a suitable detail in Fig. NC-4244(e)-1.

NC-3354 Structural Attachment Welds

Welds for structural attachments shall meet the requirements of NC-4430.

¹⁸ Written for fittings with internal threads but also applicable to externally threaded and socket or butt welded fittings.

NC-3355 Welding Grooves

The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration, except as otherwise permitted in NC-3352.4.

NC-3356 Fillet Welds

(a) Fillet welds may be used as strength welds within the limitations given in NC-3352 and Fig. NC-4427-1. Particular care shall be taken in the layout of joints in which fillet welds are to be used in order to assure complete fusion at the root of the fillet.

(b) Corner or tee joints may be made with fillet welds, provided the plates are properly supported independently of such welds, except that independent supports are not required for joints used for lugs or clips.

(c) The allowable load on fillet welds shall equal the product of the weld area based on minimum leg dimensions, the allowable stress value in tension of the material being welded, and a joint efficiency of 0.55.

NC-3357 Welded Joints Subject to Bending Stresses

Except where specific details are permitted in other paragraphs, fillet welds shall be added where necessary to reduce stress concentration. The requirements of NC-3356(b) apply.

NC-3358 Design Requirements for Head Attachments

NC-3358.1 Skirt Length of Formed Heads

(a) Ellipsoidal and other types of formed heads, concave or convex to the pressure, shall have a skirt length not less than that shown in Fig. NC-3358.1(a)-1.

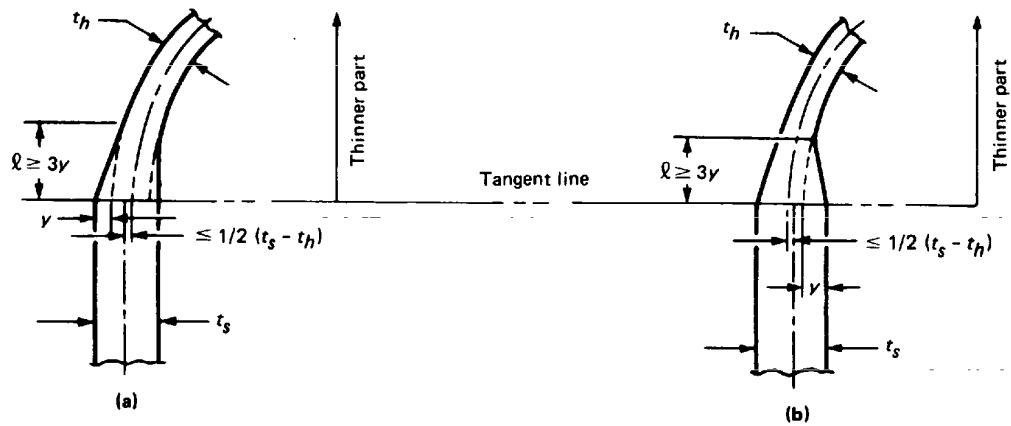
(b) A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections, as shown in Fig. NC-3358.1(a)-1, shall be provided at joints between formed heads and shells that differ in thickness by more than one-fourth the thickness of the thinner section or by more than $\frac{1}{8}$ in. (3.2 mm), whichever is less. When a taper is required on any formed head thicker than the shell and intended for butt welded attachment [Fig. NC-3358.1(a)-1], the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.

NC-3358.2 Unstayed Flat Heads Welded to Shells.

The requirements for the attachment of unstayed flat heads welded to shells are given in NC-3325, NC-3358.3, and NC-3358.4.

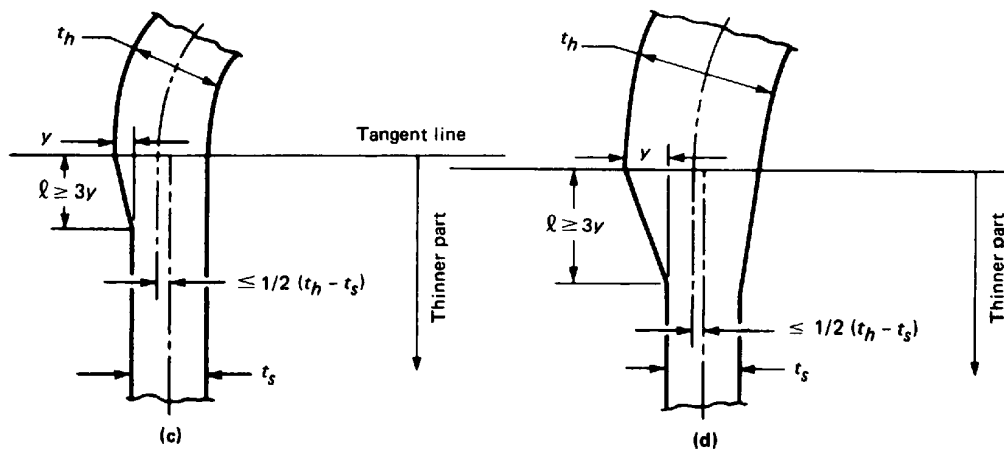
Page 126

Page 127



GENERAL NOTES [sketches (a) and (b)] :

- (a) Length of required taper ℓ may include the width of the weld.
- (b) In all cases, the projected length of taper ℓ shall be not less than $3y$.
- (c) The shell plate center line may be on either side of the head plate center line.



GENERAL NOTES (sketches (c) and (d)):

- (a) In all cases ℓ shall be not less than 3 times y when t_h exceeds $1.25t_s$; minimum length of skirt is $3t_h$, but need not exceed 1-1/2 in. except when necessary to provide required length of taper.
- (b) When t_h is equal to or less than $1.25t_s$, length of skirt shall be sufficient for any required taper.
- (c) Length of required taper ℓ may include the width of the weld.
- (d) The shell plate center line may be on either side of the head plate center line.

FIG. NC-3358.1(a)-1 HEADS ATTACHED TO SHELLS

FIG. NC-3358.1(a)-1 HEADS ATTACHED TO SHELLS

NC-3358.3 Head Attachments Using Corner Joints.

When shells, heads, or other pressure parts are welded to a forged or rolled plate to form a corner joint, as in Figs. NC-4243-1 and NC-4243-2, the joint shall meet the applicable requirements of (a) through (f) below.

(a) On the cross section through the welded joint, the line of fusion between the weld metal and the forged or rolled plate being attached shall be projected on planes both parallel to and perpendicular to the surface of the plate being attached, in order to determine the dimensions a and b , respectively.

(b) For flange rings of bolted flanged connections and for flat heads and unsupported tubesheets with a projection having holes for a bolted connection, the sum of a and b shall be not less than three times the nominal thickness of the abutting pressure part.

(c) For supported tubesheets with a projection having holes for a bolted connection, the sum of a and b shall not be less than two times the nominal wall thickness of the abutting pressure part. A supported tubesheet is defined as one in which not less than 80% of the pressure load on the tubesheet is carried by tubes, stays, or braces.

(d) For other components, the sum of a and b shall be not less than two times the nominal wall thickness of the abutting pressure part. Examples of such components are flat heads and supported and unsupported tubesheets without a projection having holes for a bolted connection.

(e) Other dimensions of the joint shall be in accordance with details shown in Figs. NC-4243-1 and NC-4243-2 where:

(1) Fig. NC-4243-1

Sketches (a), (b), and (c)

(a) for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle not greater than 45 deg. measured from the face:

$$\begin{aligned} t_c &= 0.7 t_n \text{ or } \frac{1}{4} \text{ in., whichever is less} \\ t_w &= \text{the lesser of } t_n/2 \text{ or } t/4 \\ t, t_n &= \text{nominal thickness of welded parts, in.} \end{aligned}$$

(b) for all other material forms and for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle greater than 45 deg. measured from the face:

$$\begin{aligned} t_c &= 0.7 t_n \text{ or } \frac{1}{4} \text{ in., whichever is less} \\ t_w &= \text{the lesser of } t_n \text{ or } t/2 \\ t, t_n &= \text{nominal thicknesses of welded parts, in.} \end{aligned}$$

Sketch (d)

$$t, t_n = \text{nominal thickness of welded parts, in., either leg of fillet weld} = 0.25 t_n \text{ but not less than } \frac{1}{4} \text{ in.}$$

Sketches (e) and (f)

$$\begin{aligned} t, t_n &= \text{nominal thickness of welded parts, in.} \\ t_c &= 0.7 t_n \text{ or } \frac{1}{4} \text{ in., whichever is less} \end{aligned}$$

(2) Fig. NC-4243-2

Sketch (a)

$$\begin{aligned} a + b &\text{ not less than } 2t_s \\ t_w &\text{ not less than } t_s \end{aligned}$$

t_s =actual thickness of shell, in.
 t_p not less than t_s

Sketch (b)

$a + b$ not less than $2t_s$
 t_s =actual thickness of shell, in.

Sketch (c)

t_s =actual thickness of shell, in.
 t_r =required thickness of shell, in.

for supported tubesheets:

c not less than $0.7t_s$ or $1.4t_r$,
 whichever is less

$a + b$ not less than $2t_s$

for flange rings, flat heads, and unsupported tubesheets:

c not less than t_s or $2t_r$, whichever is less

$a + b$ not less than $3t_s$

Sketch (d)

t_s =actual thickness of shell, in.
 t_r =required thickness of shell, in.
 $a + b$ not less than $3t_s$
 c not less than t_s

(f) In Fig. NC-4243-1,

t_c	= $0.7 t_n$ or $\frac{1}{4}$ in., whichever is less
t_w	= the lesser of t_n or $t/2$
t_s, t_n	= nominal thicknesses, in.

(g) Joint details that have a dimension through the joint less than the thickness of the shell, head, or other pressure part, or that provide eccentric attachment are not permissible.

NC-3358.4 Flat Heads and Tubesheets With Hubs.

Hubs for butt welding to the adjacent shell, head, or other pressure part, as in Fig. NC-4243.1-1, shall not be machined from rolled plate. The component having the hub shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material, in a direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension test specimen (subsize if necessary) taken in this direction and as close to the hub as is practical. In Fig. NC-4243.1-1, the minimum dimensions are as follows:

Sketch (a)

r not less than $1.5t_s$

Sketch (b)

r not less than $1.5t_s$ and e not less than t_s

Sketch (c)

h not less than $1.5t_s$

Sketch (d)

t_f not less than $2t_s$

r not less than $3t_f$

Sketch (e)

t_f not less than $2t_s$

r not less than $3t_f$

e not less than t_f

NC-3359 Design Requirements for Nozzle Attachment Welds

In addition to the requirements of NC-3352.4, the minimum design requirements for nozzle attachment welds are given in (a) and (b) below.

(a) *Required Weld Strength.* Sufficient welding shall be provided on either side of the line through the center of the opening parallel to the longitudinal axis of the shell to develop the strength of the reinforcing parts as required in NC-3336, through shear or tension in the weld, whichever is applicable. The strength of groove welds shall be based on the area subjected to shear or to tension. The strength of fillet welds shall be based on the area subjected to shear, computed on the minimum leg dimension. The inside diameter of a fillet weld shall be used in figuring its length. Calculations are not required when full penetration welds are used.

(b) *Allowable Stress Values for Welds.* The allowable stress values for groove and fillet welds and for shear in nozzles, in percentage of stress values for the vessel material, are as follows:

Nozzle wall shear	70%
Groove weld tension	74%
Groove weld shear	60%
Fillet weld shear	49%

NC-3360 SPECIAL VESSEL REQUIREMENTS

NC-3361 Tapered Transitions

A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections (Fig. NC-3361-1) shall be provided at joints between sections that differ in thickness by more than one-fourth of the thickness of the thinner section or by more than $\frac{1}{8}$ in., whichever is less. The transition may be formed by any process that will provide a uniform taper. The weld may be in the tapered section or adjacent to it. This also applies when there is a reduction in thickness within a spherical shell or cylindrical shell course and to a taper at a Category A joint within a formed head. Provisions for tapers at circumferential butt welded joints connecting formed heads to main shells are contained in NC-3358.1(b).

NC-3362 Bolted Flange and Studded Connections

(a) It is recommended that the dimensional requirements of bolted flange connections to external piping conform to ANSI Standard B16.5, Steel Pipe Flanges and Flanged Fittings; MSS SP-42, 150 lb. Corrosion Resistant Cast Flanged Valves; or API Standard 605, Large Diameter Carbon Steel Flanges. Such flanges and flanged fittings may be used for the pressure-temperature ratings given in the appropriate standard. Flanges and flanged fittings to other standards may be used, provided they have been designed in accordance with the rules of Appendix XI for the vessel design loadings and are used within the pressure-temperature ratings so determined.

(b) Where tapped holes are provided for studs, the threads shall be full and clean and shall engage the stud for a length not less than the larger of d_s or

$$0.75 d_s \times \frac{\text{Maximum allowable stress value of stud material at Design Temperature}}{\text{Maximum allowable stress value of tapped material at Design Temperature}}$$

in which d_s is the diameter of the stud. The thread engagement need not exceed $1\frac{1}{2}d_s$.

NC-3363 Access or Inspection Openings¹⁹

NC-3363.1 General Requirements

(a) All vessels for use with compressed air, except as otherwise permitted, and those subject to internal corrosion or having parts subject to erosion or mechanical abrasion shall be provided with suitable manhole, handhole, or other inspection openings for examination and cleaning.

(b) Vessels over 12 in. (305 mm) inside diameter under air pressure which also contain other substances which will prevent corrosion need not have openings for inspection only, provided the vessel contains suitable openings through which inspection can be made conveniently and provided such openings are equivalent in size and number to the requirements for inspection openings in NC-3363.3.

¹⁹ All dimensions given are nominal.

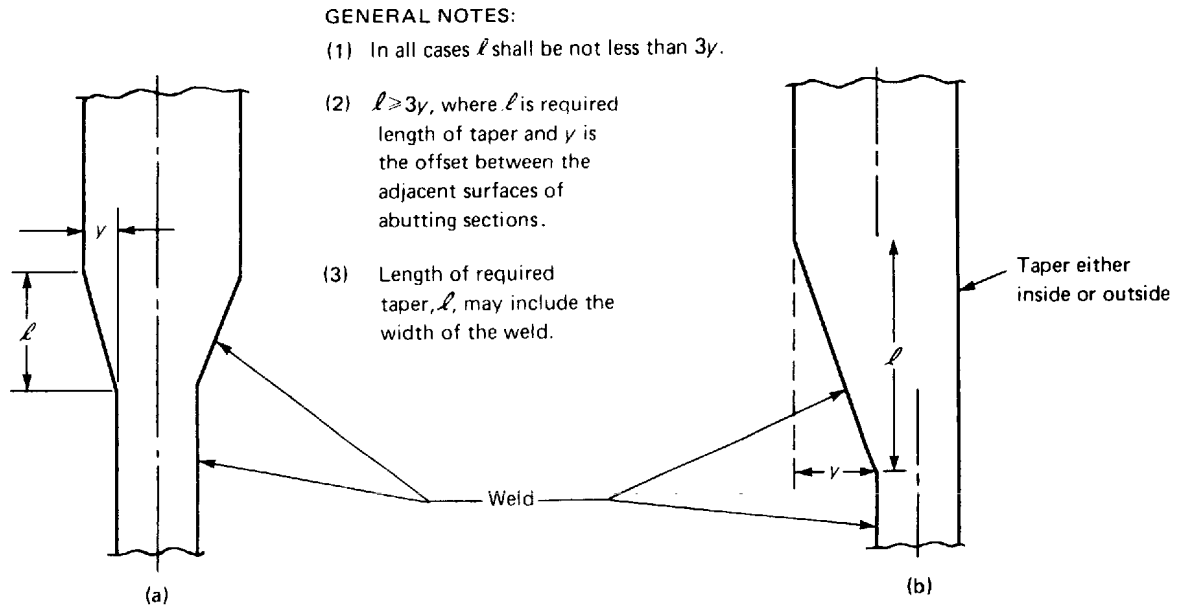


FIG. NC-3361-1 BUTT WELDING OF SECTIONS OF UNEQUAL THICKNESSES

FIG. NC-3361-1 BUTT WELDING OF SECTIONS OF UNEQUAL THICKNESSES

(c) Compressed air is not intended to include air which has had moisture removed to the degree that it has an atmospheric dew point of -50°F (-46°C) or less. The Certificate Holder's Data Report shall include a statement "for noncorrosive service" when inspection openings are not provided.

(d) When provided with telltale holes complying with the provisions of (e) below, inspection openings as required in NC-3363 may be omitted in vessels subject only to corrosion. This provision does not apply to vessels for compressed air.

(e) Telltale holes may be used to provide some positive indication when the thickness has been reduced to a dangerous degree. When telltale holes are provided, they shall be at least $\frac{3}{16}$ in. (4.8 mm) in diameter and have a depth not less than 80% of the thickness required for a seamless shell of like dimensions. These holes shall be provided in the surface opposite to that where deterioration is expected.

NC-3363.2 Requirements for Vessels 12 in. (305 mm) Inside Diameter and Smaller.

For vessels 12 in. (305 mm) or less in inside diameter, openings for inspection only may be omitted if there are at least two removable pipe connections not less than $\frac{3}{4}$ in. (19 mm) nominal pipe size.

NC-3363.3 Requirements for Vessels Over 12 in. (305 mm), but Not Over 16 in. (406 mm) Inside Diameter.

Vessels over 12 in. but not over 16 in. inside diameter, that are to be installed so that they may be disconnected from an assembly to permit inspection, need not be provided with openings for inspection only, if there are at least two removable pipe connections not less than $1\frac{1}{2}$ in. nominal pipe size (DN 40).

NC-3363.4 Equipment of Vessels Requiring Access or Inspection Openings.

Vessels that require access or inspection openings shall be equipped as required in (a) through (f) below.

(a) All vessels less than 18 in. (457 mm) and over 12 in. (305 mm) inside diameter shall have at least two handholes or two plugged, threaded inspection openings of not less than 1½ in. nominal pipe size (DN 40).

(b) All vessels 18 in. to 36 in. (457 mm to 914 mm), inclusive inside diameter, shall have a manhole or at least two handholes or two threaded pipe plug inspection openings of not less than 2 in. nominal pipe size (DN 50).

(c) All vessels over 36 in. (914 mm) inside diameter shall have a manhole, except that those whose shape or use makes one impracticable shall have at least two handholes 4 in. × 6 in. (102 mm × 152 mm) or two equal openings of equivalent area.

(d) When handholes or pipe plug openings are permitted for inspection openings in place of a manhole, one

Page 130

handhole or one pipe plug opening shall be in each head or in the shell near each head.

(e) Openings with removable heads or cover plates intended for other purposes may be used in place of the required inspection openings, provided they are equal at least to the size of the required inspection openings.

(f) A single opening with removable head or cover plate may be used in place of all the smaller inspection openings, provided it is of such size and location as to afford at least an equal view of the interior.

NC-3363.5 Size and Type of Access and Inspection Openings.

When inspection or access openings are required, they shall comply at least with the requirements of (a) and (b) below.

(a) An elliptical or obround manhole shall be not less than 11 in. × 15 in. (280 mm × 318 mm) or 10 in. × 16 in. (254 mm × 406 mm). A circular manhole shall be not less than 15 in. (381 mm) inside diameter.

(b) A handhole opening shall be not less than 2 in. × 3 in. (51 mm × 76 mm) but should be as large as is consistent with the size of the vessel and the location of the opening.

NC-3363.6 Design of Access and Inspection Openings in Shells and Heads.

All access and inspection openings in a shell or unstayed head shall be designed in accordance with the rules for openings.

NC-3363.7 Minimum Gasket Bearing Width for Manhole Cover Plates.

Manholes of the type in which the internal pressure forces the cover plate against a flat gasket shall have a minimum gasket bearing width of 1½ in.

NC-3363.8 Threaded Openings.

When a threaded opening is to be used for inspection or cleaning purposes, the closing plug or cap shall be of a material suitable for the pressure and no material shall be used at a temperature exceeding the maximum temperature allowed for that material. The thread shall be a standard taper pipe thread, except that a straight thread of equal strength may be used if other sealing means to prevent leakage are provided.

NC-3364 Attachments

Attachments used to transmit support loads shall meet the requirements of NC-3135.

NC-3365 Supports

All vessels shall be so supported and the supporting members shall be arranged or attached to the vessel wall in such a way as to withstand the maximum imposed loadings (NC-3111 and Subsection NF).

NC-3366 Bellows Expansion Joints

Expansion joints of the bellows type may be used to provide flexibility for vessels. Expansion joints in piping portions of vessels shall meet the requirements of NC-3649. The design, material, fabrication, examination, and testing of expansion joints which are constructed as a part or appurtenance of a vessel shall comply with the requirements of (a) through (i) below.

(a) Bellows may be used to absorb axial movement, lateral deflection, angular rotation, or any combination of these movements. They are not normally designed for absorbing torsion. The layout, anchorage, guiding, and support shall be such as to avoid the imposition of motions or forces on the bellows other than those for which they have been designed.

(b) In all systems containing bellows, the hydrostatic end force caused by either pressure or the bellows spring force or both shall be resisted by rigid anchors, cross connections of the expansion joint ends, or other means.

(c) The expansion joint shall be installed in such locations as to be accessible for scheduled inspection, where applicable.

(d) The joints shall be provided with bars or other suitable members for maintaining the proper face-to-face dimension during shipment and installation. Bellows shall not be extended or compressed to make up for deficiencies in length or offset to accommodate connecting parts which are not properly aligned, unless such movements have been specified by the system designer or can be justified by the expansion joint manufacturer.

(e) The expansion joints shall be marked to show the direction of flow, if applicable, and shall be installed in accordance with this marking.

(f) Internal sleeves shall be provided for expansion joints over 6 in. (152 mm) diameter when flow velocities exceed the following values:

(1) air, steam, and other gases - 25 ft/sec (7.6 m/s);

(2) water and other liquids - 10 ft/sec (3.0 m/s).

(g) Pressure retaining materials in the expansion joint shall comply with the requirements of NC-2000.

(h) All welded joints shall comply with the requirements of NC-4400.

(i) Design of bellows type expansion joints shall comply with the requirements of NC-3649.4.

Page 131

NC-3400 PUMP DESIGN

NC-3410 GENERAL REQUIREMENTS FOR CENTRIFUGAL PUMPS

NC-3411 Scope

NC-3411.1 Applicability.

The rules of NC-3400 apply to (a) through (j) below:

(a) pump casings

(b) pump inlets and outlets

(c) pump covers

(d) clamping rings

(e) seal housings, seal glands, and packing glands

(f) related bolting

(g) pump internal heat exchanger piping

(h) pump auxiliary nozzle connections up to the face of the first flange or circumferential joint in welded connections excluding the connecting weld

(i) piping identified with the pump and external to and forming part of the pressure retaining boundary and supplied with the pump

(j) external and internal integral attachments to the pressure retaining boundary

Hydrostatic test of seal glands and packing glands is not required.

[98]

NC-3411.2Exemptions.

The rules of NC-3400 do not apply to (a) through (c) below:

(a) pump shafts and impellers (shafts may be designed in accordance with Appendix S)

(b) nonstructural internals

(c) seal packages

[98]

NC-3412 Acceptability

The requirements for the design of pumps are given in (a) and (b) below.

(a) The design shall be such that the requirements of NC-3100 are satisfied.

(b) The rules of this Subarticle are met.

NC-3413 Design Specification

Design and Service Conditions (NCA-2142) shall be stipulated in the Design Specification (NCA-3250). Loads from thermal expansion, deadweight, and applicable seismic forces from the connected piping shall be included in the Design Specification.

NC-3414 Design and Service Conditions

The general design considerations, including definitions, of NC-3100 plus the requirements of NC-3320, NC-3330, NC-3361, and NC-3362 are applicable to pumps. The pump shall conform to the requirements of NC-3400. The stress limits listed in NC-3416 shall be used for the specified Design and Service Conditions. Classical bending and direct stress equations, where free body diagrams determine a simple stress distribution that is in equilibrium with the applied loads, or any design equations, which have been demonstrated to be satisfactory, may be used.

NC-3415 Loads From Connected Piping

Loads imposed on pump inlets and outlets by connected piping shall be considered in the pump casing design.

NC-3416 Stress and Pressure Limits for Design and Service Conditions

Stress²⁰ limits for Design and Service Conditions are specified in Table NC-3416-1. The symbols used in Table NC-3416-1 are defined as follows:

σ_m

= general membrane stress, ksi. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

σ_L

= local membrane stress, ksi. This stress is the same as σ_m except that it includes the effect of discontinuities.

σ_b

= bending stress, ksi. This stress is equal to the linear varying portion of the stress across the solid section under

consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

S

= allowable stress value, ksi, given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1. The allowable stress shall correspond to the highest metal temperature of the section under consideration during the condition under consideration.

NC-3417 Earthquake Loadings

(a) The effects of earthquake shall be considered in the design of pumps, pump supports, and restraints. The stresses resulting from these earthquake effects shall be included with the stresses resulting from pressure or other applied loads.

20 Stress means the maximum normal stress.

(b) Where pumps are provided with drivers on extended supporting structures and these structures are

Page 132

essential to maintaining pressure integrity, an analysis shall be performed when required by the Design Specifications.

**TABLE NC-3416-1
STRESS AND PRESSURE LIMITS FOR DESIGN AND SERVICE LOADINGS**

Service Limit	Stress Limits [Note (1)]	$P_{\max}$ [Note (2)]
Level A	$\sigma_m \leq S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5S$	1.0
Level B	$\sigma_m \leq 1.1S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65S$	1.1
Level C	$\sigma_m \leq 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$	1.2
Level D	$\sigma_m \leq 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$	1.5

NOTES:

- (1) These requirements for acceptability of pump design are not intended to assure the operability of the pump.
(2) The maximum pressure shall not exceed the tabulated factors listed under $P_{\max}$ times the Design Pressure.

TABLE NC-3416-1 STRESS AND PRESSURE LIMITS FOR DESIGN AND SERVICE LOADINGS

NC-3418 Corrosion

The requirements of NC-3121 apply.

NC-3419 Cladding

Cladding dimensions used in the design of pumps shall be required as in NC-3122.

NC-3420 DEFINITIONS

NC-3421 Radially Split Casing

A radially split casing shall be interpreted as one in which the primary sealing joint is radially disposed around the shaft.

NC-3422 Axially Split Casing

An axially split casing shall be interpreted as one in which the primary sealing joint is axially disposed with respect to the shaft.

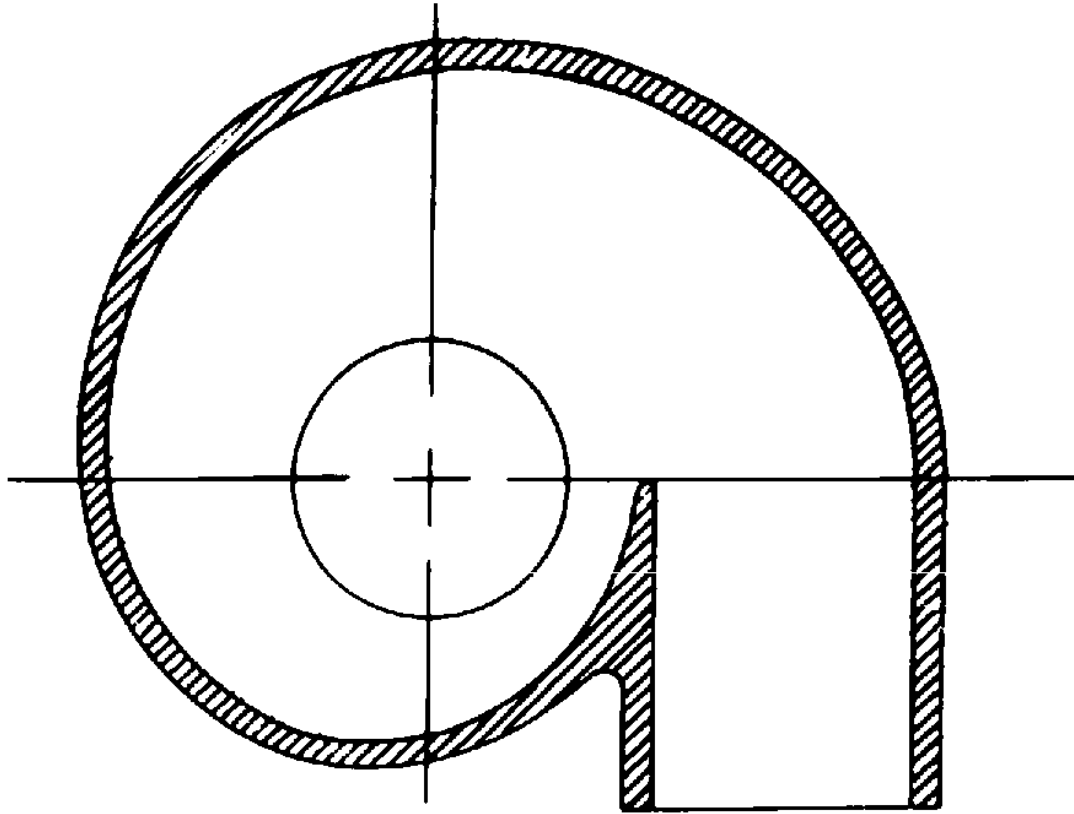


FIG. NC-3423-1 TYPICAL SINGLE VOLUTE CASING

FIG. NC-3423-1 TYPICAL SINGLE VOLUTE CASING

NC-3423 Single and Double Volute Casings

Figures NC-3423-1 and NC-3423-2 show typical single and double volute casings, respectively.

NC-3424 Seal Housing

A seal housing is defined as that portion of the pump cover or casing assembly which contains the seal and forms a part

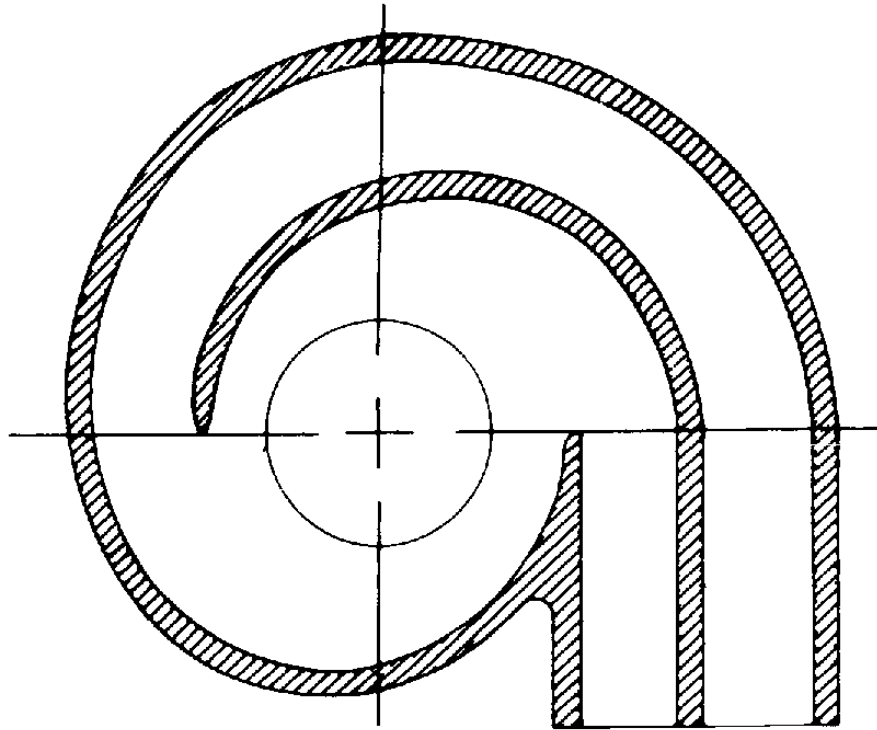


FIG. NC-3423-2 TYPICAL DOUBLE VOLUTE CASING

FIG. NC-3423-2 TYPICAL DOUBLE VOLUTE CASING

NC-3425 Typical Examples of Pump Types

Figures NC-3441.1-1 through NC-3441.9-2 are intended to be typical examples to aid in the determination of a pump type and are not considered as limiting. Bearing locations and inlet and outlet orientations are optional.

NC-3430 DESIGN REQUIREMENTS FOR CENTRIFUGAL PUMPS

NC-3431 Design of Welded Construction

(a) The design of welded construction shall be in accordance with NC-3350.

(b) Partial penetration welds, as shown in Fig. NC-4244(d)-1 sketch (c-3) and Fig. NC-4266(d)-1 sketches (a) and (b), are allowed for nozzles such as vent and drain connections and openings for instrumentation. Nozzles shall not exceed 2 in. nominal pipe size (DN 50). For such nozzles, all reinforcement shall be integral with the portion of the shell penetrated.

Partial penetration welds shall be of sufficient size to develop the full strength of the nozzles.

NC-3432 Flanged Connections

NC-3432.1 Pressure Design

(a) Pumps with flanged connections that are cast integrally with the casing and meet all dimensional requirements (including tolerances) of flanged fittings (as shown in Table NC-3132-1) with regard to the flange dimensions and required wall thicknesses, shall be considered to meet the pressure design requirements of this subarticle and are suitable for use within the pressure-temperature range shown in Appendix I for the material utilized.

(b) Flanged connections not meeting the requirements of (a) shall be designed in accordance with XI-3000 or L-3000.

(c) Pump flanges meeting all requirements of Table NC-3132-1 and welded onto the integral inlets and outlets of the casing, shall be considered as meeting the pressure design requirements of this subarticle, provided that the inlet and outlet wall thicknesses comply with the standard flanged fitting. However, the nozzle-to-flange welds shall meet the requirements of NC-1150.

NC-3432.2 External Loads.

When external nozzle loads interact with pumps, it is very likely that operability will dictate the maximum allowable loads. The major areas of concern are distortion of the casing and misalignment of driver and driven equipment. The casing shall be capable of withstanding the external loading plus the design pressure, provided in the Design Specification, without distortion that would impair the operation of the pump. In addition, the pump supports shall be capable of accommodating the external loads without sustaining any significant displacements that would cause unacceptable misalignment of rotating parts.

(a) Flanged connections meeting the requirements of NC-3432.1 do not require further analysis when all requirements of NC-3658.2 or NC-3658.3 are met. All other flanged connections shall all meet the requirements of NC-3432.2(b) below.

(b) Flanged connections shall meet the requirements of NC-3658.1.

NC-3433 Reinforcement of Pump Casing Inlets and Outlets

NC-3433.1 Axially Oriented Inlets and Outlets

(a) An axially oriented pump casing inlet or outlet shall be considered similar to an opening in a vessel and shall be reinforced. It shall be treated as required in NC-3330.

(b) To avoid stress concentrations, the outside radius r_2 of Figs. NC-3441.1(a)-1 and NC-3441.3-2 shall not be less than one-half the thickness of the inlets and outlets as reinforced.

NC-3433.2 Radially Oriented Inlets and Outlets.

Reinforcement of radially oriented inlets and outlets is required. The applicable portions of NC-3330 shall apply.

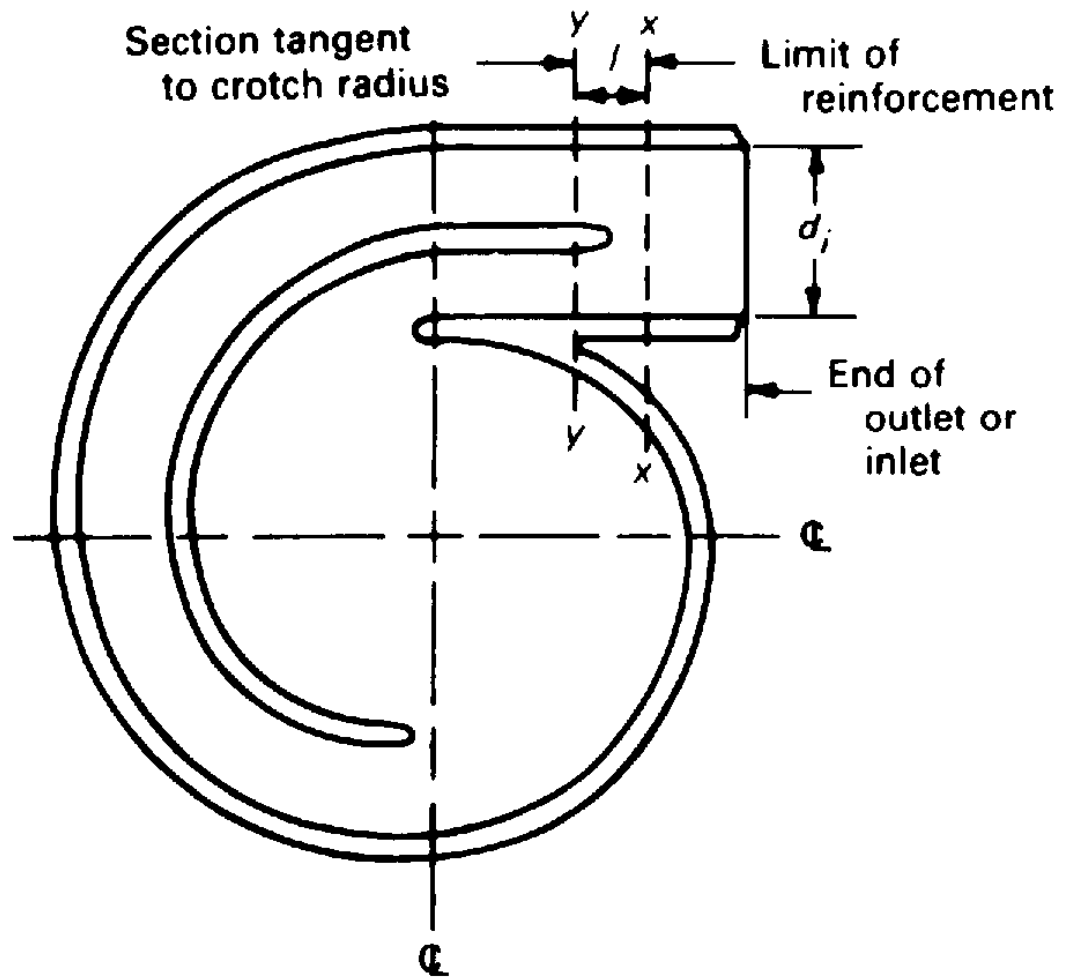


FIG. NC-3433.4-1 MINIMUM TANGENTIAL INLET AND OUTLET WALL THICKNESS

FIG. NC-3433.4-1 MINIMUM TANGENTIAL INLET AND OUTLET WALL THICKNESS

NC-3433.3 Tangential Inlets and Outlets.

Except as modified in NC-3433.4, any design method which has been demonstrated to be satisfactory for the specified Design Loadings may be used.

NC-3433.4 Minimum Tangential Inlet and Outlet Wall Thicknesses.

In Fig. NC-3433.4-1, the value of l , in., shall be determined from the relationship

$$l = 0.5\sqrt{r_m t_m}$$

where

r_m	$= r_i + 0.5t_m$, in.
r_i	$=$ maximum inlet or outlet inside radius, in.
	$= d_i/2$
t_m	$=$ mean inlet or outlet wall thickness, in., taken between section x-x and a parallel section y-y tangent to crotch radius

The wall thickness of the inlet and outlet shall not be less than the minimum wall thickness of the casing for a distance l as shown in Fig. NC-3433.4-1. The wall thickness beyond the distance l may be reduced to the minimum wall thickness of the connected piping. The change in wall thickness shall be gradual and have a maximum slope as indicated in Fig. NC-4250-1.

NC-3434 Bolting

NC-3434.1 Radially Split Configurations.

Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with the procedure described in Appendix XI.

NC-3434.2 Axially Split Configurations.

Bolting in axially split configurations shall be designed in accordance with the procedure given in NC-3441.7 for Type G pumps.

NC-3435 Piping

NC-3435.1 Piping Under External Pressure.

Piping located within the pressure retaining boundary of the pump shall be designed in accordance with NC-3640.

NC-3435.2 Piping Under Internal Pressure.

Piping identified with the pump and external to or forming a part of the pressure retaining boundary, such as auxiliary water connections, shall be designed in accordance with NC-3640.

NC-3436 Attachments

(a) External and internal attachments to pumps shall be designed so as not to cause excessive localized bending stresses or harmful thermal gradients in the pump. The effects of stress concentrations shall be considered.

(b) Attachments shall meet the requirements of NC-3135.

NC-3437 Pump Covers

Pump covers shall be designed in accordance with NC-3325 or NC-3326. Covers for which specific design rules are not given in NC-3325 or NC-3326 shall be designed by any method shown by analysis or experience to be satisfactory.

NC-3438 Supports

Pump supports shall be designed in accordance with the requirements of Subsection NF, unless included under the rules of NC-3411.1(j).

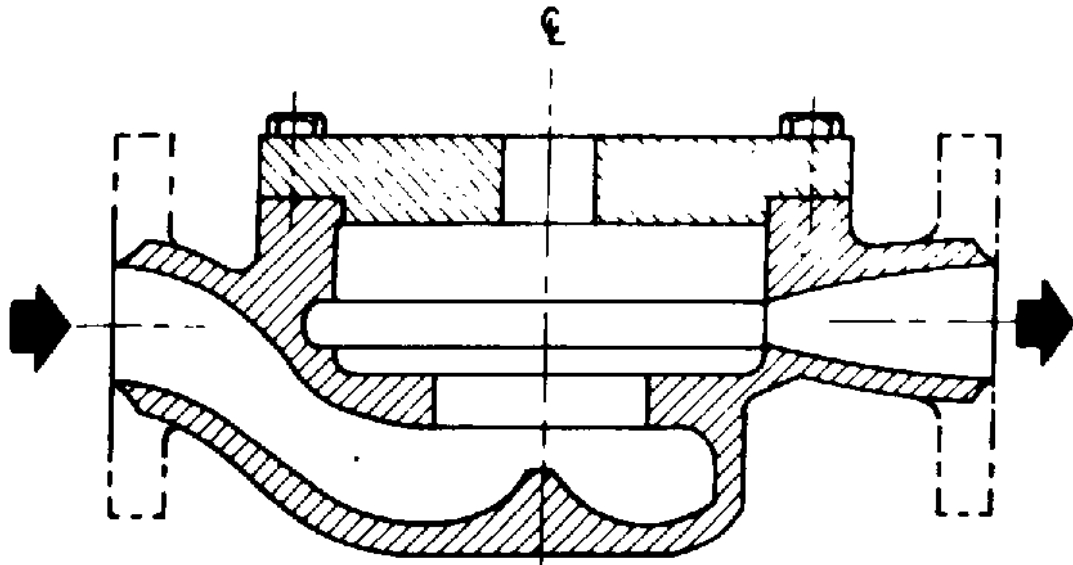


FIG. NC-3441.1-1 TYPE A PUMP

FIG. NC-3441.1-1 TYPE A PUMP

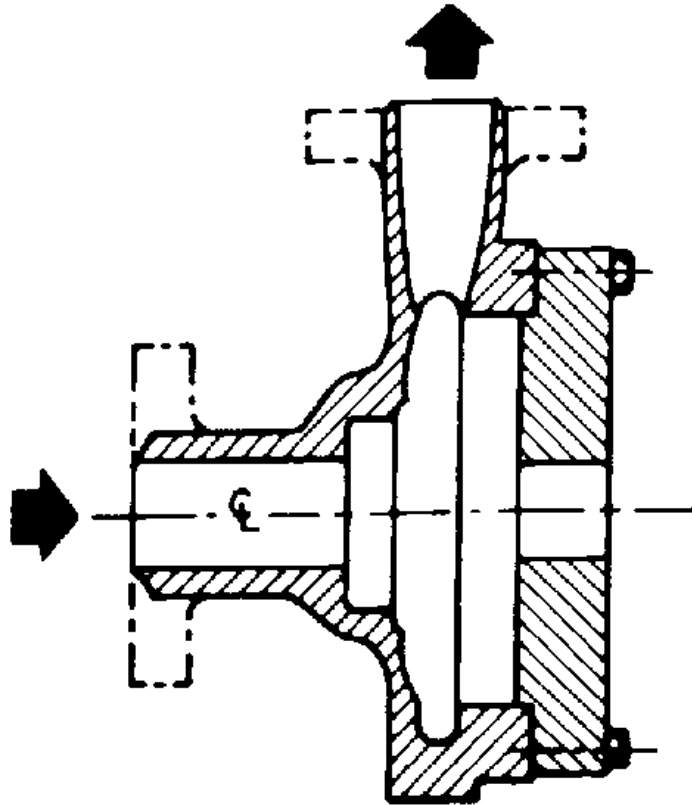


FIG. NC-3441.1-2 TYPE A PUMP

FIG. NC-3441.1-2 TYPE A PUMP

NC-3440 DESIGN OF SPECIFIC PUMP TYPES

NC-3441 Standard Pump Types

NC-3441.1 Design of Type A Pumps.

Type A pumps are those having single volutes and radially split casings with a single suction as illustrated in Fig. NC-3441.1-1 and NC-3441.1-2. Pumps with nozzle sizes NPS 4 (DN 100) discharge and smaller shall be constructed in accordance with NC-3441.1(a) through NC-3441.1(e). Larger pumps are permitted as stipulated in NC-3441.1(f).

(a) *Casing Wall Thickness.* Except where specifically indicated in these rules, no portion of the casing wall shall be thinner than the value of t which is determined as follows:

$$t = (PA)/S$$

or 0.25 in., whichever is greater, where

t	= minimum allowable wall thickness, in.
P	= Design Pressure, psig
A	= scroll dimension, in., inside casing as shown in Fig. NC-3441.1(a)-1. If the value of dimension A exceeds 20 in., the formula shall not be used and (f) below applies.
S	= allowable stress, including casting factor, psi (NC-2571 and Tables 1A, 1B, and 3, Section II, Part D, Subpart 1)

(b) *Cutwater Tip.* The cutwater tip radius shall not be less than $0.05t$.

(c) *Cutwater Fillets.* All cutwater fillets, including the tips, where they meet the casing wall, shall have a minimum radius of $0.10t$ or 0.25 in., whichever is greater.

(d) *Crotch Radius [Fig. NC-3441.1(a)-1].* The crotch radius shall not be less than $0.3t$.

(e) *Bottom of Casing.* That section of the pump casing within the diameter defined by dimension A in Fig. NC-3441.1(a)-1 on the inlet side of the casing, normally referred to as the bottom of the casing, shall have a wall thickness the greater of t from NC-3441.1(a) or t_b . The value of t_b shall be determined by methods of NC-3300 or Appendix A using the appropriate equations for the casing shape or by methods permitted in Appendix XIII.

(f) Pumps with an "A" dimension greater than 20 in. (508 mm) or nozzles larger than NPS 4 (DN 100) discharge are permitted. Design of these larger pumps must be performed in accordance with Appendix II, Experimental Stress Analysis, or Appendix XIII, Design Based on Stress Analysis for Vessels. If the design is qualified by analysis, the analysis shall be certified in accordance with NCA-3551.1.

NC-3441.2 Design of Type B Pumps.

Type B pumps are those having single volutes and radially split casings with double suction as illustrated in Fig. NC-3441.2-1. Any design method that has been demonstrated to be satisfactory for the specified design conditions may be used.

NC-3441.3 Design of Type C Pumps.

Type C pumps are those having double volutes and radially split casings with single suction as illustrated in Figs. NC-3441.3-1 and NC-3441.3-2. The splitter is considered a structural part of the casing. Their design shall be in accordance with the requirements of this Subarticle and with those given in (a) through (e) below.

(a) *Casing Wall Thickness.* Except where specifically indicated in these rules, no portion of the casing wall shall be thinner than the value of t determined as follows:

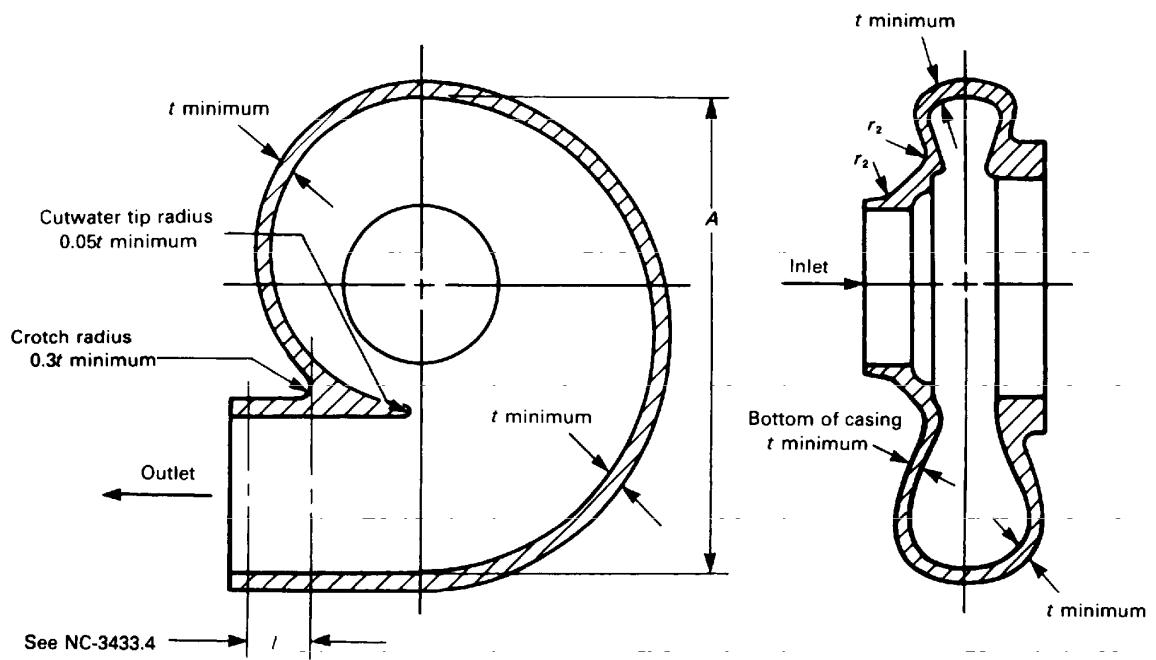


FIG. NC-3441.1(a)-1 TYPE A PUMP

FIG. NC-3441.1(a)-1 TYPE A PUMP

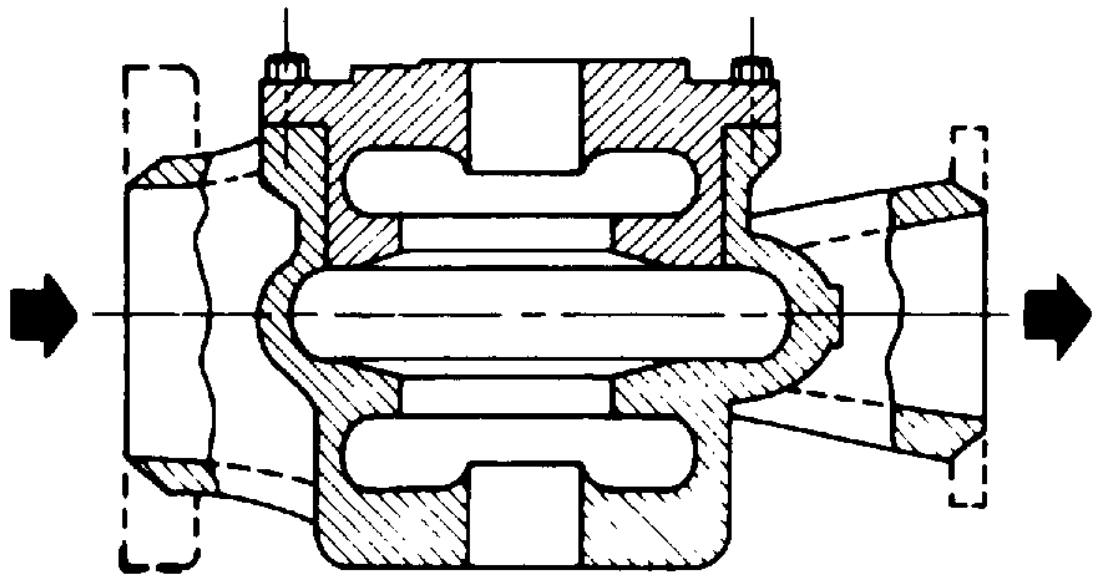


FIG. NC-3441.2-1 TYPE B PUMP

FIG. NC-3441.2-1 TYPE B PUMP

$$t = (0.5 PA)/S$$

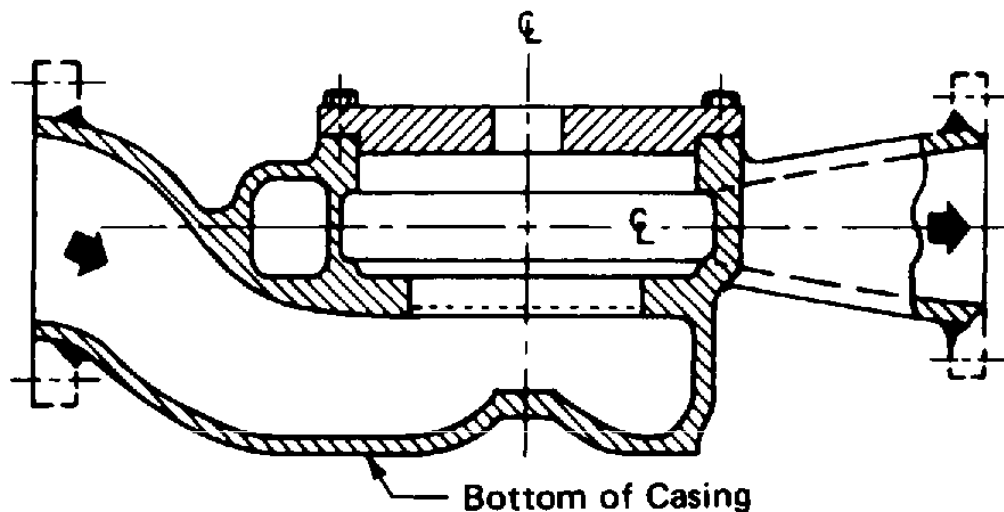


FIG. NC-3441.3-1 TYPE C PUMP

FIG. NC-3441.3-1 TYPE C PUMP

where

t	= minimum allowable wall thickness, in.
P	= Design Pressure, psig
A	= scroll dimension inside casing as shown in Fig. NC-3441.3-2, in.
S	= allowable stress, including casting factor, psi (NC-2571 and Tables 1A, 1B, and 3, Section II, Part D, Subpart 1)

(b) Splitter Wall Thickness

(1) The splitter, which is considered a structural part of the casing, shall have a minimum wall thickness of $0.7t$ as determined above for the casing wall and shall extend from point B in Fig. NC-3441.3-2 sketch (a) through a minimum angle of 135 deg. to point C.

Page 137

Beyond point C, the splitter wall may be reduced in thickness and tapered to blend with the cutwater tip radius.

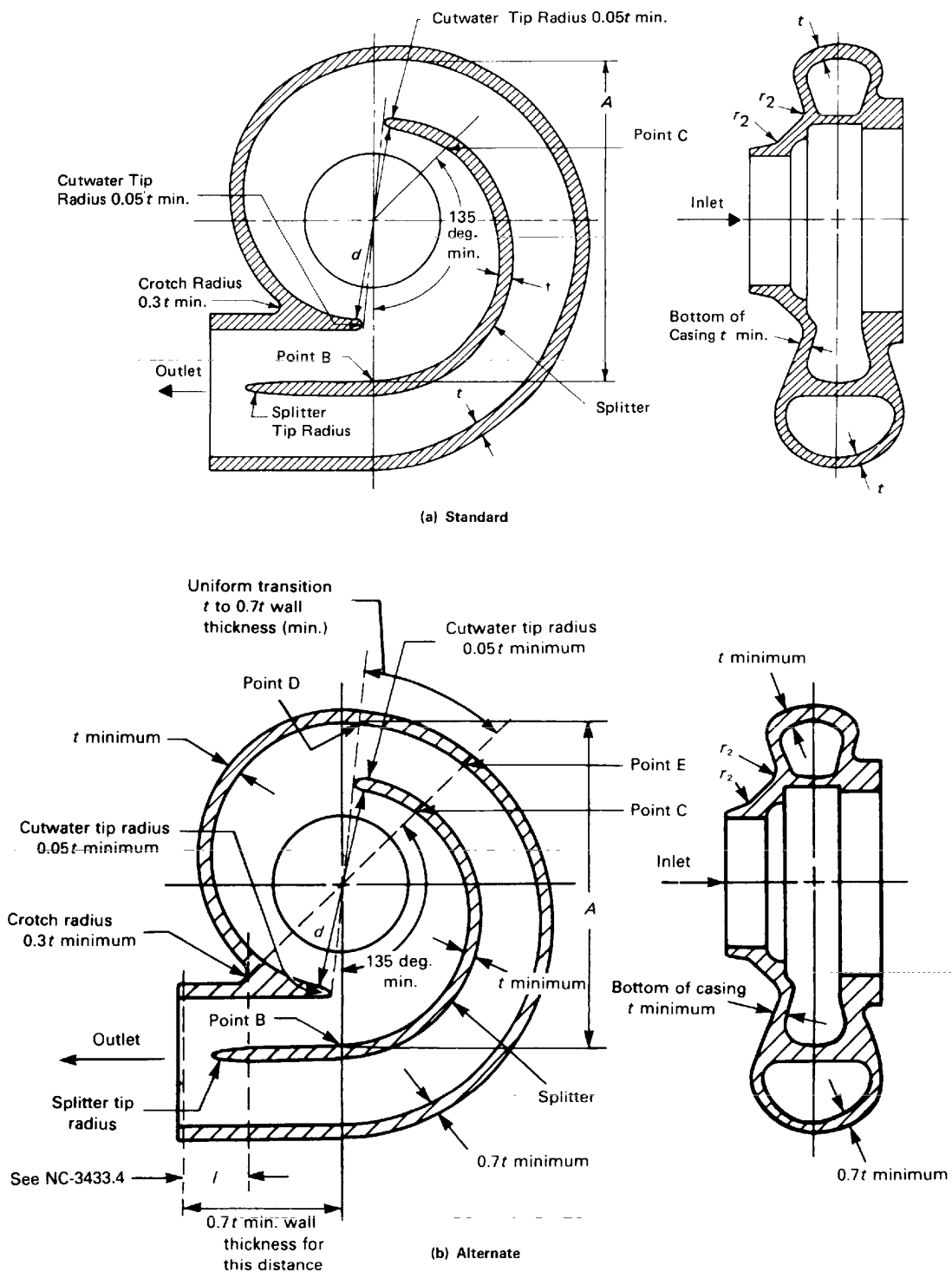


FIG. NC-3441.3-2 TYPE C PUMP

FIG. NC-3441.3-2 TYPE C PUMP

(2) Cutwater tip and splitter tip radii shall not be less than $0.05t$.

(3) All cutwater and splitter fillets, including the tips, where they meet the casing wall, shall have a minimum radius of $0.10t$ or 0.25 in. (6 mm), whichever is greater.

(c) *Crotch Radius (Fig. NC-3441.3-2).* The crotch radius shall not be less than $0.3t$.

(d) *Bottom of Casing.* That section of the pump casing within the diameter defined by dimension A in Fig. NC-3441.3-2 on the inlet side of the casing, normally referred to as the bottom of the casing, shall have a wall thickness no less than the value of t determined in (a) above.

(e) *Alternative Rules for Casing Wall Thickness and Splitter Wall Thickness.* As an alternative to (a) and (b) above, it is permissible to use a smaller casing wall thickness and a larger splitter wall thickness when requirements of (1) through (3) below are met.

(1) The casing wall thickness, as determined by (a) above, shall be maintained at a minimum t , in., between the tangent point of the crotch radius to a point D radially opposite the splitter tip [Fig. NC-3441.3-2 sketch (b)]. The casing wall shall be decreased uniformly to point E from which point a minimum thickness of $0.7t$ shall be continued around the casing wall to a point on the discharge nozzle a distance l , in., from the crotch, where l is defined in Fig. NC-3433.4-1.

(2) The splitter wall thickness shall be as defined in (b) above, except that the splitter shall have a minimum thickness t , in., instead of $0.7t$.

(3) The requirements of (b)(2) and (b)(3) above shall apply.

NC-3441.4 Design of Type D Pumps

(a) Type D pumps are those having double volutes and radially split casings with double suction as illustrated in Fig. NC-3441.4(a)-1. Their design shall be in accordance with the applicable requirements of NC-3400.

(b) The requirements of NC-3441.3(a), (b), and (c), governing casing wall thickness, splitter wall thickness, and crotch radius, apply.

(c) In the casing portion between the cover and the casing wall, a wall thickness in excess of t may be required.

NC-3441.5 Design of Type E Pumps.

Type E pumps are those having volute-type radially split casings and multivane diffusers which form structural parts of the casing as illustrated in Fig. NC-3441.5-1. The design shall be in accordance with the applicable requirements of NC-3400.

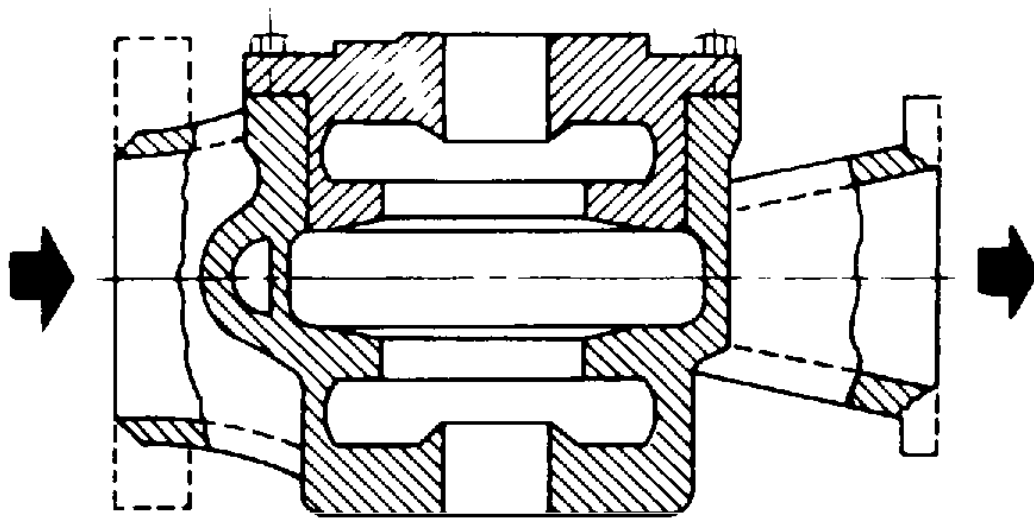


FIG. NC-3441.4(a)-1 TYPE D PUMP

FIG. NC-3441.4(a)-1 TYPE D PUMP

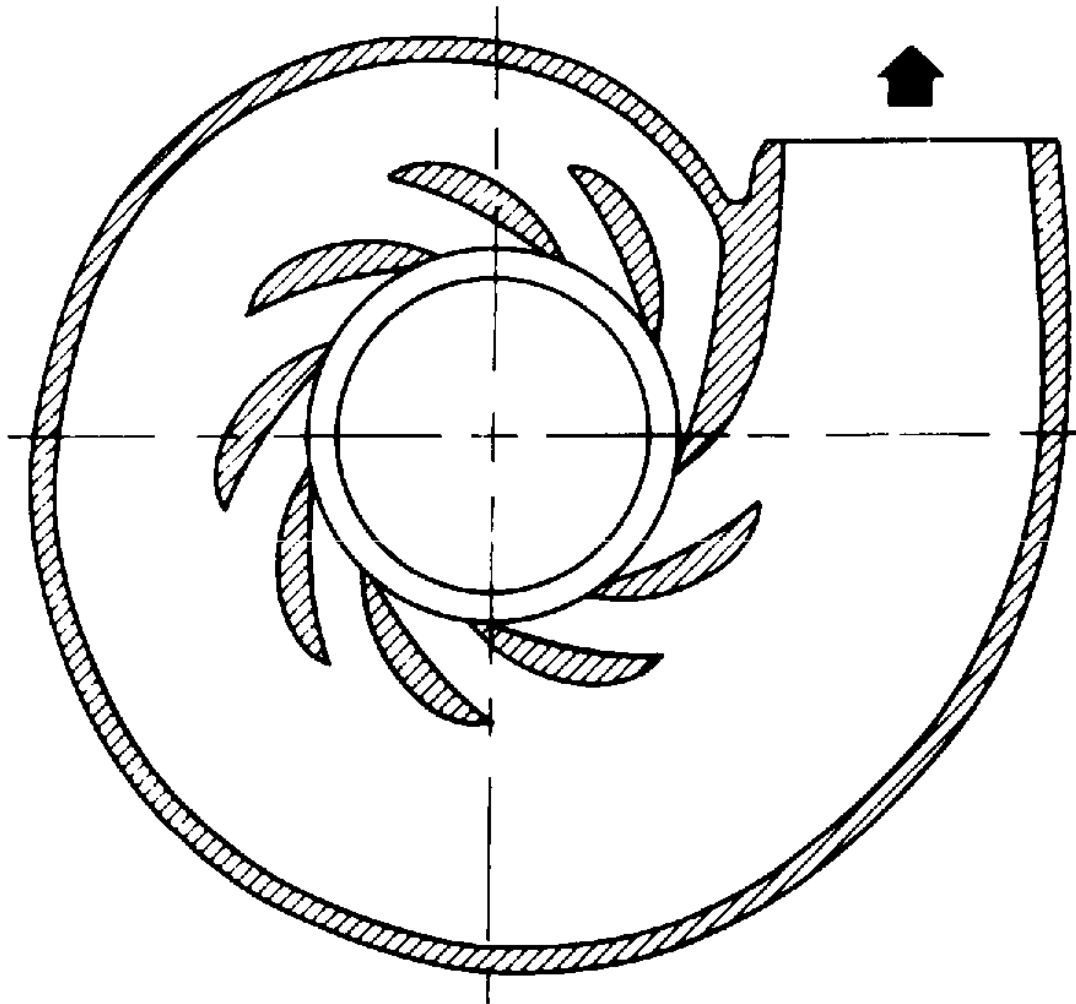


FIG. NC-3441.5-1 TYPE E PUMP

FIG. NC-3441.5-1 TYPE E PUMP

NC-3441.6 Design of Type F Pumps

(a) Type F pumps are those having radially split, axisymmetric casings with either tangential or radial outlets as illustrated in Fig. NC-3441.6(a)-1. The basic configuration of a Type F pump casing is a shell with a dished head attached at one end and a bolting flange at the other. The outlet may be either tangent to the side or normal to the center line of the casing. Variations of these inlet and outlet locations are permitted.

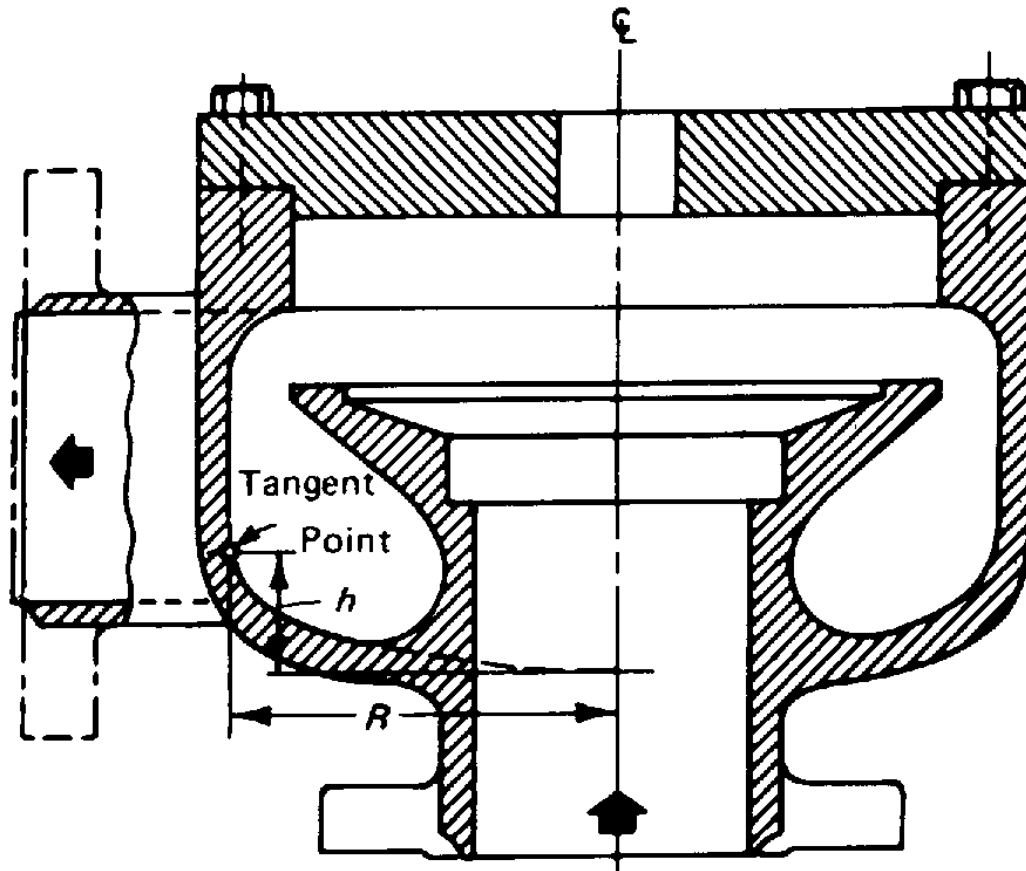


FIG. NC-3441.6(a)-1 TYPE F PUMP

FIG. NC-3441.6(a)-1 TYPE F PUMP

NC-3441.7 Design of Type G Pumps²¹

(a) Type G pumps are those having axially split, single or double volute casings [Figs. NC-3441.7(a)-1 and NC-3441.7(a)-2].

(b) Manufacturers proposing this design should thoroughly review nondestructive examination requirements for compatibility.

(c) An acceptable method for calculating the stress in the most highly stressed section of the pump case, such as the section with the greatest span, is given in (1) and (2) below. This method is not acceptable for those designs in which

more than one bolt falls within a given section [Fig. NC-3441.7(c)-1, Section B-B].

(1) The following assumptions are made:

(a) assign one bolt to Section X; assign one-half bolt to Section Y, and one-half bolt to Section Z (Section Z is identical to Section Y);

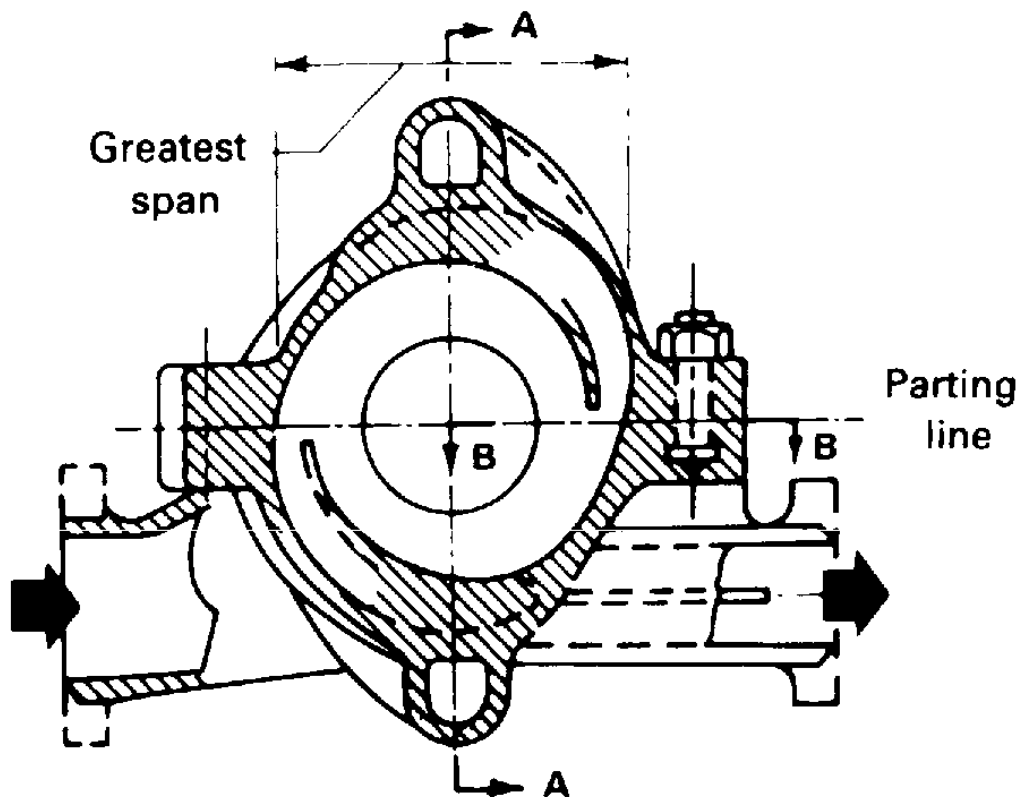
(b) the flange and bolts act together in bending;

(c) the maximum moment occurs at the bolt;

(d) the total moment is distributed between the flange and case in proportion to their moments of inertia.

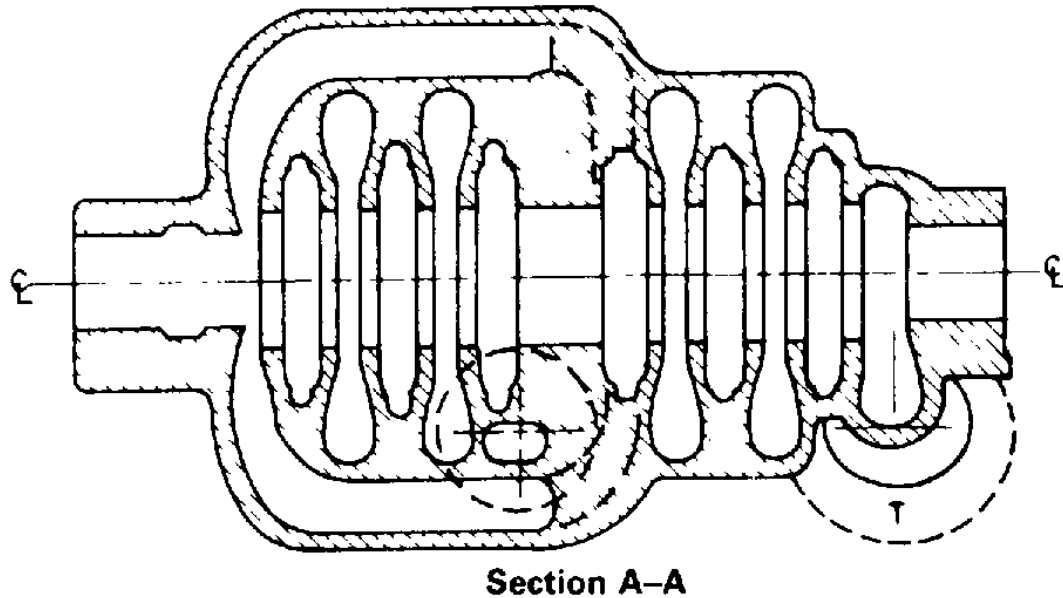
(2) Typical sections are shown in Figs. NC-3441.7(c)(2)-1, NC-3441.7(c)(2)-2, and NC-3441.7(c)(2)-3. The procedure for the calculation is given in (a) through (o) below.

21 It is recognized that other acceptable procedures may exist which also constitute adequate design methods, and it is not the intention to rule out these alternative methods, provided they can be shown to have been satisfactory by actual service experience.



**FIG. NC-3441.7(a)-1 AXIALLY SPLIT CASING,
VOLUTE PUMP, TYPE G**

FIG. NC-3441.7(a)-1 AXIALLY SPLIT CASING, VOLUTE PUMP, TYPE G



**FIG. NC-3441.7(a)-2 AXIALLY SPLIT CASING,
VOLUTE PUMP, TYPE G**

FIG. NC-3441.7(a)-2 AXIALLY SPLIT CASING, VOLUTE PUMP, TYPE G

(a) Establish the Design Pressure P , psi. Establish dimensions $A, B, C, F, R, t_c, t_p, w$, and b from Figs. NC-3441.7(c)(2)-1, NC-3441.7(c)(2)-2, and NC-3441.7(c)(2)-3 and determine the following:

A_G	= effective gasket area, sq in.
D	= diameter of bolt hole, in.
G	= $B + 0.5t_c$, in.
R	= $C - (B + t_c)$, in.
w	= section width, in.
W	= load used in calculating preliminary bolt stress, lb
W	= W_X, W_Y, W_Z
d	= bolt root diameter, in.

A_b

= bolt root area, sq in.

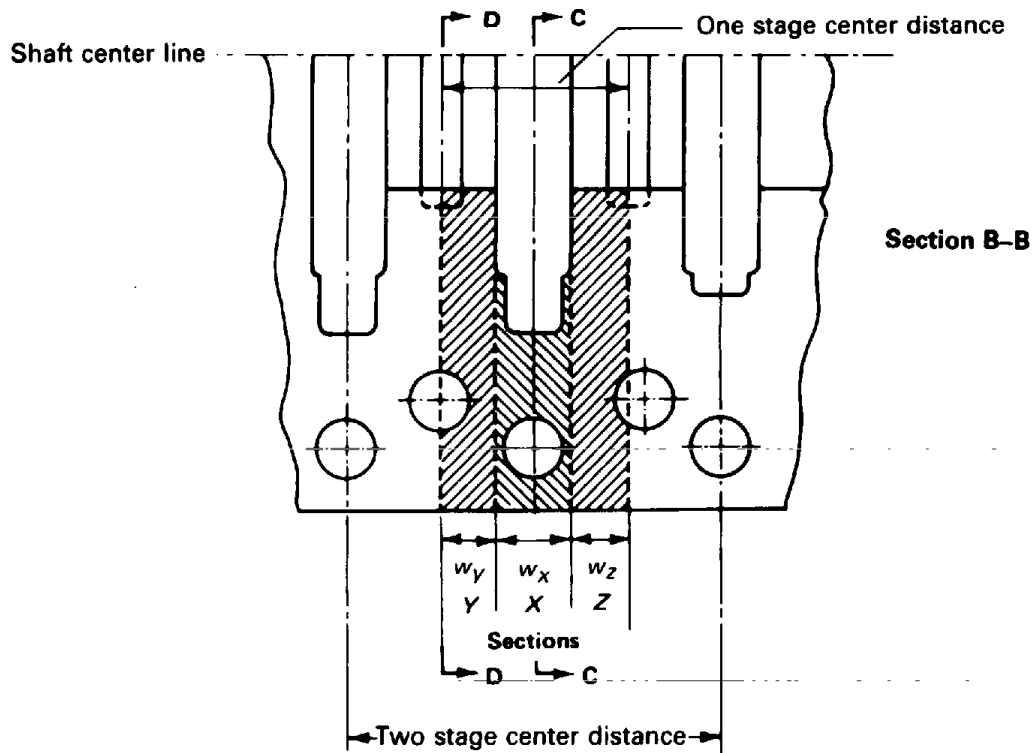


FIG. NC-3441.7(c)-1 AXIALLY SPLIT CASING, VOLUTE PUMP, TYPE G
Section B-B Typical Highly Stressed Sections of Pump Case

FIG. NC-3441.7(c)-1 AXIALLY SPLIT CASING, VOLUTE PUMP, TYPE G

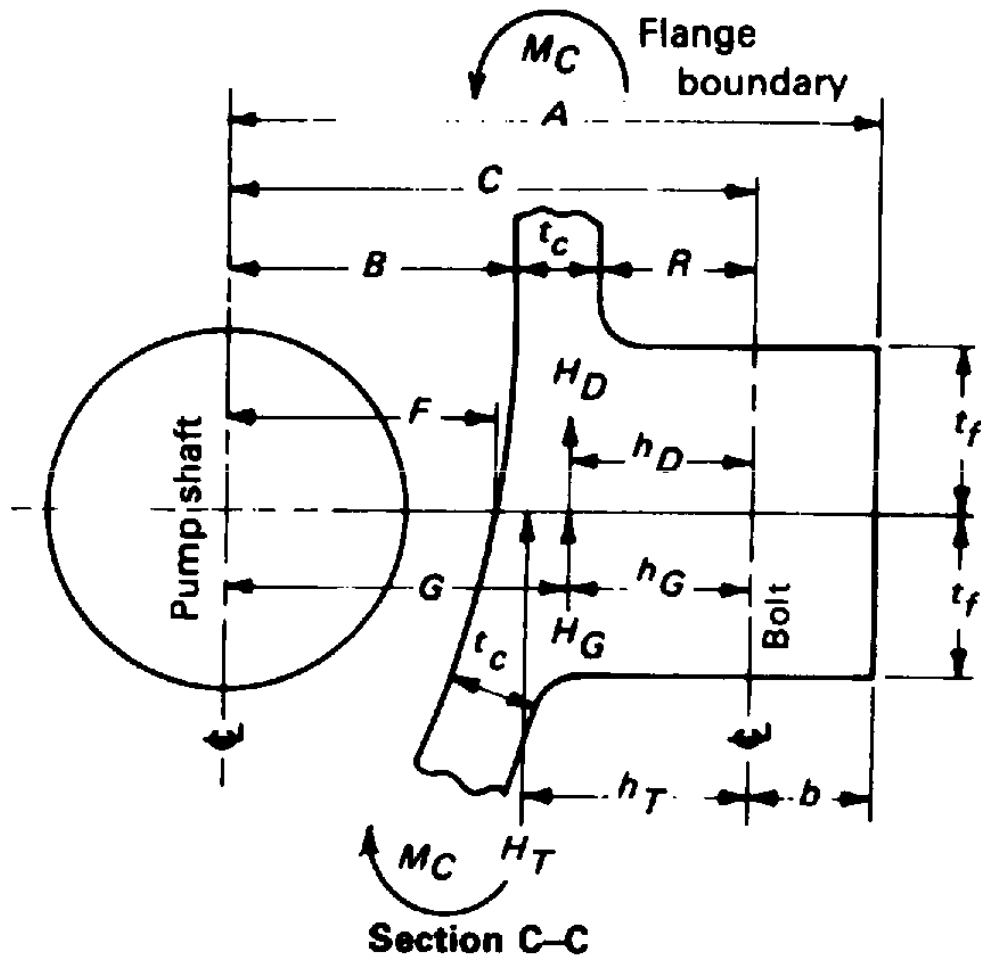
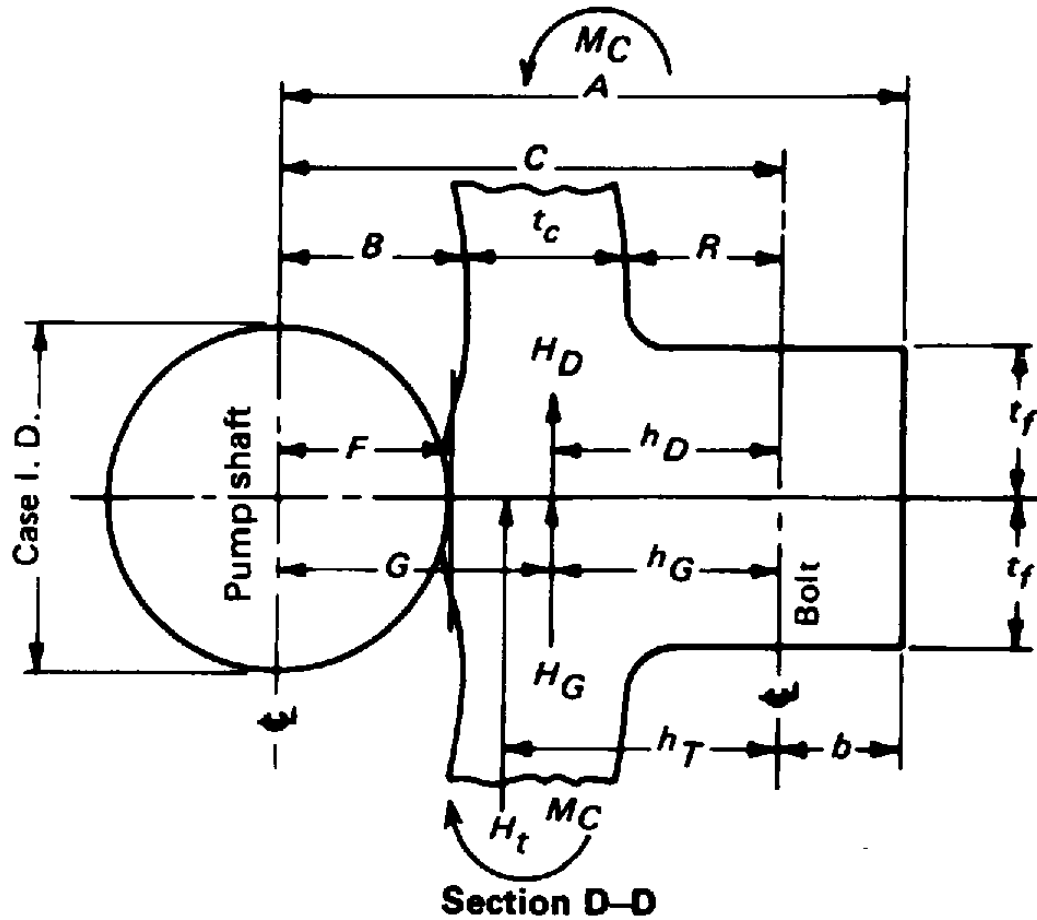


FIG. NC-3441.7(c)(2)-1 TYPICAL SECTION OF TYPE G PUMPS

FIG. NC-3441.7(c)(2)-1 TYPICAL SECTION OF TYPE G PUMPS



**FIG. NC-3441.7(c)(2)-2 TYPICAL SECTION
OF TYPE G PUMPS**

FIG. NC-3441.7(c)(2)-2 TYPICAL SECTION OF TYPE G PUMPS

y	= gasket design seating stress, psi (Table XI-3221.1-1)
m	= gasket factor (Table XI-3221.1-1)
E	= modulus of elasticity of bolt at service temperature, psi
e	= unit thermal elongation of bolt, in./in./°F

DTF

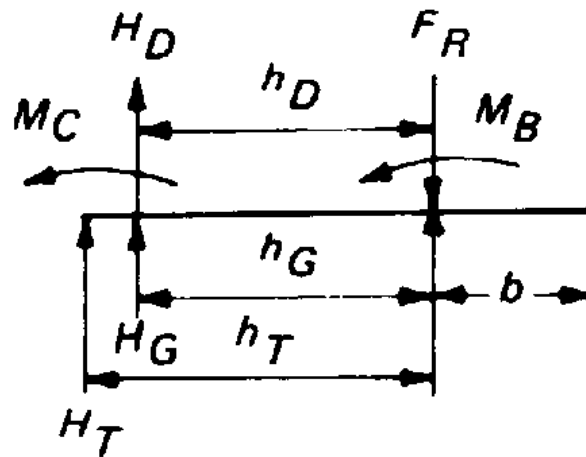
= Design Temperature, °F

S_b

= allowable stress, bolt, psi

S_c

= allowable stress, case, psi



Equivalent Beam

FIG. NC-3441.7(c)(2)-3 TYPICAL LOADS ON TYPE G PUMPS

FIG. NC-3441.7(c)(2)-3 TYPICAL LOADS ON TYPE G PUMPS

(b) Determine the effective gasket area A_G sq in., for Sections X and Y :

$$A_G = \left[(A - F)w - \frac{\pi D^2}{4} \right] \times K$$

For the factor K , use 0.20 if case face is crowned for greatest contact pressure at inner edge and use 0.50 for flat surfaces.

(c) Determine bolt load, lb (N), and preliminary bolt stress σ_{PRE} , psi:

$$H = G \times w \times P$$

$$H_p = A_G \times m \times P$$

$$W_{m1} = H + H_p$$

$$W_{m2} = 0.5A_G \gamma$$

$$W = \text{greater of } W_{m1} \text{ or } W_{m2}$$

$$\sigma_{PRE} = W/A_b$$

(d) Determine the total load H_o , lb:

$$H_D = B \times w \times P$$

$$H_G = H_p$$

$$H_T = H - H_D$$

$$H_o = H_D + H_G + H_T$$

(e) Determine the lever arms h_D , h_G and h_T , in.:

$$h_D = R + 0.5t_c$$

$$h_G = h_D$$

$$h_T = 0.5(R + t_c + h_G)$$

(f) Determine the total moment M_o , in.-lb:

$$M_D = H_D h_D$$

$$M_G = H_G h_G$$

$$M_T = H_T h_T$$

$$M_o = M_D + M_G + M_T$$

(g) Determine the moments of inertia, in.⁴, I_F (flange), I_B (bolt), I_C (case), and I_T (total):

$$I_F = [w(t_f)^3/12] - [D(t_f)^3/12]$$

$$I_B = 0.049d^4$$

$$I_C = w(t_c)^3/12$$

$$I_T = I_F + I_B + I_C$$

(h) Determine the moments, in.-lb (N·mm), carried M_F (flange), M_B (bolt), and M_C (case):

$$M_F = M_o I_F / I_T$$

$$M_B = M_o I_B / I_T$$

Page 142

$$M_C = M_o I_C / I_T$$

(i) Determine the resultant bolt load F_R lb:

$$F_R = [H_D(b + h_D) + H_G(b + h_G) + H_T(b + h_T) - M_C - M_B]/b$$

or

$$F_R = H_o + [(M_o - M_C - M_B)/b]$$

(j) Determine the resultant bolt stresses, psi:

$$\sigma_{\text{Load}} = F_R / A_b$$

$$\sigma_{\text{Temp}} = eE$$

$$\sigma_{\text{Tensile}} = \sigma_{\text{Load}} + \sigma_{\text{Temp}}$$

$$\sigma_{\text{Bending}} = M_B d / 2I_B$$

(k) Determine the shear and bending flange stresses σ'_s , psi, and σ'_b , psi, respectively:

$$\sigma'_s = H_o / wt_f$$

$$\sigma'_b = M_F t_f / 2I_F$$

(l) Determine the tensile and bending case stresses σ''_t , psi, and σ''_b , psi, respectively:

$$\sigma''_t = H_D / wt_c$$

$$\sigma''_b = M_C t_c / 2I_C$$

(m) Use the following method for combining stress in combined sections.

Let F_X = load on Section X,

F_Y =load on Section Y, etc.

Let S_X =stress on Section X,

S_Y =stress on Section Y, etc.

Then the combined stress S_{COMB} is as follows:

$$S_{\text{COMB}} = (F_X + F_Y) / [(F_X/S_X) + (F_Y/S_Y)], \text{ etc.}$$

(n) Determine the maximum stresses using (1) through (4) below.

(1) To determine the preliminary bolt stress, establish the load W and the stress σ_{PRE} for Section X and for Section (Y + Z):

$$\sigma_{\text{PRE COMB}} = \frac{W_X + W_{(Y+Z)}}{\frac{W_X}{\sigma_{\text{PRE}_X}} + \frac{W_{(Y+Z)}}{\sigma_{\text{PRE}_{(Y+Z)}}}}$$

The allowable limit for this stress is S_b .

(2) To determine the resultant bolt stress, establish the load F_R and the stresses σ_t and σ_b for Section X and for Section (Y + ZF):

$$\sigma_{i\text{COMB}} = \frac{F_{R_X} + F_{R_{(Y+Z)}}}{\frac{F_{R_X}}{\sigma_{i_X}} + \frac{F_{R_{(Y+Z)}}{\sigma_{i_{(Y+Z)}}}}$$

The allowable limit for $\sigma_{i\text{COMB}}$ is $2S_b$.

$$\sigma_{b\text{COMB}} = \frac{F_{R_X} + F_{R_{(Y+Z)}}}{\frac{F_{R_X}}{\sigma_{b_X}} + \frac{F_{R_{(Y+Z)}}{\sigma_{b_{(Y+Z)}}}}$$

The allowable limit for $\sigma_{i\text{COMB}} + \sigma_{b\text{COMB}}$ is $3S_b$.

(3) To determine the flange stresses, establish the load H_o , the shear stress σ'_s , and the bending stress σ'_b for Section X and for Section $(Y+Z)$:

$$\sigma'_{s\text{ COMB}} = \frac{H_{oX} + H_{o(Y+Z)}}{\frac{H_{oX}}{\sigma'_{sX}} + \frac{H_{o(Y+Z)}}{\sigma'_{s(Y+Z)}}}$$

$$\sigma'_{b\text{ COMB}} = \frac{H_{oX} + H_{o(Y+Z)}}{\frac{H_{oX}}{\sigma'_{bX}} + \frac{H_{o(Y+Z)}}{\sigma'_{b(Y+Z)}}}$$

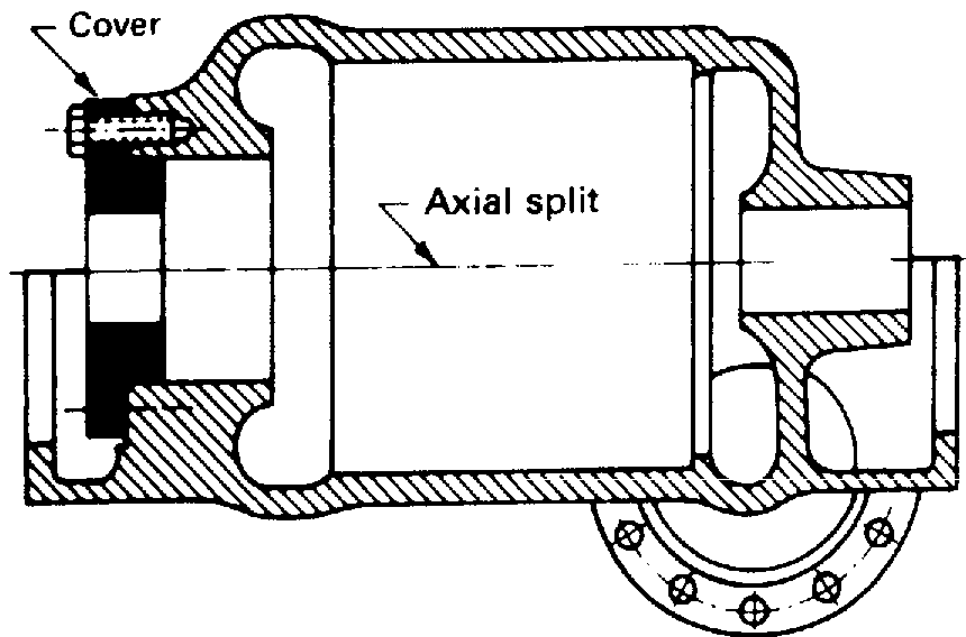
$$\sigma'_{s\text{ max}} = [(\sigma'_{s\text{ COMB}})^2 + (\sigma'_{b\text{ COMB}}/2)^2]^{1/2}$$

$$\sigma'_{n\text{ max}} = \sigma'_{s\text{ max}} + (\sigma'_{b\text{ COMB}}/2)$$

where $\sigma'_{n_{\max}}$ is the maximum normal stress. The allowable limit for $\sigma'_{s_{\max}}$ is S_c and the allowable limit for $\sigma'_{n_{\max}}$ is $1.5S_c$.

TEXT

Page 143



**FIG. NC-3441.8-1 LONGITUDINAL SECTION
THROUGH TYPE H PUMP**

FIG. NC-3441.8-1 LONGITUDINAL SECTION THROUGH TYPE H PUMP

(4) To determine the case stresses, establish the load H_D , the tensile stress σ_t'' , and the bending stress σ_b'' for Section X and for Section $(Y+Z)$:

$$\sigma_t''_{\text{COMB}} = \frac{H_{D_X} + H_{D_{(Y+Z)}}}{\frac{H_{D_X}}{\sigma_t''_X} + \frac{H_{D_{(Y+Z)}}{\sigma_t''_{(Y+Z)}}}$$

$$\sigma_b''_{\text{COMB}} = \frac{H_{D_X} + H_{D_{(Y+Z)}}}{\frac{H_{D_X}}{\sigma_b''_X} + \frac{H_{D_{(Y+Z)}}{\sigma_b''_{(Y+Z)}}}$$

The allowable limit for $\sigma_t''_{\text{COMB}}$ is S_c . The total stress is $\sigma_t''_{\text{COMB}} + \sigma_b''_{\text{COMB}}$. The allowable limit for total stress is $1.5S_c$.

TEXT

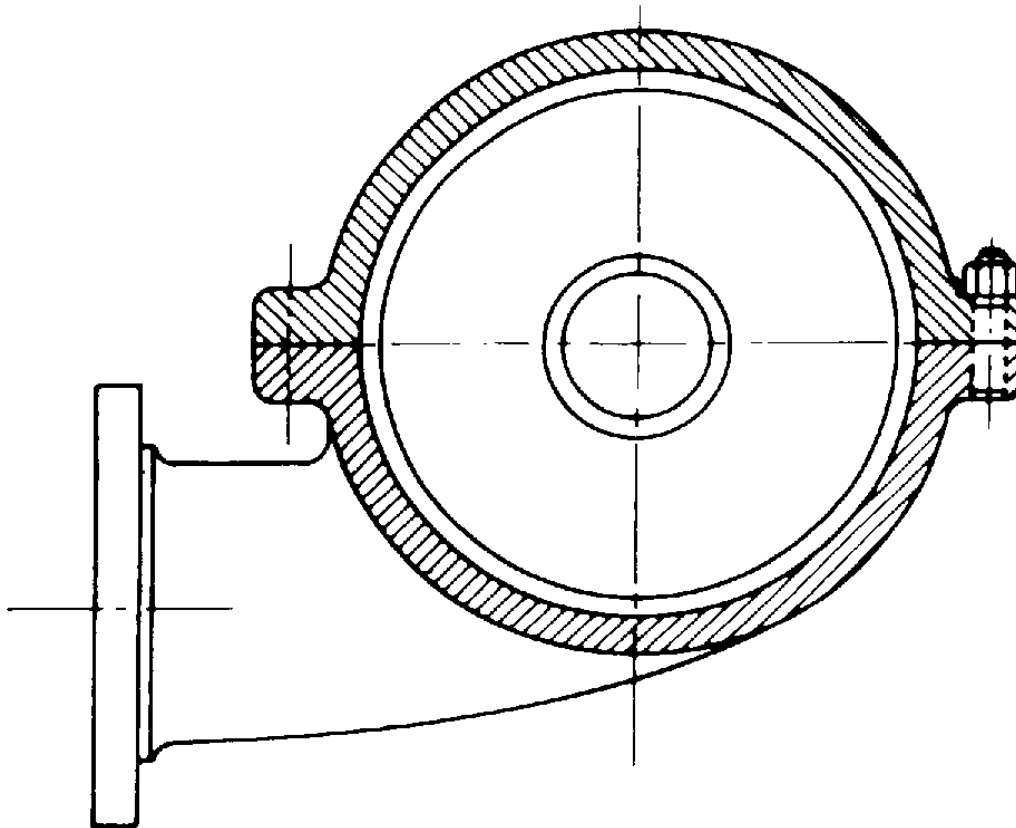
(o) The above procedure will generally show some bolt stresses in excess of the indicated allowable values. Under these circumstances it is permissible to average bolt stresses between adjacent bolts. Such averaged stresses shall not exceed the specified allowables.

NC-3441.8 Design of Type H Pumps.

Type H pumps are those having axially split, barrel-type casings (Figs. NC-3441.8-1 and NC-3441.8-2) and radially split covers. The axially split casing shall be designed in accordance with the rules of NC-3441.7 for Type G pumps. The radially split cover shall be designed in accordance with the rules of NC-3437.

NC-3441.9 Design of Type K Pumps.

Type K pumps are vertical pumps of one or more stages having a radially split casing as illustrated in Figs. NC-3441.9-1 and NC-3441.9-2. The basic configuration is a casing consisting of a barrel and a head joined by bolted flanges and an inner assembly consisting of internal chambers of the head, one or more bowls and columns, and a suction bell, all joined by flanges and arranged so that the external surfaces of these parts are subjected to inlet pressure. These pumps may be furnished with or without column(s) and with or without lateral restraints between the inner assembly and outer casing.



**FIG. NC-3441.8-2 TRANSVERSE SECTION
THROUGH TYPE H PUMP**

FIG. NC-3441.8-2 TRANSVERSE SECTION THROUGH TYPE H PUMP

(a) *Casing.* The barrel and head of the casing shall be designed in accordance with the requirements of NC-3400 and with those given in (1) through (3) below.

(1) *Barrel.* The Design Pressure for the barrel shall be the pump inlet pressure or as otherwise stated in the Design Specification (NCA-3250), but in no case shall it be less than the maximum pressure at the pump inlet under any Service Condition. The static head shall be considered in the selection of the Design Pressure.

(2) *Head*

(a) The external walls of the head, which form the pressure containing boundary to the atmosphere, shall be designed for the pressures specified in (b) and (c) below. The Design Pressure for the internal chambers shall be as specified under the inner assembly rules.

(b) The Design Pressure for the portions of the head that form the pressure containing boundary between the outlet pressure and the atmosphere shall be the outlet pressure or as otherwise stated in the Design Specification, but in no case shall it be less than the

Page 144

maximum pressure at the pump outlet under any Service Condition.

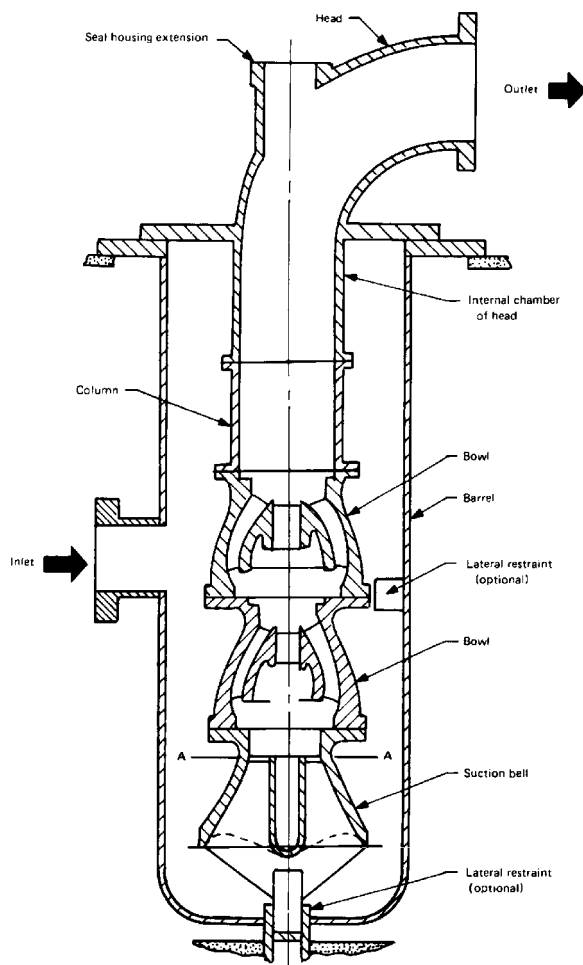


FIG. NC-3441.9-1 TYPE K PUMP

FIG. NC-3441.9-1 TYPE K PUMP

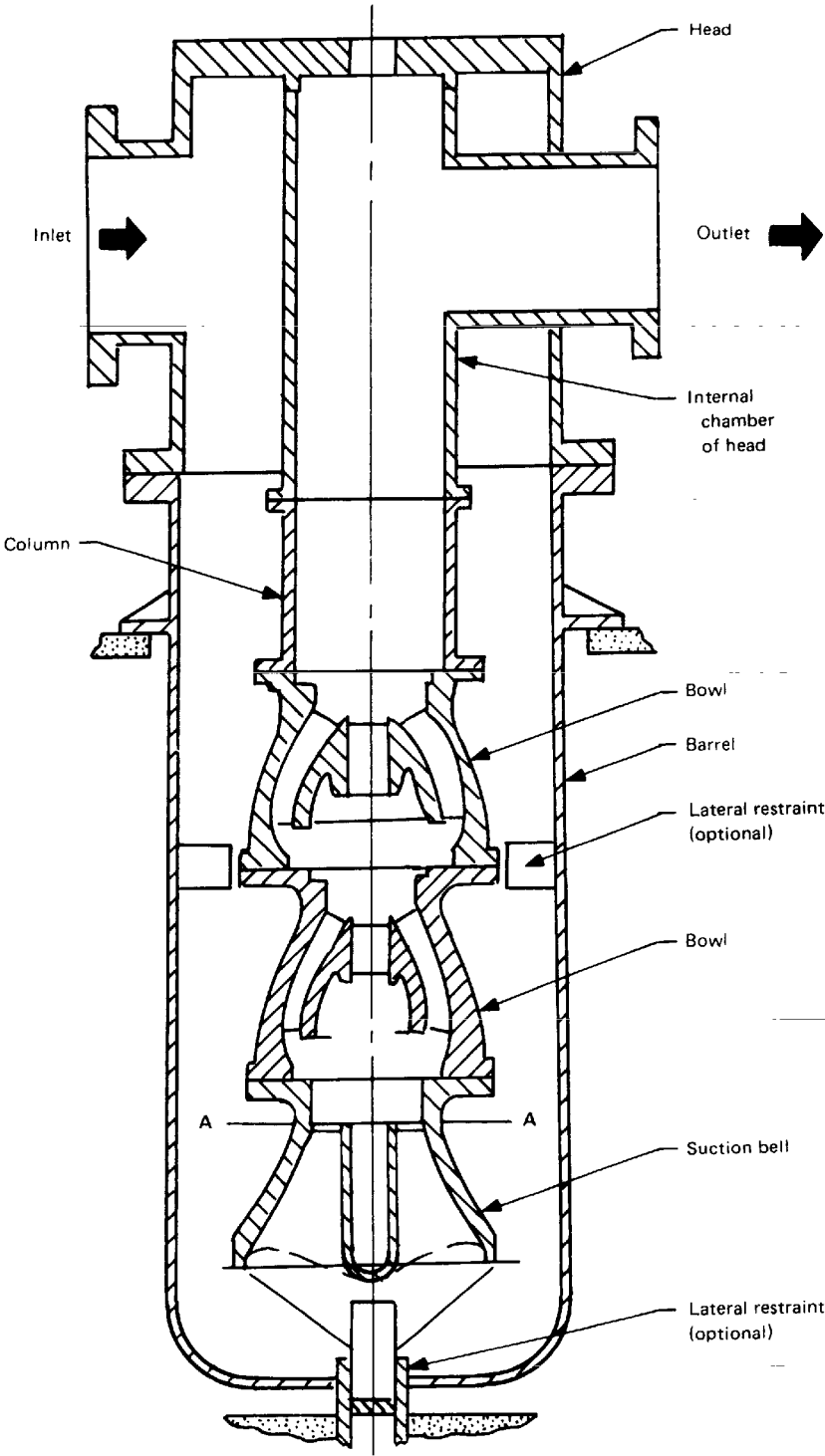


FIG. NC-3441.9-2 TYPE K PUMP

FIG. NC-3441.9-2 TYPE K PUMP

(c) The Design Pressure for the portions of the head that form the pressure containing boundary between the inlet pressure and the atmosphere shall be the inlet pressure or as otherwise stated in the Design Specification, but in no case shall it be less than the maximum pressure at the pump inlet under any Service Condition.

(3) *Flanged Joints, Other Than Inlets and Outlets.* Flanged joints shall be designed in accordance with Appendix XI. Class FF flanges which utilize full face gaskets are allowed, provided that allowance for gasket compression is included in calculations of the bolt load W and the flange thickness t .

(b) *Inner Assembly.* The inner assembly consists of internal chambers of the head, the bowls and columns, and the upper flange of the suction bell. It comprises those elements of the pump subjected to differential pressure within the pump and those which do not form part of the pressure boundary to the atmosphere. Design rules are under development. Until they are available, the design shall be by analysis or any procedure which can be shown to have been satisfactory by actual service experience. However, their design shall meet the rules of NC-3400 and the rules given in (1) and (2) below.

(1) *Columns and Internal Chambers of the Head.* The Design Pressure for columns and internal chambers of the head shall be not less than the maximum differential pressure which can be developed across the wall of that column or chamber under any Service Condition.

(2) *Bowls and Suction Bell*

(a) The Design Pressure for the bowl(s) shall be not less than the maximum differential pressure to which each respective bowl may be subjected under any Service Condition. Potential for interchangeability of bowls of different design ratings shall be taken into consideration.

(b) The Design Pressure for the upper flange of the suction bell (section above line A-A in Figs. NC-3441.9-1 and NC-3441.9-2) shall be not less than the maximum pressure differential developed by the first stage of the pump under any Service Condition. The remaining portion of the bell is not considered to be subject to pressure loads.

(c) Each bowl and suction bell shall be manufactured of material meeting the rules of NC-2190 and designed using the casting quality factors listed in Note (4) of Tables 1A, 1B, and 3, Section II, Part D, Subpart 1.

NC-3442 Special Pump Types

NC-3442.1 Design of Type J Pumps (Centrifugal)

(a) Type J pumps are those that cannot logically be classified with any of the preceding types of centrifugal pumps.

(b) It is not planned to establish rules for Type J pumps. Any design method which has been demonstrated to be satisfactory for the specified Design Conditions may be used.

NC-3442.2 Design of Reciprocating Pumps.

See NC-3450.

NC-3450 DESIGN OF CLASS 2 RECIPROCATING PUMPS

NC-3451 Scope

(a) These rules cover the strength and pressure integrity of the structural parts of the liquid end [Fig. NC-3451(a)-1], whose failure would violate the pressure boundary. Such parts include:

- (1) liquid cylinder and valve chambers
- (2) valve covers
- (3) liquid cylinder heads

- (4) stuffing boxes
- (5) packing glands
- (6) manifolds
- (7) piping and nozzles normally identified with the pump and furnished by the pump supplier
- (8) related bolting
- (9) external and internal integral attachments to the pressure retaining boundary

(b) These rules do not apply to the plunger or piston, nonstructural internals, including valves, valve seats, gaskets, packing, and cylinder mounting bolting. Hydrostatic testing of packing glands is not required.

NC-3452 Acceptability

The pressure boundary parts shall be capable of withstanding the specified Design Pressures, and the design shall be such that the requirements of NC-3100 are satisfied in addition to these rules.

NC-3453 Material and Stresses

Material and allowable stresses shall conform to the requirements of NC-2000.

Page 147

Page 148

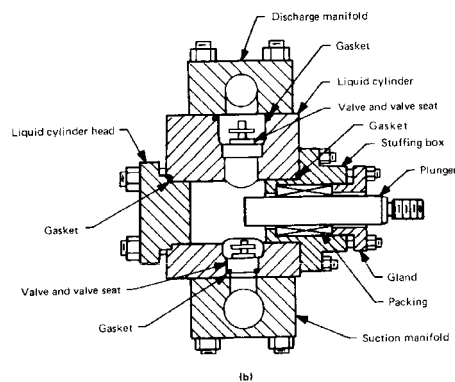
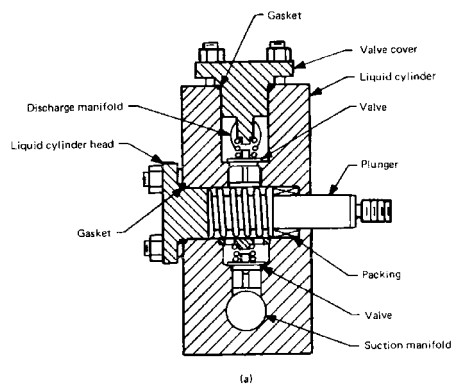


FIG. NC-3451(a)-1 HORIZONTAL SINGLE-ACTING POWER PUMP LIQUID ENDS

FIG. NC-3451(a)-1 HORIZONTAL SINGLE-ACTING POWER PUMP LIQUID ENDS

NC-3454 Design Requirements

NC-3454.1 Design of Welded Construction

(a) Design of welded construction shall be in accordance with NC-3350.

(b) Partial penetration welds, as shown in Fig. NC-4244(e)-1 sketch (c-3) and Fig. NC-4266(d)-1 sketches (a) and (b), are allowed for nozzles such as vent and drain connections and openings for instrumentation. Nozzles shall not exceed 2 in. nominal pipe size (DN 50). For such nozzles, all reinforcement shall be integral with the portion of the shell penetrated. Partial penetration welds shall be of sufficient size to develop the full strength of the nozzles.

NC-3454.2 Piping.

Piping located within the pressure retaining boundary of the pump, and identified with the pump, shall be designed in accordance with NC-3600.

NC-3454.3 Liquid End.

Any design method which has been demonstrated to be satisfactory for the specified design may be used.

NC-3454.4 Fatigue.

The liquid cylinder and pressure retaining bolting are exposed to significant fatigue loadings which shall be considered in the design. Any design method which has been demonstrated to be satisfactory for the specified design may be used.

NC-3454.5 Earthquake Loadings.

The effects of earthquake shall be considered in the design of pumps. The stresses resulting from these earthquake effects shall be included with the stresses resulting from pressure or other applied loads.

NC-3454.6 Corrosion.

In designs where corrosion of material is a factor, allowances shall be made.

NC-3454.7 Bolting.

Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with the procedure described in Appendix XI.

NC-3500 VALVE DESIGN

NC-3510 GENERAL REQUIREMENTS

22 CAUTIONARY NOTE: Certain types of double seated valves have the capability of trapping liquid in the body or bonnet cavity in the closed position. If such a cavity accumulates liquid and is in the closed position at a time when adjacent system piping is increasing in temperature, a substantial and uncontrolled increase in pressure in the body or bonnet cavity may result. Where such a condition is possible, it is the responsibility of the Owner or his designee to provide, or require to be provided, protection against harmful overpressure in such valves.

NC-3511 Design Specification²²

Design and Service Conditions (NCA-2142) shall be stipulated in the Design Specification (NCA-3250). The requirements of NCA-3254(a) for specifying the location of valve boundary jurisdiction may be considered to have been met by employing the minimum limits of NC-1131, unless the Design Specification extends the boundary of jurisdiction beyond these minimum limits. The requirements of NCA-3254(b) for specifying the boundary conditions are not applicable to valve end connections.

NC-3512 Standard Design Rules

NC-3512.1 Flanged and Butt Welded End Valves.

The design of valves with flanged and butt welded ends shall conform to the applicable requirements for Standard Class category valves of ANSI B16.34, except as provided in (a) and (b) below.

(a) Valves with flanged and butt welded ends may be designated as Class 75 in sizes larger than 24 in. nominal pipe size (DN 600), provided that the following additional requirements are met.

(1) The maximum rated pressure shall be 75 psi (517 kPa) for fluid temperatures from -20°F to 350°F (-29°C to 179°C).

(2) The minimum valve body wall thickness, exclusive of corrosion allowance, shall be in accordance with the following:

$$t_m = 0.4t_o + 0.2 \text{ for } d \leq 50 \text{ in.}$$

or

$$t_m = 0.008d + 0.2 \text{ for } d > 50 \text{ in.}$$

where

t_m = minimum body wall thickness, in.

t_o = minimum body wall thickness as tabulated in ANSI B16.34 for Class 150, in.

d = inside diameter, in.

(3) Flanges shall be designed in accordance with the requirements of Appendix XI, AWWA-C207 Class E, MSS-SP-44, or API-605.

(4) The minimum hydrostatic shell test pressure shall be 125 psi (861 kPa) and shall be maintained for a minimum of 10 min.

(5) The minimum valve closure test pressure shall be 85 psi (586 kPa) and shall be maintained for a minimum of 10 min.

Page 149

(b) Valves with flanged ends in sizes larger than 24 in. nominal pipe size (DN 600) may be used, provided that the following additional requirements are met.

(1) For MSS-SP-44, the Pressure Class shall be limited to Class 600 and lower, and for API-605, the Pressure Class shall be limited to Class 150 and Class 300.

(2) The operating temperatures shall be limited to the range of -20°F to 650°F (-29°C to 343°C).

(3) Flanges are designed in accordance with the requirements of Appendix XI, MSS-SP-44, or API-605.

NC-3512.2 Socket Welded End and Nonwelded End Valves.

The design of valves with socket welded end connections and nonwelded piping end connections other than ANSI B16.5 flanges shall conform to the applicable requirements for Standard Class category butt welding and valves of ANSI B16.34, except that the end connections shall conform to the applicable requirements of NC-3661 or NC-3671.

NC-3512.3 Wafer or Flangeless Valves.

The design of valves that can be bolted between flanges (i.e., butterfly valves) shall conform to the applicable requirements of Standard Class category valves of ANSI B16.34 and the requirements of (a) through (e) below.

(a) The design shall provide for bolt-up using all of the bolt holes and the bolt circle of the specified flange.

(b) Bolt holes parallel to the body run may be either threaded or unthreaded. Threaded holes may be blind holes suitable for use with bolt studs.

(c) The required minimum valve body wall thickness shall be measured from the valve inside circumference to either the valve outside circumference or the circumference of a circle inscribed about the inner tangents to the bolt holes, whichever is smaller.

(d) The inner ligament of either a through hole or a blind threaded hole in the vicinity of a stem penetration shall not be less than 25% of the required body neck thickness.

(e) The inner ligament for singular holes parallel to the body run shall not be less than 25% of the required valve body wall thickness. Such holes shall not be larger than $\frac{3}{8}$ in. diameter.

NC-3512.4 Design and Service Loadings.

The design requirements of NC-3512.1 and NC-3512.2 include pressure-temperature ratings for Design Loadings and Service Loadings for which Level A Limits are designated. When any Service Loadings are stipulated for which Level B, Level C, or Level D Limits are designated in the Design Specification, the requirements of NC-3520 shall be met.

NC-3512.5 Openings for Auxiliary Connections.

Openings for auxiliary connections, such as for drains, bypasses, and vents, shall meet the requirements of ANSI B16.34 and the applicable requirements of NC-3330.

NC-3513 Alternative Design Rules

For butt welding end valves and for socket welding end valves whose end connections conform to the requirements of NC-3661, the design requirements for Special Class category valves of ANSI B16.34 may be used in place of NC-3512 when permitted by the Design Specification, provided that the following requirements are met.

(a) The nondestructive examination requirements of ANSI B16.34, Special Class, shall be met for all sizes of butt welding and socket welding end valves in accordance with the examination methods and acceptance standards of NC-2500.

(b) When any Service Loadings are stipulated for which Level B, Level C, or Level D Limits are designated in the Design Specification, the requirements of NC-3520 shall be met.

(c) Openings for auxiliary connections, such as for drains, bypasses, and vents, shall meet the requirements of ANSI B16.34 and the applicable reinforcement requirements of NC-3330.

NC-3515 Acceptability of Metal Bellows and Metal Diaphragm Stem Sealed Valves

Valves using metal bellows or metal diaphragm stem seals shall be constructed in accordance with the rules of this Subarticle, based on the assumption that the bellows or diaphragms do not retain pressure and Design Pressure is imposed on a required backup stem seal such as packing. The bellows or diaphragms need not be constructed in accordance with the requirements of this Section.

NC-3516 Acceptability of Elastomer Diaphragm Valves

Valves using elastomer diaphragms, wherein the diaphragm performs the function of a disc or plug, shall be constructed in accordance with NC-3500. This is based on the assumptions that the diaphragms do not retain pressure, design pressure is imposed on the backup stem seal, and the additional requirements below.

(a) Design temperature shall not exceed 350°F.

Page 150

(b) Valve size and Pressure Class shall not exceed NPS 12 (DN 300) for Class 150 and NPS 4 (DN 100) for Class 300.

(c) A backup seal stem shall be provided.

(d) Diaphragms shall meet the requirements of MSS SP-100.

NC-3520 LEVEL B, C, AND D SERVICE LIMITS

NC-3521 Design Requirements

(a) When the piping system in which the valve is located is designed to the requirements of NC-3600, the valve body is considered adequate to withstand piping end loads, provided that conditions (1) and (2) below are satisfied. In lieu of (1) and (2), the design procedure of NB-3545.2 is acceptable.

(1) The section modulus and metal area at a plane normal to the flow passage through the region at the valve body crotch, that is, in the plane A-A of Fig. NC-3521-1, shall be not less than 110% of the section modulus and metal area of the piping connected to the valve body inlet and outlet nozzles.

(2) The allowable stress for valve body material is equal to or greater than the allowable stress of the connected piping material. If the valve body material allowable stress is less than that of the connected piping material, the valve section modulus and metal area shall be not less than 110% of the section modulus and metal area of the connected piping multiplied by the ratio $S_{\text{pipe}}/S_{\text{valve}}$.

(b) The maximum internal pressure resulting from Service Loadings for which Level A, Level B, Level C, or Level D limits are designated shall not exceed the tabulated factors in Table NC-3521-1 times the Design Pressure or the rated pressure at the applicable service temperature. If these pressure limits are met, loadings for the stress limits in Table NC-3521-1 are considered to be satisfied.

(c) Where valves are provided with operators having extended structures and these structures are essential to maintaining pressure integrity, an analysis, when required by the Design Specification, shall be performed based on static forces resulting from equivalent earthquake accelerations acting at the centers of gravity of the extended masses. The valve bodies shall conform to the stress limits listed in NC-3522. Classical bending and direct stress equations, where free body diagrams determine a simple stress distribution that is in equilibrium with the applied loads, may be used.

NC-3522 Stress and Pressure Limits

Stress limits for service loadings are specified in Table NC-3521-1. The symbols used in Table NC-3521-1 are defined as follows:

σ_m	= general membrane stress, psi. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.
σ_L	= local membrane stress, psi. This stress is the same as σ_m except that it includes the effect of discontinuities.
σ_b	= bending stress, psi. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.
S	= allowable stress value given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1, psi. The allowable stress shall correspond to the highest metal temperature at the section under consideration during the loading under consideration.

NC-3530 GENERAL RULES

NC-3531 Hydrostatic Tests

The following requirements apply to valves designated to either NC-3512 or NC-3513.

NC-3531.1 Shell Hydrostatic Test.

A shell hydrostatic test shall be made using either water or air in accordance with the requirements of ANSI B16.34. Stem seal leakage during this test is permissible. Hydrostatic tests for metal bellows of metal diaphragm stem sealed valves shall include hydrostatic testing of the valve body, bonnet, body-to-bonnet joint, and either the bellows or diaphragm or the required backup stem seal. End closure seals for retaining fluid at test pressure in welding end valves may be positioned in the welding end transitions as defined in ANSI B16.34 in reasonable proximity to the end plane of the valve so as to ensure safe application of the test pressure.

NC-3531.2 Valve Closure.

After the shell hydrostatic test, a valve closure test shall be performed in accordance with ANSI B16.34, except that all valve sizes shall be subjected to a test differential pressure across the valve disk not less than 110% of the 100°F (38°C) pressure rating. During this test, seat leakage value is defined by the Design Specification.

Page 151

Page 152

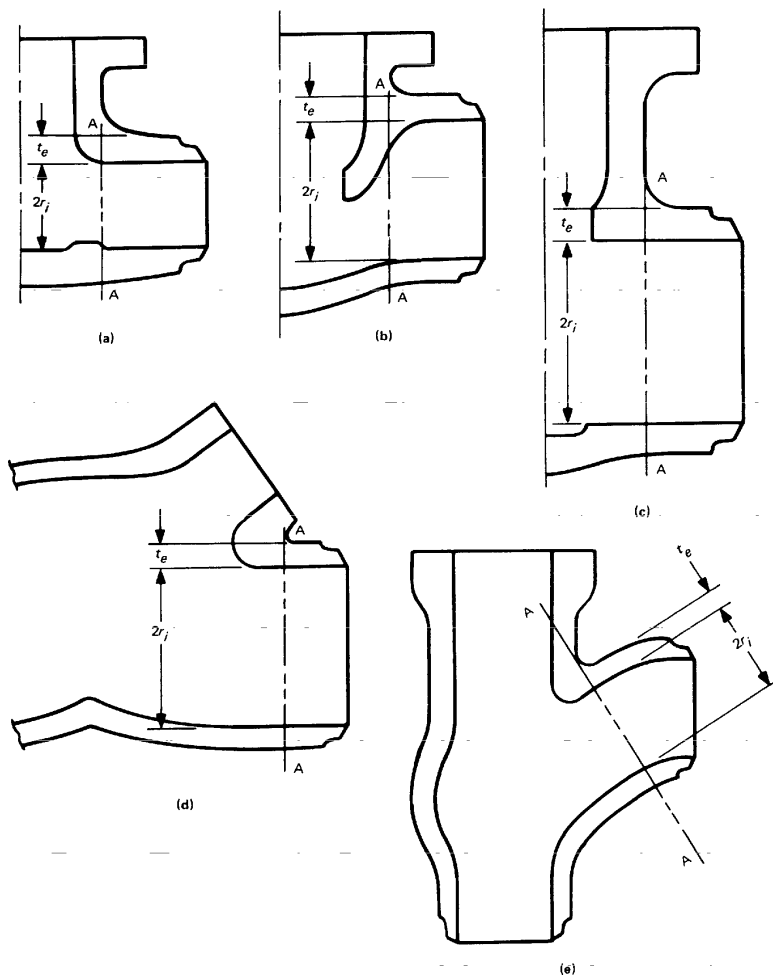


FIG. NC-3521-1 TYPICAL SECTIONS OF VALVE BODIES

FIG. NC-3521-1 TYPICAL SECTIONS OF VALVE BODIES

**TABLE NC-3521-1
LEVEL A, B, C, AND D SERVICE LIMITS**

Service Limit	Stress Limits [Notes (1)–(4)]	$P_{\max}$ [Note (5)]
Level A	$\sigma_m \leq S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5S$	1.0
Level B	$\sigma_m \leq 1.1S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65S$	1.1
Level C	$\sigma_m \leq 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$	1.2
Level D	$\sigma_m \leq 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$	1.5

NOTES:

- (1) A casting quality factor of 1 shall be assumed in satisfying these stress limits.
- (2) These requirements for the acceptability of valve design are not intended to assure the functional adequacy of the valve.
- (3) Design requirements listed in this Table are not applicable to valve disks, stems, seat rings, or other parts of the valves which are contained within the confines of the body and bonnet.
- (4) These rules do not apply to safety relief valves.
- (5) The maximum pressure shall not exceed the tabulated factors listed under $P_{\max}$ times the Design Pressure or times the rated pressure at the applicable service temperature.

TABLE NC-3521-1 LEVEL A, B, C, AND D SERVICE LIMITS

NC-3531.3 Time at Pressure.

The duration of the shell hydrostatic test shall meet the requirements of NC-6223. The duration of the valve closure test shall be the greater of either 1 min/in. of minimum wall thickness t_m or the testing time requirement of ANSI B16.34, but not less than 1 min.

NC-3531.4 Exemptions to the Valve Closure Test

(a) For valves that are designed for Service Conditions that have the pressure differential across the closure member limited to values less than the 100°F pressure rating, or that have closure members or actuating devices (direct, mechanical, fluid, or electrical) that would be subject to damage at high differential pressures, the test pressure may be reduced to 110% of the maximum specified differential pressure in the closed position. This exception shall be identified in the Design Specification, and this maximum specified differential pressure shall be noted on the valve nameplate and the N Certificate Holder's Data Report Form.

(b) For valves designed for nonisolation service, the primary function of which is to modulate flow, and which by their design are prevented from providing full closure, the valve closure test defined in NC-3531.2 is not required. This exception shall be identified in the Design Specification and noted on the valve nameplate and the N Certificate Holder's Data Report Form.

NC-3590

NC-3590 PRESSURE RELIEF VALVE DESIGN

NC-3591 Acceptability

NC-3591.1 General.

The rules of this Subsubarticle constitute the requirements for the design acceptability of spring loaded pressure relief valves. The design rules for pilot operated and power actuated pressure relief valves are covered by NC-3500. The rules of this Subsubarticle cover the pressure retaining integrity of the valve inlet and outlet connections, nozzle, disk, body structure, bonnet (yoke), and body-to-bonnet (yoke) bolting. The rules of this Subsubarticle also cover other items such as the spring, spindle (stem), spring washers, and set pressure adjusting screw. The rules of this Subsubarticle do not apply to guides, control rings, bearings, set screws, and other nonpressure-retaining items. Figures NC-3591.1-1 and NC-3591.1-2 are illustrations of typical pressure relief valves.

NC-3591.2 Definitions.

The definitions for pressure relief valve terms used in this Subsubarticle are given in the American National Standard ANSI B95.1-1977, Terminology for Pressure Relief Devices, and also in NC-7000. Pressure relief valves characteristically have multipressure zones within the valve, that is, a primary

Page 153

pressure zone and a secondary pressure zone as illustrated by Figs. NC-3591.1-1 and NC-3591.1-2.

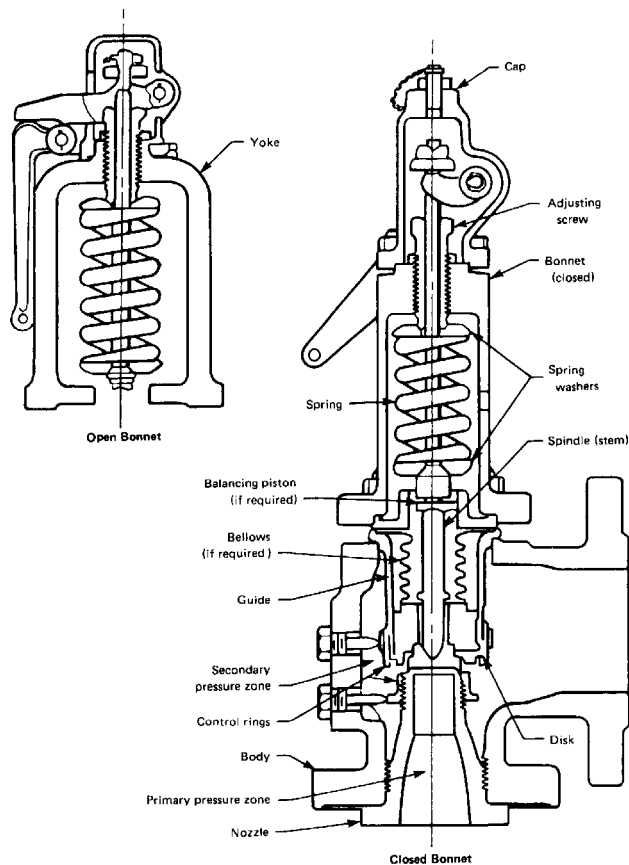


FIG. NC-3591.1-1 TYPICAL PRESSURE RELIEF DEVICES

FIG. NC-3591.1-1 TYPICAL PRESSURE RELIEF DEVICES

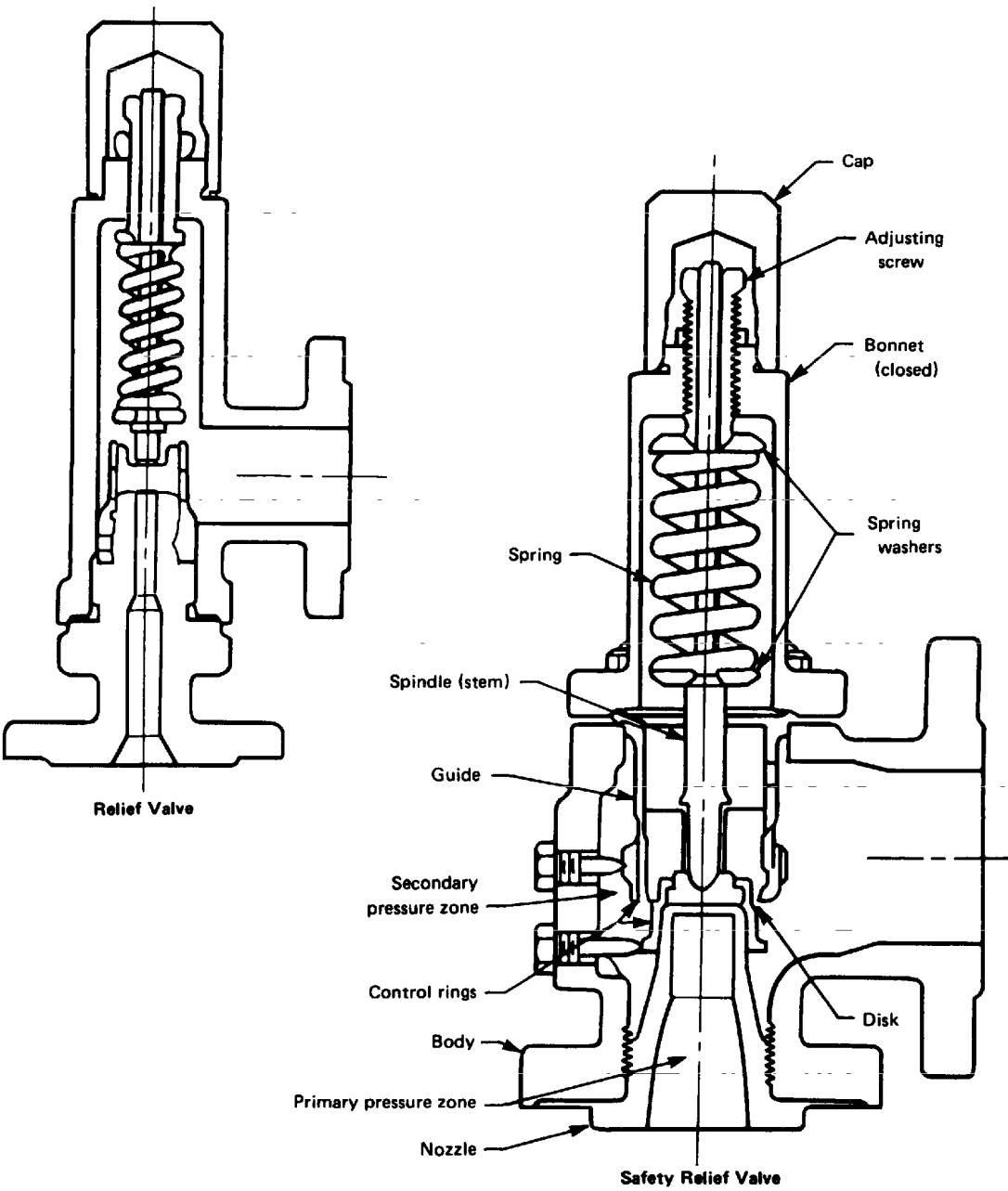


FIG. NC-3591.1-2 TYPICAL PRESSURE RELIEF DEVICES

FIG. NC-3591.1-2 TYPICAL PRESSURE RELIEF DEVICES

NC-3591.3 Acceptability of Small Pressure Relief Valves.

Pressure relief valves having inlet piping connections 2 in. NPS and under shall comply with the wall thickness requirements of NC-3595.1. Other elements of the valve shall be designed to ensure pressure integrity, in accordance with appropriate design practices based on successful experience in comparable service conditions.

NC-3591.4 Acceptability of Large Pressure Relief Valves.

The design shall be such that the requirements of this Subsubarticle are met.

NC-3592 Design Considerations

NC-3592.1 Design Conditions.

The general design requirements of NC-3100 are applicable, with consideration for the design conditions of the primary and secondary pressure zones. In case of conflict between NC-3100 and NC-3590, the requirements of NC-3590 shall apply. Mechanical loads for both the closed and open (full discharge) positions shall be considered in conjunction with the service conditions. In addition, the requirements of NC-7000 shall be met.

NC-3592.2 Stress Limits for Specified Service Loadings

(a) *Level A Service Loadings.* Stress limits for Level A service loadings for the valve shall be as follows.

- (1) The general membrane stress shall not exceed S .
- (2) The general membrane stress plus bending stress shall not exceed $1.5S$.
- (3) Substantiation by analysis of localized stresses associated with contact loading of bearing or seating surfaces is not required.
- (4) The values of S shall be in accordance with Tables 1A, 1B, and 3, Section II, Part D, Subpart 1.

(b) *Level B, C, and D Service Loadings.* Stress limits for Level B, C, and D service loadings are specified in Table NC-3592.2(b)-1. The symbols used in Table NC-3592.2(b)-1 are defined in NC-3522.

NC-3593 Special Rules

NC-3593.1 Hydrostatic Test.

Pressure relief valve shell hydrostatic tests shall be made in accordance with NC-3531.1 and NC-3531.3 except that the inlet (primary pressure containing) portion of the pressure relief valve shall be shell tested at a pressure at least equal to 1.5 times the set pressure marked on the valve. For closed system application, the outlet portion of the pressure relief valve shall be shell tested to 1.5 times the design secondary pressure (NC-7111).

**TABLE NC-3592.2(b)-1
CLASS 2 PRESSURE RELIEF DEVICES:
LEVEL B, C, AND D SERVICE LOADINGS**

Service Loadings	Stress Limits
Level B	$\sigma_m \leq 1.1S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65S$
Level C	$\sigma_m \leq 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$
Level D	$\sigma_m \leq 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$

GENERAL NOTES:

- (a) A casting quality factor is not required to satisfy these limits.
- (b) These requirements for the acceptability of valve design are not intended to ensure the functional adequacy of the valve. However, the designer is cautioned that the requirements of NC-7000 relative to set pressure, lift, blowdown, and closure shall be met.
- (c) Design requirements listed in this Table are applicable to those portions of the valves which are pressure retaining or affect pressure retaining items of these valves.

TABLE NC-3592.2(b)-1 CLASS 2 PRESSURE RELIEF DEVICES: LEVEL B, C, AND D SERVICE LOADINGS

NC-3593.2 Marking.

In addition to marking required by NCA-8220 and NC-7000, the secondary Design Pressure shall be marked on the valve or valve nameplate.

NC-3594 Design Requirements for Level B, C, and D Service Loadings

(a) When the piping system in which the valve is located is designed to the requirements of NC-3600, the valve body may be considered adequate to withstand piping end loads, provided that conditions (1) and (2) below are satisfied.

(1) The section modulus and metal area at a plane normal to the flow passage through the region at the valve inlet and outlet (Figs. NC-3591.1-1 and NC-3591.1-2) shall be not less than 110% of the section modulus and metal area of the piping connected (or joined) to the valve inlet and outlet.

(2) The allowable stress for valve body material shall be equal to or greater than the allowable stress of the connected piping material. If the valve body material allowable stress is less than that of the connected piping material, the valve section modulus and metal area shall be not less than 110% of the section modulus and metal area of the connecting pipe multiplied by the ratio $S_{\text{pipe}}/S_{\text{valve}}$.

(b) The pressure retaining portions of pressure relief valves shall conform to the stress limits listed in Table NC-3592.2(b)-1

Page 156

for those Service Loadings stipulated as level B, C, or D.

(c) Pressure relief valves have extended structures, and these structures are essential to maintaining pressure integrity. An analysis, when required by the Design Specification, shall be performed based on static forces resulting from equivalent earthquake accelerations acting at the centers of gravity of the extended masses. Classical bending and direct stress equations, where free body diagrams determine a simple stress distribution that is in equilibrium with the applied loads, may be used.

NC-3595 Design of Pressure Relief Valve Parts

NC-3595.1 Body.

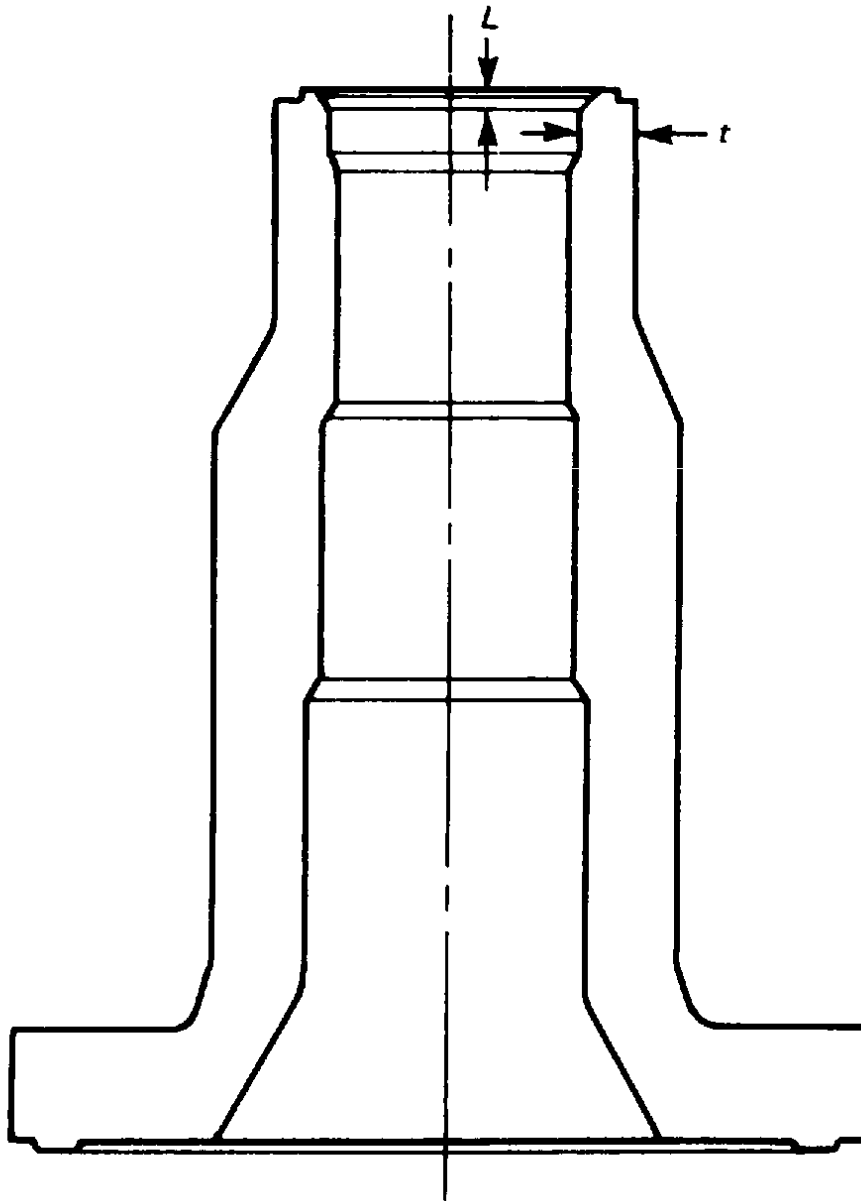
Minimum wall thicknesses of valve bodies shall conform to the applicable requirements for Standard Class category valves of ANSI B16.34, taking into account the dimensional and pressure conditions of the primary and secondary zones. Minimum wall thickness adjacent to the inlet nozzle and for a distance equal to that minimum wall thickness from the plane of the back face of the inlet flange shall be that required for Standard Class category valves of ANSI B16.34 for the inlet flange size and pressure class. Minimum wall thicknesses elsewhere in the secondary zone shall be determined by the requirements for Standard Class category valves of ANSI B16.34 for the outlet flange size and pressure class, including such other rules and considerations of ANSI B16.34 as may be applicable. In valve design where the outlet flange is an extension of the bonnet, the bonnet design shall conform to these rules. Where the inlet flange geometry involves inside contours encroaching on the metal section boundary represented by dimension B in Tables 9, 12, 15, 18, 21, 24, or 27 in ANSI B16.5, adequacy of the design shall be proven by stress calculation in accordance with NC-3658. Additional metal thickness needed for operating stresses, shapes other than circular, stress concentrations, and adequate structural strength of the crotch area of the neck of the valve for bending stresses and installation stress that may be imposed on the valve must be determined by the manufacturer.

NC-3595.2 Bonnet (Yoke).

The bonnet (yoke) may be analyzed using classic bending and direct stress formulae, with appropriate free body diagrams. The general membrane stress and the general membrane stress plus bending stress shall not exceed the stress limits of NC-3592.2.

NC-3595.3 Nozzle.

The minimum wall thickness of the nozzle shall be determined from the limit on general membrane stress. Alternatively, the rules of NB-3594.3 may be used. These requirements are not applicable to the transition region to the seat contacting area of the nozzle defined by L in Fig. NC-3595.3-1, provided the dimension L is less than the nominal wall thickness t .



t = nozzle wall thickness, in.
 L = length of seal transition region, in.
 $L \leq t$

FIG. NC-3595.3-1 VALVE NOZZLE

NC-3595.4 Body-to-Bonnet Joint.

For valves having inlet piping connections 2 in. nominal pipe size (DN 50) and less, body-to-bonnet connections may be threaded. The thread shear stress, considering all loadings, shall not exceed 0.6 times the allowable stress S . The body-to-bonnet bolting shall be designed to resist the hydrostatic end force of the rated maximum secondary Design Pressure combined with the total spring load to full lift, and to maintain sufficient compression for a tight joint on the gasket or joint contact surface. The bolt stresses for these loadings shall not exceed the allowable stress values of Table 3, Section II, Part D, Subpart 1.

NC-3595.5 Disk.

The stress evaluation shall be made for the condition which results in the maximum stress in the disk. The bending stress shall not exceed the stress limits of NC-3592.2.

NC-3595.6 Spring Washer.

The shear stress shall not exceed $0.6S$. The bending stress shall not exceed the stress limits of NC-3592.2.

NC-3595.7 Spindle (Stem).

The general membrane stress shall not exceed the stress limits of NC-3592.2.

NC-3595.8 Adjusting Screw.

The adjusting screw shall be analyzed for thread stress in accordance with the method of ANSI B1.1, and this stress shall not exceed $0.6S$. The general membrane stress of the adjusting screw shall not exceed the stress limits of NC-3592.2, based on the root diameter of the thread.

NC-3595.9 Spring.

The valve spring shall be designed so that the full lift spring compression shall be no greater than 80% of the nominal solid deflection. The permanent set of the spring (defined as the difference between the free height and the height measured a minimum of 10 min after the spring has been compressed solid three additional times after presetting at room temperature) shall not exceed 1.0% of the free height.

NC-3596 Design Reports

NC-3596.1 General Requirements.

The manufacturer shall certify compliance with the requirements of this Subsubarticle in accordance with the provisions of NCA-3570.

NC-3600 PIPING DESIGN

NC-3610 GENERAL REQUIREMENTS

NC-3611 Acceptability

The requirements for acceptability of a piping system are given in the following subparagraphs.

NC-3611.1 Allowable Stress Values.

Allowable stress values to be used for the design of piping systems are given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

NC-3611.2 Stress Limits

(a) *Design and Service.* Loadings shall be specified in the Design Specification.

(b) *Design Loadings.* The sum of stresses due to design internal pressure, weight, and other sustained loads shall meet the requirements of Eq. (8), NC-3652.

**TABLE NC-3611.2(e)-1
STRESS RANGE REDUCTION FACTORS**

Number of Equivalent Full Temperature Cycles <i>N</i>	<i>f</i>
7,000 and less	1.0
7,000 to 14,000	0.9
14,000 to 22,00	0.8
22,000 to 45,000	0.7
45,000 to 100,000	0.6
100,000 and over	0.5

TABLE NC-3611.2(e)-1 STRESS RANGE REDUCTION FACTORS

(c) *Service Loadings.* The following service limits shall apply to Service Loadings as designated in the Design Specifications.

(1) *Level A and B Service Limits.* For Service Loadings for which Level A and B Service Limits are designated in the Design Specification, the requirements of NC-3653 shall be met. When Level B Limits apply, the peak pressure $P_{\max}$ alone shall not exceed 1.1 times the pressure P_a calculated in accordance with Eq. (5), NC-3641.1.

(2) *Level C Service Limits.* For Service Loadings for which Level C Service Limits are designated in the Design Specification, the sum of stresses shall meet the requirements of NC-3654.

(3) *Level D Service Limits.* For Service Loadings for which Level D Service Limits are designated in the Design Specification, the sum of stresses shall meet the requirements of NC-3655.

(4) *Test Conditions.* Testing shall be in accordance with NC-6000. Occasional loads shall not be considered as acting at time of test.

(d) *External Pressure Stress.* Piping subject to external pressure shall meet the requirements of NC-3641.2.

(e) *Allowable Stress Range for Expansion Stresses.* The allowable stress range S_A is given by Eq. (1):

$$(1) S_A = f(1.25S_c + 0.25S_h)$$

where

S_c	= basic material allowable stress at minimum (cold) temperature, psi
S_h	= basic material allowable stress at maximum (hot) temperature, psi
f	= stress range reduction factor for cyclic conditions for total number N of full temperature cycles over total number of years during which system is expected to be in service from Table NC-3611.2(e)-1

Page 158

(1) In determining the basic material allowable stresses S_c and S_h , joint efficiencies need not be applied.

(2) Stress reduction factors apply essentially to noncorrosive service and to corrosion resistant materials, where employed to minimize the reduction in cyclic life caused by corrosive action.

(3) If the range of temperature change varies, equivalent full temperature cycles may be computed as follows:

$$(2) N = N_E + r_1^5 N_1 + r_2^5 N_2 + \dots + r_n^5 N_n$$

where

N_E	= number of cycles at full temperature change ΔT_E for which expansion stress S_E has been calculated
$N_1, N_2, \dots, N_n$	= number of cycles at lesser temperature changes, $\Delta T_1, \Delta T_2, \dots, \Delta T_n$
$r_1, r_2, \dots, r_n$	= $(\Delta T_1)/(\Delta T_E), (\Delta T_2)/(\Delta T_E), \dots, (\Delta T_n)/(\Delta T_E)$ = the ratio of any lesser temperature cycles for which the expansion stress S_E has been calculated

(f) *Allowable Stress for Nonrepeated Stresses.* The allowable stress due to any single nonrepeated anchor movement (e.g., predicted building settlement) calculated in accordance with Eq. (10a) of NC-3653.2(b) shall be $3.0S_c$.

NC-3612 Pressure-Temperature Ratings for Piping Products

NC-3612.1 Piping Products Having Specific Ratings

(a) Pressure-temperature ratings for certain piping products have been established and are contained in some of the standards listed in Table NC-3132-1. The pressure ratings at the corresponding temperatures given in the standards listed in Table NC-3132-1 shall not be exceeded, and piping products shall not be used at temperatures in excess of those given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1 for the materials of which the products are made.

(b) Where piping products have established pressure-temperature ratings which do not extend to the upper material temperature limits permitted by this Subsection, the pressure-temperature ratings between those established and the upper material temperature limit may be determined in accordance with the rules of this Subsection.

NC-3612.2 Piping Products Not Having Specific Ratings.

Should it be desired to use methods of manufacture or design of piping products not now covered by this Subsection, it is intended that the manufacturer shall comply with the requirements of NC-3640 and NC-3690 and other applicable requirements of this Subsection for the Design Loadings involved. The manufacturer's recommended pressure ratings shall not be exceeded.

NC-3612.4 Considerations for Local Conditions and Transients

(a) Where piping systems operating at different pressures are connected by a valve or valves, the valve or valves shall be designed for the higher pressure system requirements of pressure and temperature. The lower pressure system shall be designed in accordance with (1), (2), or (3) below.

(1) The requirement of the higher pressure system shall be met.

(2) Pressure relief devices or safety valves shall be included to protect the lower pressure system in accordance with NC-7311 and NC-7321.

(3) Assure compliance with all the conditions of (a) through (e) below.

(a) Redundant check or remote actuated valves shall be used in series at the interconnection, or a check in series with a remote actuated valve.

(b) When mechanical or electrical controls are provided, redundant and diverse controls shall be installed which will prevent the interconnecting valves from opening when the pressure in the high pressure system exceeds the Design Pressure of the low pressure system.

(c) Means shall be provided such that operability of all components, controls, and interlocks can be verified by test.

(d) Means shall be provided to assure that the leakage rate of the interconnecting valves does not exceed the relieving capacity of the relief devices on the low pressure system.

(e) Adequate consideration shall be given to the control of fluid pressure caused by heating of the fluid trapped between two valves.

The low pressure system relieving capacity may be determined in accordance with NC-7311 and NC-7321, on the basis of the interconnecting valve being closed but leaking at a specified rate, when (a) through (e) above are met. The pressure relief devices or safety valves shall adjoin or be as close as possible to the interconnecting valve and shall relieve preferably to a system where the relieved effluent may be contained. The design of the overpressure protection system shall be based on pressure transients that are specified in

Page 159

the Design Specification, and all other applicable requirements of NC-7000 shall be met.

(b) When pressure reducing valves are used and one or more pressure relief devices or safety valves are provided, bypass valves may be provided around the pressure reducing valves. The combined relieving capacity of the pressure relief devices, safety valves, and relief piping shall be such that the lower pressure system service pressure will not exceed the lower pressure system Design Pressure by more than 10% if the pressure reducing valve fails in the open position and the bypass valve is open at the same time. If the pressure reducing valve and its bypass valve are mechanically or electrically interlocked so that only one may be open at any time, the high pressure system is at a pressure higher than the Design Pressure of the low pressure system, the relieving capacity of the pressure relief devices, safety valves, and relief piping shall be at least equal to the maximum capacity of the larger of the two valves. The interlocks shall be redundant and diverse.

(c) Exhaust and pump suction lines for any service and pressure shall have relief valves of a suitable size, unless the lines and attached equipment are designed for the maximum pressure and temperature to which they may be accidentally or otherwise subjected.

(d) The effluent from relief devices may be discharged outside the containment only if provisions are made for the disposal of the effluent.

(e) Drip lines from steam headers, mains, separators, or other equipment operating at different pressures shall not discharge through the same trap. Where several traps discharge into a single header that is or may be under pressure, a stop valve and a check valve shall be provided in the discharge line from each trap. The Design Pressure of trap discharge piping shall not be less than the maximum discharge pressure to which it may be subjected. Trap discharge piping shall be designed for the same pressure as the trap inlet piping, unless the discharge piping is vented to a system operated under lower pressure and has no intervening stop valves.

(f) Blowdown, dump, and drain piping from water spaces of a steam generation system shall be designed for saturated steam at the pressures and temperatures given below.

Vessel Pressure, psi	Design Pressure, psi	Design Temperature, °F
600 and below	250	410
601 to 900	400	450
901 to 1500	600	490
1501 and above	900	535

These requirements for blowdown, dump, and drain piping apply to the entire system beyond the blowdown valves to the blowdown tank or other points where the pressure is reduced to approximately atmospheric and cannot be increased by closing a valve. When pressures can be increased because of calculated pressure drop or otherwise, this shall be taken into account in the design. Such piping shall be designed for the maximum pressure to which it may be subjected.

(g) Pump discharge piping shall be designed for the maximum pressure exerted by the pump at any load and for the highest corresponding temperature actually existing.

(h) Where a fluid passes through heat exchangers in series, the Design Temperature of the piping in each section of the system shall conform to the most severe temperature condition expected to be produced by heat exchangers in that section.

NC-3613 Allowances

NC-3613.1 Corrosion or Erosion.

When corrosion or erosion is expected, the wall thickness of the piping shall be increased over that required by other design requirements. This allowance shall be consistent with the specified design life of the piping.

NC-3613.2 Threading and Grooving.

The calculated minimum thickness of piping that is to be threaded or grooved shall be increased by an allowance equal to the depth of the cut.

NC-3613.3 Mechanical Strength.

When necessary to prevent damage, collapse, or buckling of pipe due to superimposed loads from supports or other causes, the wall thickness of the pipe shall be increased, or, if this is impractical or would cause excessive local stresses, the superimposed loads or other causes shall be reduced or eliminated by other design methods.

NC-3613.4 Steel Casting Quality Factors.

The quality factors for castings required in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1 apply to castings which are designed using the stresses contained in this Subsection. The minimum examination required for these castings is that stipulated in the applicable material specification and in NC-2570. Castings satisfying these minimum requirements shall be designed with a quality factor of 1.00.

Page 160

NC-3620 DESIGN CONSIDERATIONS

NC-3621 Design and Service Loadings

The provisions of NC-3110 shall apply, except as modified in this Subarticle.

NC-3621.1 Cooling Effects on Pressure.

When the cooling of a fluid may reduce the pressure in the piping to below atmospheric, the piping shall be designed to withstand the external pressure or provision shall be made to break the vacuum.

NC-3621.2 Fluid Expansion Effects.

When the expansion of a fluid may increase the pressure, the piping system shall be designed to withstand the increased pressure or provision shall be made to relieve the excess pressure.

NC-3622 Dynamic Effects

NC-3622.1 Impact.

Impact forces caused by either external or internal loads shall be considered in the piping design.

NC-3622.2 Reversing Dynamic Loads.

Reversing dynamic loads are those loads which cycle about a mean value and include building filtered loads, earthquake, and the reflected waves in a piping system due to flow transients resulting from sudden opening or closure of valves (see Fig. NC-3622-1). A reversing dynamic load shall be treated as a nonreversing dynamic load in applying the rules of NC-3600 when either of the following conditions exist:

(a) The frequency ratio of the dynamic dominant load driving frequency to the lowest piping system natural frequency is less than 0.5.

(b) The number of reversing dynamic load cycles, exclusive of earthquake, exceed 20.

NC-3622.3 Vibration.

Piping shall be arranged and supported so that vibration will be minimized. The designer shall be responsible, by design and by observation under startup or initial service conditions, for ensuring that vibration of piping systems is within acceptable levels.

NC-3622.4 Exposed Piping.

Exposed piping shall be designed to withstand wind loadings, using meteorological data to determine wind forces. When State, Province, or Municipal ordinances covering the design of building structures are in effect and specify wind loadings, these values shall be considered the minimum design values. However, it is not necessary to consider earthquake and wind loadings to be acting concurrently.

NC-3622.5 Nonreversing Dynamic Loads.

Nonreversing dynamic loads are those loads which do not cycle about a mean value and include the initial thrust force due to sudden opening or closure of valves and waterhammer resulting from entrapped water in two-phase flow systems (see Fig. NC-3622-1).

NC-3623 Weight Effects

Piping systems shall be supported to provide for the effects of live and dead weights, as defined in the following subparagraphs, and they shall be arranged or properly restrained to prevent undue strains on equipment.

NC-3623.1 Live Weight.

The live weight shall consist of the weight of the fluid being handled or of the fluid used for testing or cleaning, whichever is greater.

NC-3623.2 Dead Weight.

The dead weight shall consist of the weight of the piping, insulation, and other loads permanently imposed upon the

piping.

NC-3624 Thermal Expansion and Contraction Loads

NC-3624.1 General Requirements

(a) The design of piping systems shall take account of the forces and moments resulting from thermal expansion and contraction and from the effects of expansion joints.

(b) Thermal expansion and contraction shall be provided for, preferably by pipe bends, elbows, offsets, or changes in direction of the pipeline.

(c) Hangers and supports shall permit expansion and contraction of the piping between anchors.

NC-3624.2 Expansion Joints.

Expansion joints of the corrugated slip sleeve, ball, or swivel types may be used if they conform to the requirements of NC-3649.1 through NC-3649.7; their structural and working parts are designed for the maximum pressure and temperature of the piping system; and their design prevents the complete disengagement of working parts while in service.

NC-3640 PRESSURE DESIGN OF PIPING PRODUCTS

NC-3641 Straight Pipe

[98]

NC-3641.1 Straight Pipe Under Internal Pressure.

The minimum thickness of pipe wall required for Design Pressures and for temperatures not exceeding those for

Page 161

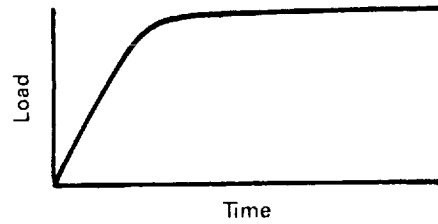
Page 162

the various materials listed in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1, including allowances for mechanical strength, shall not be less than that determined by Eq. (3) as follows:

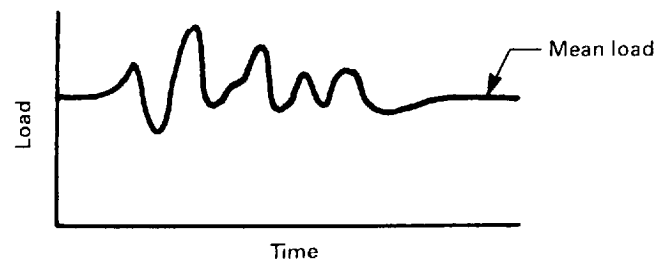
$$t_m = \frac{PD_o}{2(S + Py)} + A \quad (3)$$

$$t_m = \frac{Pd + 2SA + 2yPA}{2(S + Py - P)} \quad (4)$$

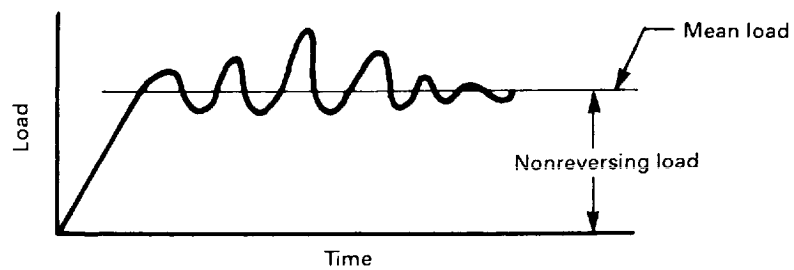
(3 - 4)



**(a) Nonreversing Dynamic Load
(Relief/Safety Valve Open End Discharge)**



**(b) Reversing Dynamic Load
(Earthquake Load Cycling About Normal Operating Condition)**



**(c) Nonreversing Followed By Reversing
(Initial Water Slug Followed By Reflected Pressure Pulses)**

FIG. NC-3622-1 EXAMPLES OF REVERSING AND NONREVERSING DYNAMIC LOADS

FIG. NC-3622-1 EXAMPLES OF REVERSING AND NONREVERSING DYNAMIC LOADS

where

t_m	= minimum required wall thickness, in. If pipe is ordered by its nominal wall thickness, the manufacturing tolerance on wall thickness must be taken into account. After the minimum pipe wall thickness t_m is determined by Eq. (4), this minimum thickness shall be increased by an amount sufficient to provide the manufacturing tolerance allowed in the applicable pipe specification or required by the process. The next heavier commercial wall thickness shall then be selected from standard thickness schedules such as contained in ANSI B36.10 or from manufacturers' schedules for other than standard thickness.
P	= internal Design Pressure, psi
D_o	= outside diameter of pipe, in. For design calculations, the outside diameter of pipe as given in tables of standards and specifications shall be used in obtaining the value of t_m . When calculating the allowable pressure of pipe on hand or in stock, the actual measured outside diameter and actual measured minimum wall thickness at the thinner end of the pipe may be used to calculate this pressure.
d	= inside diameter of pipe, in. In using Eq. (4) the value of d is for the maximum possible inside diameter allowable under the purchase specifications.
S	= maximum allowable stress for the material at the Design Temperature, psi (Section II, Part D, Subpart 1, Tables 1A and 1B)
A	= an additional thickness to provide for material removed in threading, corrosion or erosion allowance, and material required for structural strength of the pipe during erection, as appropriate, in.

The allowable working pressure of pipe may be determined from the following equation:

$$P_a = \frac{2St}{D_o - 2yt} \quad (5)$$

(5)

**TABLE NC-3641.1(a)-1
VALUES OF A**

Type of Pipe	A , in.
Threaded steel & nonferrous pipe:	
$\frac{3}{4}$ in. nominal & smaller	0.065
1 in. nominal & larger	Depth of Thread
Grooved steel & nonferrous pipe	Depth of Groove
	plus $\frac{1}{64}$ in.

TABLE NC-3641.1(a)-1 VALUES OF A

where

t

= the specified or actual wall thickness minus, as appropriate, material removed in threading, corrosion or erosion allowance, material manufacturing tolerances, bending allowance (NC-3642.1), and material to be removed by counterboring, in.

P_a

= the calculated maximum allowable internal pressure, psi, for straight pipe which shall at least equal the Design Pressure. P_a may be used for piping products with pressure ratings equal to that of straight pipe (see ANSI B16.9). For standard flanged joints, the rated pressure shall be used instead of P_a . For other piping products where the pressure rating may be less than that of the pipe [for example, flanged joints designed to Appendix XI and reinforced branch connections (NC-3643) where part of the required reinforcement is in the run pipe], the Design Pressure shall be used instead of P_a . P_a may be rounded out to the next higher unit of 10.

y

= a coefficient having a value of 0.4, except that, for pipe with a D_o/t_m ratio less than 6, the value of y shall be taken as

$$y = \frac{d}{d + D_o} \quad (6)$$

(6)

(a) To compensate for material removed or wall thinning due to threading, or grooving, required to make a mechanical joint. The values of A listed in Table NC-3641.1(a)-1 are minimum values for material removed in threading.

(b) To provide for mechanical strength of the pipe. Small diameter, thin wall pipe or tubing is susceptible to mechanical damage due to erection, operation, and maintenance procedures. Accordingly, appropriate means must be employed to protect such piping against

Page 163

these types of loads if they are not considered as Design Loads. Increased wall thickness is one way of contributing to resistance against mechanical damage.

**TABLE NC-3642.1(c)-1
MINIMUM THICKNESS FOR BENDING**

Radius of Bends	Minimum Thickness Recommended Prior to Bending [Note (1)]
6 pipe diameters or greater	$1.06t_m$
5 pipe diameters	$1.08t_m$
4 pipe diameters	$1.16t_m$
3 pipe diameters	$1.25t_m$

NOTE:

(1) t_m is determined by Eq. (3) or (4) of NC-3641.1.

TABLE NC-3642.1(c)-1 MINIMUM THICKNESS FOR BENDING

(c) To provide for corrosion or erosion. Since corrosion and erosion vary widely from installation to installation, it is the responsibility of designers to determine the proper amounts which must be added for either or both of these conditions.

[98]

NC-3641.2 Straight Pipe Under External Pressure.

For determining wall thickness and stiffening requirements for straight pipe under external pressure, the procedures outlined in NC-3133 shall be followed.

NC-3642 Curved Segments of Pipe

NC-3642.1 Pipe Bends.

Pipe bends shall be subject to the limitations in (a), (b), and (c) below.

(a) The minimum wall thickness after bending shall not be less than the minimum wall thickness required for straight pipe.

(b) The ovality shall meet the requirements of NC-4223.2.

(c) The information in Table NC-3642.1(c)-1 is given to guide the designer when ordering pipe.²³

NC-3642.2 Elbows.

Flanged elbows manufactured in accordance with the standards listed in Table NC-3132-1 shall be considered suitable for use at the pressure-temperature ratings specified by such standards. In the case of standards under which butt welding elbows are made to a nominal wall thickness, the elbows shall be considered suitable for use with pipe of the same nominal thickness and of the same material.

²³ The minimum thicknesses of straight pipe shown in Table NC-3642.1(c)-1 should be sufficient to allow the pipe to meet the minimum wall thickness requirements of NC-3641 after having been bent on the radii shown.

NC-3643 Intersections

[98]

NC-3643.1 General Requirements

(a) NC-3643 gives acceptable rules governing the design of branch connections to sustain internal and external pressure in cases where the axes of the branch and the run intersect, the angle between the axes of the branch and of the run is between 45 deg. and 90 deg., inclusive, and no allowance is required for corrosion or erosion.

(b) Branch connections in which the smaller angle between the axes of the branch and the run is less than 45 deg. impose special design and fabrication problems. The rules given for angles of 45 deg. and 90 deg., inclusive, may be used as a guide, but sufficient additional strength must be provided to assure safe service. Such branch connections shall be designed to meet the requirements of NC-3649.

(c) Branch connections in piping may be made by using one of the products or methods given in (1) through (4) below:

(1) flanged, butt welding, socket welding, or screwed fittings made in accordance with the applicable standards listed in Table NC-3132-1;

(2) welded outlet fittings, such as cast or forged nozzles; couplings, including ANSI B16.11 couplings, to a maximum nominal size of 3 in. (DN 80); and adaptors or similar items having butt welding, socket welding, threaded, or flanged ends for attachment of the branch pipe. Such outlet fittings shall be attached to the main pipe:

(a) by a full penetration weld; or

(b) for right angle branch connections, by a fillet weld or partial penetration weld as shown in Figs. NC-3643.2(b)-2 (e) or (f), provided the requirements of (1) through (4) below are met:

(1) the nominal size of the branch shall not exceed 2 in. or one-quarter of the nominal size of the run, whichever is less;

(2) the minimum size of the weld, $x_{\min}$, shall not be less than $1\frac{1}{4}$ times the fitting wall thickness in the reinforcement zone;

(3) the groove angle, θ , shall be equal to or greater than 45 deg.;

(4) except for attaching ANSI B16.11 couplings, the requirements of NC-3643.3 shall be met.

(3) extruded outlets at right angles to the run pipe, in accordance with NC-3643.4, where the attachment of the branch pipe is by butt welding;

(4) by attaching the branch pipe directly to the run pipe by welding or threading as stipulated in (a), (b), or (c) below:

Page 164

(a) right angle branch connections may be made by attaching the branch pipe to the run pipe by socket welding, provided the requirements of (1) through (5) below are met:

(1) the nominal size of branch does not exceed 2 in. or one-quarter the nominal size of the run, whichever is less;

(2) the depth of the socket in the run is at least equal to that shown in ANSI B16.11 with a minimum shoulder of $\frac{1}{16}$ in. (1.6 mm) between the bottom of the socket and the inside diameter of the run pipe; weld metal may be deposited on the run pipe to provide the required socket depth and to provide any reinforcement required;

(3) a minimum of $\frac{1}{16}$ in. (1.6 mm) clearance shall be provided between the bottom of the socket and the end of the inserted pipe;

(4) the size of the fillet weld shall not be less than $1\frac{1}{4}$ times the nominal branch wall thickness;

(5) the requirements of NC-3643.3 shall be met.

(b) right angle branch connections may be made by attaching the branch pipe directly to the run by threading within the provisions of NC-3671.3 and provided the requirements of (1) and (2) below are met:

(1) the nominal size of the branch does not exceed 2 in. or one-quarter of the nominal size of the run, whichever is less;

(2) minimum thread engagement shall be six full threads for $\frac{1}{2}$ in. (DN 15) and $\frac{3}{4}$ in. (DN 20) branches; seven for 1 in. (DN 25), $1\frac{1}{4}$ in. (DN 32), and $1\frac{1}{2}$ in. (DN 40) branches; and eight for 2 in. (DN 50) branches; weld metal may be deposited on the run pipe to provide sufficient thickness for required thread engagement;

(5) branch connections may be made by attaching the branch pipe directly to the run pipe:

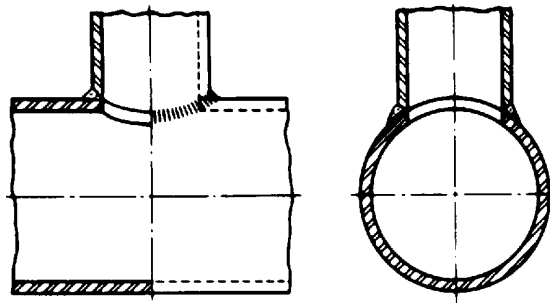
(a) by a full penetration weld as shown in Fig. NC-3643.2(b)-1, with or without pad or saddle reinforcement as shown in Fig. NC-3643.3(c)(1)-1 or Fig. NC-3643.3(c)(1)-2, provided the requirements of NC-3643.3 are met; or

(b) for right angle branch connections, by a fillet weld or partial penetration weld as shown in Fig. NC-3643.2(b)-2, sketches (a) through (d), provided the requirements of (1) through (4) below are met:

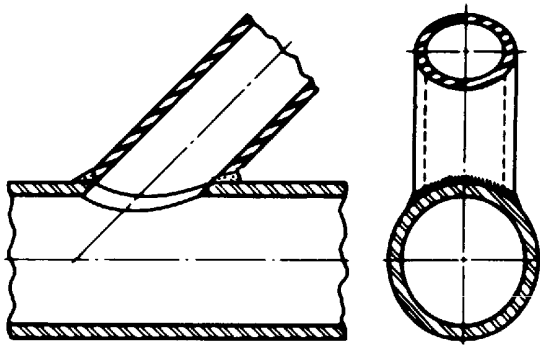
(1) the nominal size of the branch shall not exceed 2 in. (DN 50) or one-quarter of the nominal size of the run, whichever is less;

(2) the minimum size of the weld, $x_{\min}$, shall not be less than $1\frac{1}{4}$ times the nominal branch wall thickness;

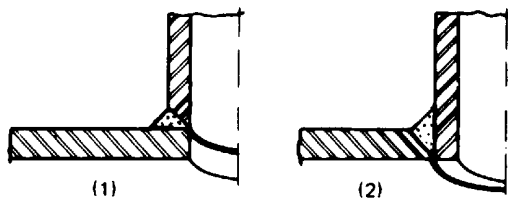
Page 165



(a) Typical Welded Branch Connection Without Additional Reinforcement



(b) Typical Welded Angular Branch Connection Without Additional Reinforcement



(c)

FIG. NC-3643.2(b)-1 TYPICAL WELDED BRANCH CONNECTIONS

FIG. NC-3643.2(b)-1 TYPICAL WELDED BRANCH CONNECTIONS

(3) the groove angle, θ , shall be equal to or greater than 45 deg.;

(4) the requirements of NC-3643.3 shall be met.

[98]

[98]

NC-3643.2 Branch Connections Not Requiring Reinforcement.

Reinforcement need not be provided if the branch connection is made in accordance with the requirements of (a) through (c) below:

(a) by the use of a fitting manufactured in accordance with one of the standards listed in Table NC-3132-1 and used within the limits of pressure-temperature ratings specified in such standard, a butt welding fitting made in accordance with ANSI B16.9 shall be of nominal thickness not less than the nominal thickness required for the adjoining pipe;

(b) by welding a coupling or half coupling directly to the run pipe, provided the nominal diameter of the branch does not exceed 2 in. pipe size (DN 50) or one-quarter the nominal diameter of the run, whichever is less; the wall thickness of the coupling is not less than that of the branch pipe; the coupling is joined to the run pipe by one of the methods shown in Fig. NC-3643.2(b)-1, sketch (c)(1) or Fig. NC-3643.2(b)-2, sketch (e); and in no case is the thickness of the coupling less than extra heavy or 3000 lb nominal rating;

(c) by using an extruded outlet, provided the nominal diameter of the branch does not exceed 2 in. pipe size (DN 50) or one-quarter of the nominal diameter of the pipe, whichever is less, and the minimum wall thickness at the abutting end of the outlet is not less than required for the branch pipe wall.

[98]

NC-3643.3 Branch Connections Requiring Reinforcement

(a) Calculations shall be made to determine the adequacy of reinforcement in branch connections, except as exempted in NC-3643.2.

(b) A branch connection may be made by extruding an integrally reinforced outlet on the run pipe. The reinforcement requirements shall be in accordance with NC-3643.4.

(c) A branch connection may be made by welding a pipe or fitting directly to the run pipe with or without added reinforcement, provided the pipe or fitting, deposited weldment, and other reinforcing devices meet the requirements of this subparagraph. This subparagraph gives rules covering the design of branch connections to sustain internal pressure in cases where the angle between the axes of the branch and of the run ranges from 45 deg. to 90 deg. NC-3643.5 gives rules governing the design of connections to sustain external pressure.

(1) *Nomenclature.* Figures NC-3643.3(c)(1)-1 and NC-3643.3(c)(1)-2 illustrate the notations used in the pressure-temperature design conditions of branch connections, which are as follows:

α	= angle between axes of branch and run, deg.
b	= subscript referring to branch
D_o	= outside diameter of pipe, in.
d_1	= inside diameter of branch for right angle connections, in.; for connections at angles between 45 deg. and 90 deg., $d_1 = (D_{ob} - 2T_b)/\sin \alpha$
d_2	= half width of reinforcing zone, in. = the greater of d_1 or $T_b + T_h + (d_1/2)$ but in no case more than D_{ob}

h	= subscript referring to run or header
L	= height of reinforcement zone outside of run or reinforcement, in. = $2.5T_b$
t_e	= thickness of attached reinforcing pad or height of the largest 60 deg. right triangle supported by the run and branch outside diameter projected surfaces and lying completely within the area of integral reinforcement, in. [Fig. NC-3643.3(c)(1)-2]
T	= nominal, actual by measurement, or minimum wall thickness of pipe, in., permissible under purchase specification
t_m	= required minimum wall thickness, in., of pipe for pressure and temperature design conditions as determined by use of Eq. (3) or (4), NC-3641.1

(2) *Requirements.* A pipe having a branch connection is weakened by the opening that must be made in it, and unless the wall thickness of the pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide additional reinforcement. The amount of reinforcement required shall be determined in accordance with NC-3643.3(c)(3) through NC-3643.3(c)(7), NC-3643.4 or NC-3643.5.

(3) *Reinforcement Area.* The required reinforcement area in sq in. for branch connections shall be the quantity $1.07(t_{mh})(d_1)(2 - \sin \alpha)$.

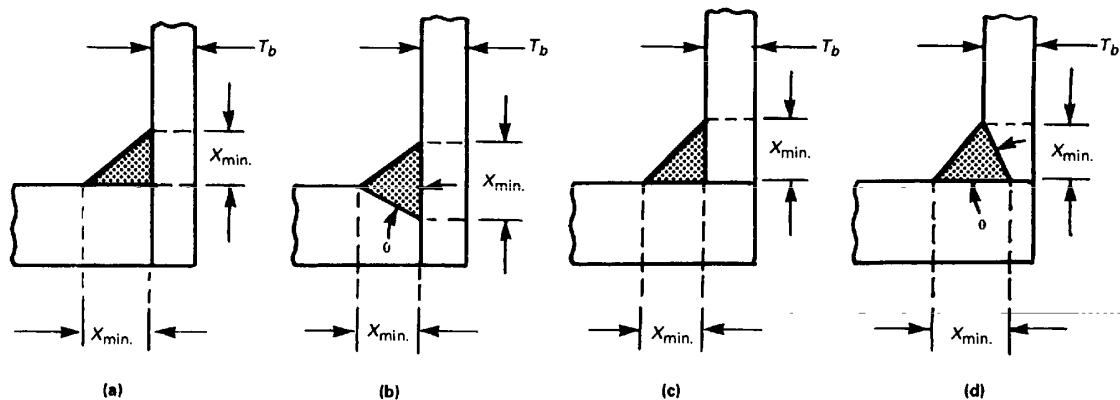
(a) For right angle connections, the required reinforcement becomes $1.07(t_{mh})(d_1)$.

(b) The required reinforcement must be within the limits of the reinforcement zone as defined in NC-3643.3(c)(5).

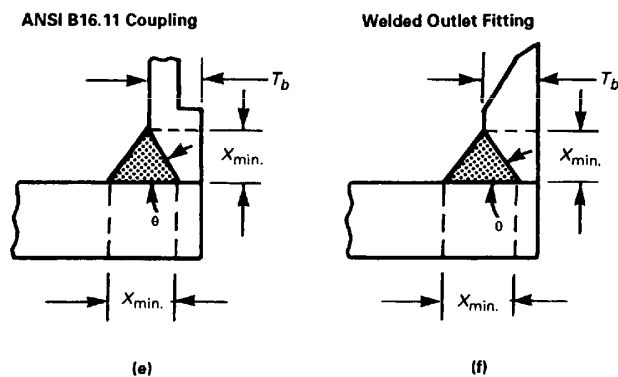
(4) *Area Contributing to Reinforcement.* Metal needed to meet reinforcement required by NC-3643.3(c) must be within the limits of the reinforcement zone determined in NC-3643.3(c)(5) and may include the following:

Page 166

Page 167



T_b = Nominal branch pipe wall thickness
 $X_{min.} = 1\frac{1}{4} T_b$
 θ = Partial penetration weld groove angle ≥ 45 deg.



T_b = Fitting wall thickness in the reinforcement zone
 (when the fitting is tapered in the reinforcement zone, use average wall thickness)
 $X_{min.} = 1\frac{1}{4} T_b$
 θ = Partial penetration weld groove angle ≥ 45 deg.

98

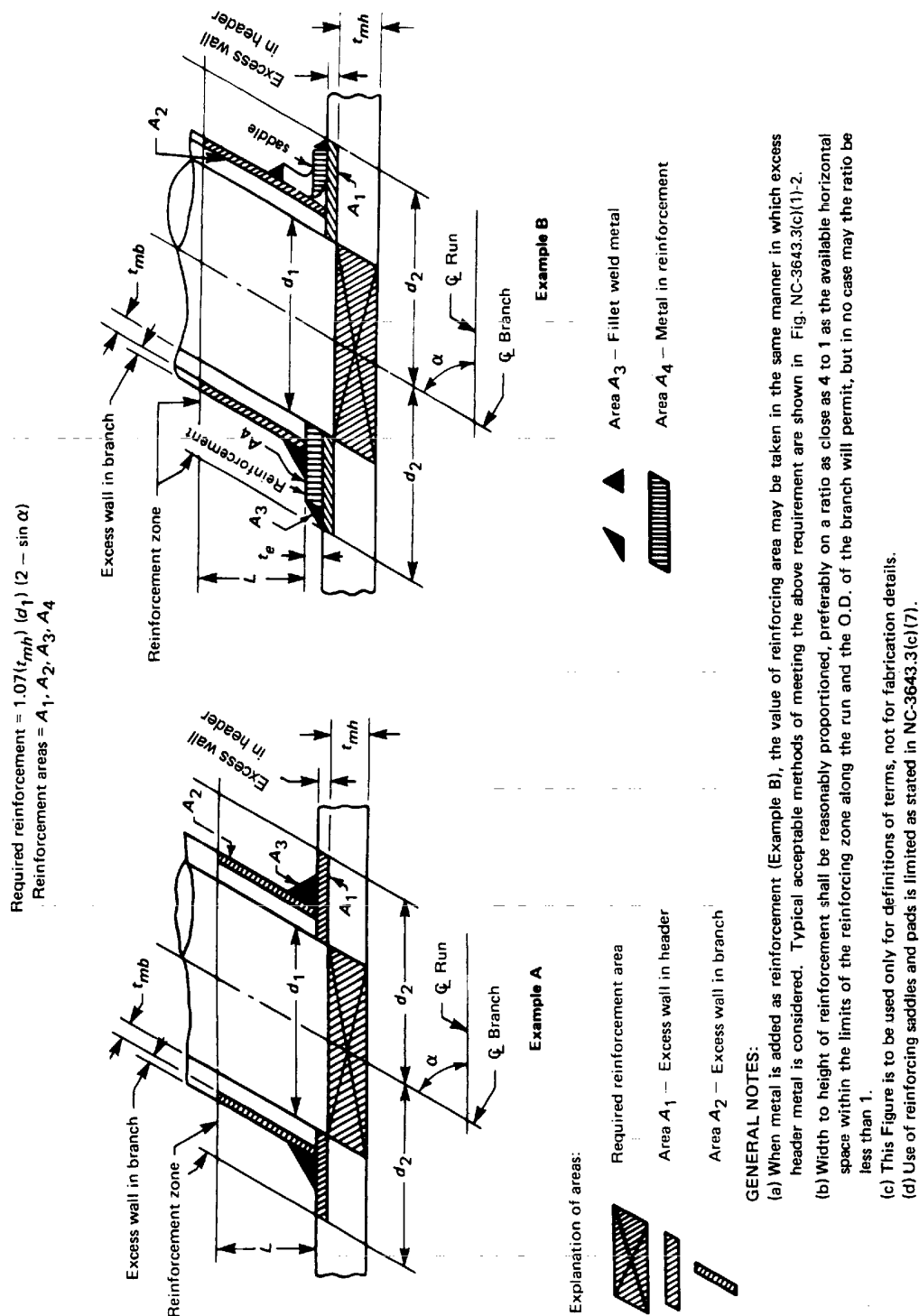
FIG. NC-3643.2(b)-2 TYPICAL RIGHT ANGLE BRANCH CONNECTIONS MADE USING A FILLET WELD OR A PARTIAL PENETRATION WELD

[98]

FIG. NC-3643.2(b)-2 TYPICAL RIGHT ANGLE BRANCH CONNECTIONS MADE USING A FILLET WELD OR A PARTIAL PENETRATION WELD

[98]

FIG. NC-3643.3(c)(1)-1 REINFORCEMENT OF BRANCH CONNECTIONS



A_1	= area provided by excess pipe wall in the run, sq in. $= (2d_2 - d_1) [(T_h - \text{mill tolerance on } T_h) - t_{mh}]$
A_2	= area provided by excess pipe wall in the branch for a distance L above the run, sq in. $= 2L/\sin \alpha [(T_b - \text{mill tolerance on } T_b) - t_{mb}]$. In areas A_1 and A_2 mill tolerance becomes zero when the minimum wall is specified instead of nominal wall.
A_3	= area provided by deposited weld metal beyond the outside diameter of the run and branch, sq in.
A_4	= area provided by reinforcement, sq in.

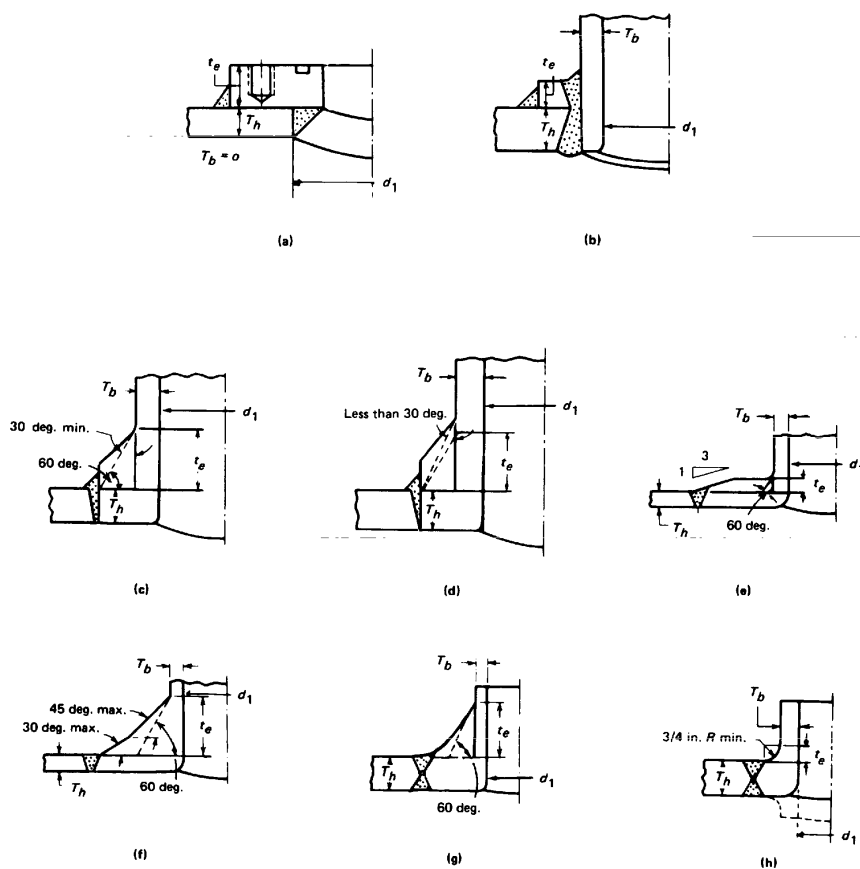


FIG. NC-3643.3(c)(1)-2 SOME REPRESENTATIVE CONFIGURATIONS DESCRIBING THE k_r REINFORCEMENT DIMENSIONS

FIG. NC-3643.3(c)(1)-2 SOME REPRESENTATIVE CONFIGURATIONS DESCRIBING THE t_e
REINFORCEMENT DIMENSIONS

When reinforcement area is composed of material with lower allowable stress than that of the run pipe, such reinforcement areas shall be increased by the inverse ratio of allowable stresses. No adjustment shall be made in reinforcement area for use of materials that have higher allowable stresses than the materials of the run pipe. Such reinforcement areas shall be decreased by the ratio of allowable stresses prior to any combination of areas to meet the reinforcement requirements of NC-3643.3(c).

(5) *Reinforcement Zone.* The reinforcement zone is a parallelogram, the length of which shall extend a distance d_2 on each side of the center line of the branch pipe and the width of which shall start at the inside surface of the run pipe and extend to a distance $(L + t_e)$ or $2.5T_p$ whichever is less, from the outside surface of the run pipe, when measured in the plane of the branch connection.

(6) *Reinforcement of Multiple Openings*

(a) When any two or more adjacent openings are so closely spaced that their reinforcement zones overlap, the two or more openings shall be reinforced in accordance with NC-3643.3(c)(3) with a combined reinforcement that has a strength equal to the combined strength of the reinforcement which would be required for the separate openings. No portion of the cross section shall be considered as applying to more than one opening or be evaluated more than once in a combined area.

(b) When more than two adjacent openings are to be provided with a combined reinforcement, the minimum distance between centers of any two of these openings should preferably be at least $1\frac{1}{2}$ times their average diameter and the area of reinforcement between them shall be at least equal to 50% of the total required for these two openings.

(7) *Rings, Pads, and Saddles*

(a) Reinforcement provided in the form of rings, pads, or saddles shall not be appreciably narrower at the side than at the crotch.

(b) A vent hole shall be provided at the ring, pad, or saddle to provide venting during welding and heat treatment.

(c) Rings, pads, or saddles may be made in more than one piece, provided the joints between pieces have full thickness welds and each piece is provided with a vent hole.

(d) Where saddles or pads are being employed for reinforcement, the potential for increased strain at the attachment welds which may occur as a result of rapid changes in differential metal temperatures between the saddle or pad, and the run should be considered in the design evaluation.

NC-3643.4 Special Requirements for Extruded Outlets.

The definitions, limitations, nomenclature, and requirements of (a) through (h) below are specifically applicable to extruded outlets.

(a) *Definition.* An extruded outlet header is a header in which the extruded lip at the outlet has a height above the surface of the run which is equal to or greater than the radius of the curvature of the external contoured portion of the outlet, $h_o \geq r_o$ [Fig. NC-3643.4(a)-1].

(b) *Cases to Which Rules Are Applicable.* These rules apply only to cases where the axis of the outlet intersects and is perpendicular to the axis of the run.

(c) *Nomenclature.* The notation used herein is illustrated in Fig. NC-3643.4(a)-1. All dimensions are in inches.

d	= outside diameter of branch pipe, in.
d_c	= corroded internal diameter of branch pipe, in.
D	= outside diameter of run, in.

D_c	= corroded internal diameter of run, in.
D_o	= corroded internal diameter of extruded outlet measured at the level of the outside surface of the run, in.
h_o	= height of the extruded lip, in.; this must be equal to or greater than r_o except as permitted in NC-3643.4(d)(4)
L	= height of reinforcement zone, in. $= 0.7\sqrt{dT_o}$
t_b	= required thickness of branch pipe according to wall thickness Eq. (3) or (5), NC-3641.1, but not including any thickness for corrosion, in.
T_b	= actual thickness of branch wall not including corrosion allowance, in.
t_r	= required thickness of the run according to Eq. (3) or (5), NC-3641.1, but not including any allowance for corrosion, in.
T_r	= actual thickness of run wall, not including the corrosion allowance, in.
T_o	= corroded finished thickness of extruded outlet measured at a height equal to r_o above the outside surface of the run, in.

Page 170

Page 171

r_1	= half width of reinforcement zone, in. $= D_o$
r_o	= radius of curvature of external contoured portion of outlet measured in the place containing the axes of the run and branch, in.; this is subject to the limitations given in (d) below

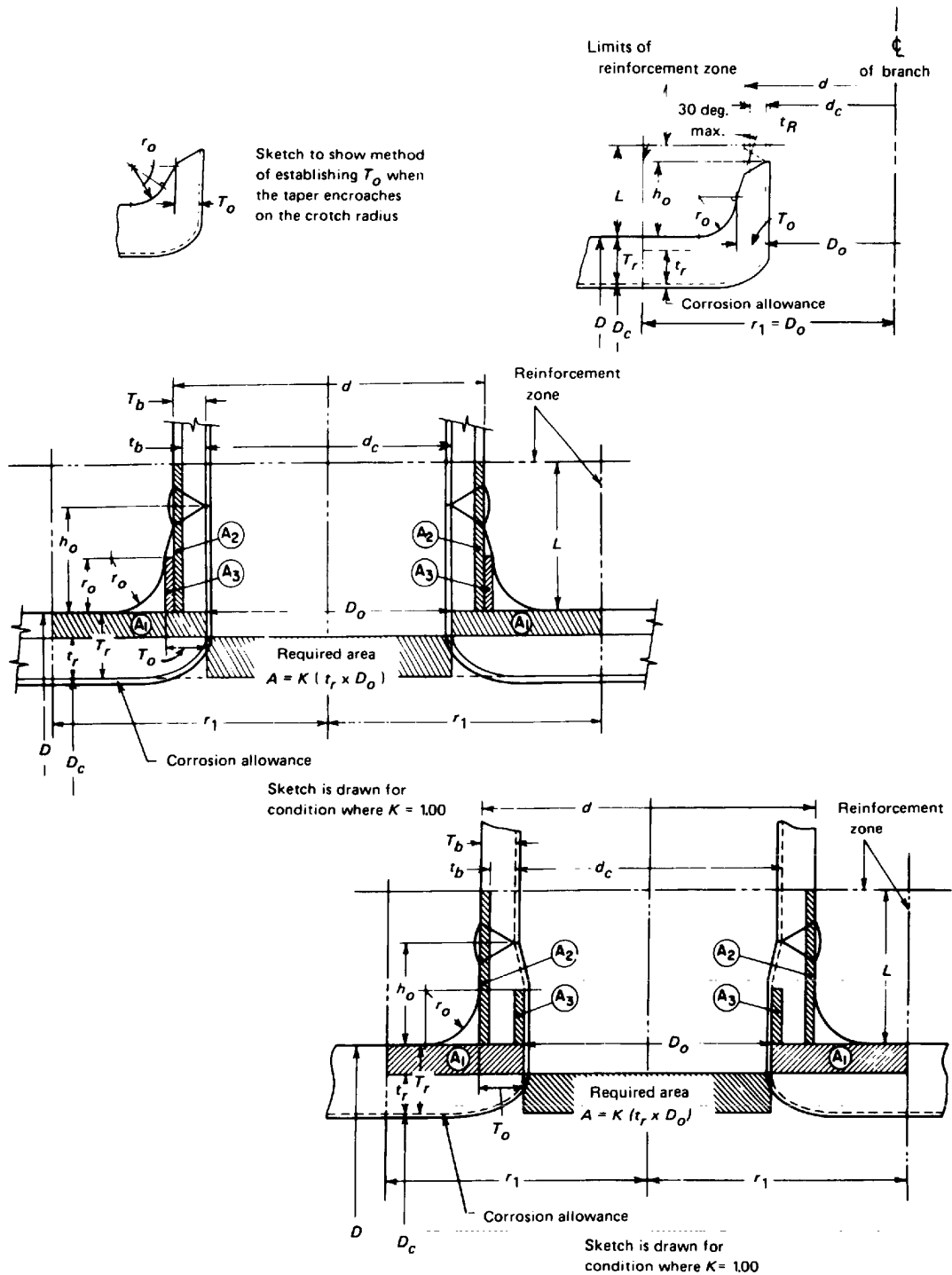


FIG. NC-3643.4(a)-1 REINFORCED EXTRUDED OUTLETS

FIG. NC-3643.4(a)-1 REINFORCED EXTRUDED OUTLETS

(d) *Radii*

(1) The minimum radius shall not be less than $0.05d$, except that on branch diameters larger than 30 in. (762 mm) it need not exceed $1\frac{1}{2}$ in. (38 mm).

(2) The maximum radius for outlet pipe sizes 6 in. nominal and larger shall not exceed $0.10d + 0.50$ in. For outlet pipe sizes less than 6 in. nominal, this dimension shall be not greater than $1\frac{1}{4}$ in.

(3) When the external contour contains more than one radius, the radius of any arc sector of approximately 45 deg. shall meet the requirements of (1) and (2) above.

(4) Machining shall not be employed in order to meet the above requirements.

(e) *Required Area.* The required area is defined as $A = K(t_r \times D_o)$ where K shall be taken as follows:

(1) for d/D greater than 0.60, $K = 1.00$

(2) for d/D greater than 0.15 and not exceeding 0.60, $K = 0.6 + 2d/3D$

(3) for d/D equal to or less than 0.15, $K = 0.70$

(f) *Reinforcement Area.* The reinforcement area shall be the sum of areas $A_1 + A_2 + A_3$ as defined in (1), (2), and (3) below.

(1) Area A_1 is the area lying within the reinforcement zone resulting from any excess thickness available in the run wall:

$$A_1 = D_o(T_r - t_r)$$

(2) Area A_2 is the area lying within the reinforcement zone resulting from any excess thickness available in the branch pipe wall:

$$A_2 = 2L(T_b - t_b)$$

(3) Area A_3 is the area lying within the reinforcement zone resulting from excess thickness available in the extruded outlet lip:

$$A_3 = 2r_o(T_o - T_b)$$

(g) *Reinforcement of Multiple Openings.* When any two or more adjacent openings are so closely spaced that the reinforcement zones overlap, the two or more openings shall be reinforced in accordance with NC-3643.4, with a combined reinforcement that has a strength equal to the combined strength of the reinforcement that would be required for separate openings. No portion of the cross section shall be considered as applying to more than one opening or be evaluated more than once in a combined area.

(h) *Marking.* In addition to the above, the Certificate Holder shall be responsible for establishing and marking on the section containing extruded outlets, the Design Pressure and Temperature, and the Certificate Holder's name or trademark.

NC-3643.5 Branch Connections Subject to External Pressure

(a) The reinforcement area in sq in. required for branch connections subject to external pressure shall be $0.54(t_{mh})(d_1)(2 - \sin \alpha)$. See NC-3643.3(c)(1).

(b) Procedures established for connections subject to internal pressure shall apply for connections subject to external pressure.

NC-3643.6. Reinforcement of Other Designs.

The adequacy of designs to which the reinforcement requirements of NC-3643 cannot be applied shall be proved by burst or proof tests (NC-3649) on scale models or on full size structures, or by calculations previously substantiated by successful service of similar design.

NC-3644 Miters

Mitered joints may be used in piping systems under the conditions stipulated in (a) through (e) below.

(a) The thickness of a segment of a miter shall be determined in accordance with NC-3641.1. The required thickness thus determined does not allow for the discontinuity stresses which exist at the junction between segments. The discontinuity stresses are reduced for a given miter as the number of segments is increased. These discontinuity stresses may be neglected for miters in noncyclic services with incompressible fluids at pressures of 100 psi (690 kPa) and under, and for gaseous vents to atmosphere. Miters to be used in other services or at higher pressures shall meet the requirements of NC-3649.

(b) The number of full pressure or thermal cycles shall not exceed 7000 during the expected lifetime of the piping system.

(c) The angle θ in Fig. NC-3673.2(b)-1 shall not be more than $22\frac{1}{2}$ deg.

(d) The center line distance between adjacent miters shall be in accordance with Fig. NC-3673.2(b)-1.

(e) Full penetration welds shall be used in joining miter segments.

Page 172

NC-3645 Attachments

(a) External and internal attachments to piping shall be designed so as not to cause flattening of the pipe, excessive localized bending stresses, or harmful thermal gradients in the pipe wall. It is important that such attachments be designed to minimize stress concentrations in applications where the number of stress cycles, due either to pressure or thermal effect, is relatively large for the expected life of the equipment.

(b) Attachments shall meet the requirements of NC-3135.

NC-3646 Closures

(a) Closures in piping systems shall be made by use of closure fittings, such as blind flanges or threaded or welded plugs or caps, either manufactured in accordance with standards listed in Table NC-3132-1 and used within the specified pressure-temperature ratings, or made in accordance with (b) below.

(b) Closures not manufactured in accordance with the standards listed in Table NC-3132-1 may be made in accordance with the rules contained in NC-3300 of this Subsection using the equation $t_m = t + A$, where

t_m	= minimum required thickness, in.
t	= pressure design thickness, calculated for the given closure shape and direction of loading using appropriate equations and procedures in NC-3000, in.
A	= sum of mechanical allowances (NC-3613), in.

(c) Connections to closures may be made by welding, extruding, or threading. Connections to the closure shall be in accordance with the limitations provided in NC-3643 for branch connections. If the size of the opening is greater than one-half the inside diameter of the closure, the opening shall be designed as a reducer in accordance with NC-3648.

(d) Other openings in closures shall be reinforced in accordance with the requirements of reinforcement for a branch connection. The total cross-sectional area required for reinforcement in any plane passing through the center of the opening and normal to the surface of the closure shall not be less than the quantity of $d_5 t$, where

d_5	= diameter of the finished opening, in.
t	= pressure design thickness for the closure, in.

NC-3647 Pressure Design of Flanged Joints and Blanks

NC-3647.1 Flanged Joints

(a) Flanged joints manufactured in accordance with the standards listed in Table NC-3132-1, as limited by NC-3612.1, shall be considered as meeting the requirements of NC-3640.

(b) Flanged joints not included in Table NC-3132-1 shall be designed in accordance with XI-3000.

[98]

NC-3647.2 Permanent Blanks.

The minimum required thickness of permanent blanks (Fig. NC-3647.2-1) shall be calculated from the following equations:

$$t_m = t + A$$

where

t_m	= the minimum required thickness, in.
t	= the pressure design thickness calculated from the equation below, in.
A	= the sum of the mechanical allowances, in. (NC-3613)

$$t = d_6 \left(\frac{3P}{16S} \right)^{1/2}$$

where

d_6	= the inside diameter of the gasket for raised or flat face flanges or the pitch diameter of the gasket for retained gasketed flanges, in.
P	= Design Pressure, psi
S	= the allowable stress in accordance with Section II, Part D, Subpart 1, Tables 1A and 1B

[98]

[98]

NC-3647.3 Temporary Blanks.

Blanks to be used for test purposes only shall have a minimum thickness not less than the pressure design thickness t

calculated as in NC-3647.2 above, except that P shall not be less than the test pressure and the allowable stress S may be taken as 95% of the specified minimum yield strength of the blank material (Section II, Part D, Subpart 1, Table Y-1).
[98]

NC-3647.4 Flanges.

Flanges shall be integral or be attached to pipe by welding, brazing, threading, or other means within the applicable standards specified in Table NC-3132-1.

NC-3647.5 Gaskets

(a) Gaskets shall be made of materials which are not injuriously affected by the fluid or by temperatures within the design temperature range.

(b) Only metallic or asbestos metallic gaskets may be used on flat or raised face flanges if the expected

Page 173

normal service pressure exceeds 720 psi (4960 kPa) or the temperature exceeds 750°F (399°C). However, compressed sheet asbestos confined gaskets are not limited as to pressures, provided the gasket material is suitable for the temperatures.

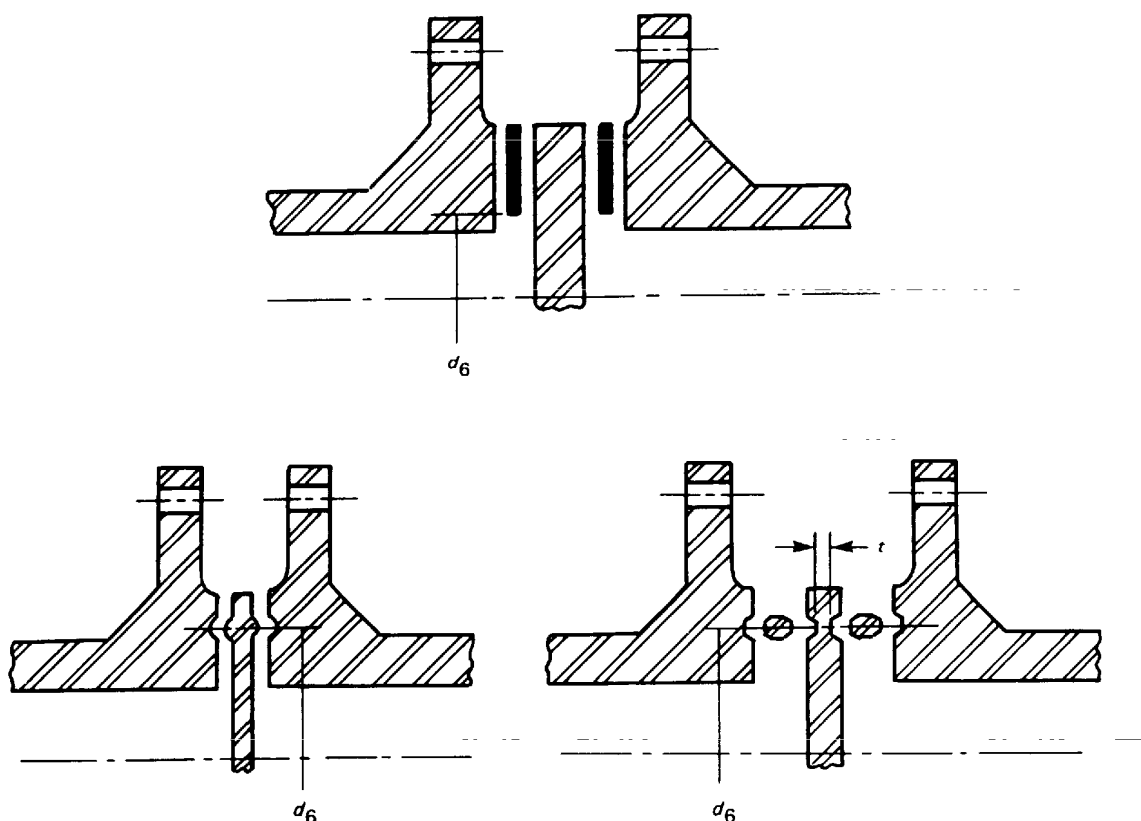


FIG. NC-3647.2-1 TYPES OF PERMANENT BLANKS

FIG. NC-3647.2-1 TYPES OF PERMANENT BLANKS

(c) The use of metal or metal asbestos gaskets is not limited as to pressure, provided the gasket materials are suitable for the fluid Design Temperature.

NC-3647.6 Bolting

(a) Bolts, stud bolts, nuts, and washers shall comply with applicable standards and specifications listed in Table NC-3132-1. Unless otherwise specified, bolting shall be in accordance with the latest edition of ANSI B16.5. Bolts and stud bolts shall extend completely through the nuts.

(b) Studs shall be threaded full length or shall be machined down to the root diameter of the thread in the unthreaded portion, provided that the threaded portions are at least $1\frac{1}{2}$ diameters in length. Studs greater than 8 diameters in length may have an unthreaded portion which has the nominal diameter of the thread, provided the following requirements are met:

(1) the threaded portions shall be at least $1\frac{1}{2}$ diameters in length;

(2) the stud shall be machined down to the root diameter of the thread for a minimum distance of 0.5 diameters adjacent to the threaded portion; and

(3) a suitable transition shall be provided between the root diameter and unthreaded portions.

(c) Carbon steel bolts shall be ANSI Standard square or heavy hexagon head bolts and shall have ANSI Standard heavy semifinished hexagon nuts.

(d) Alloy steel stud bolts shall have ANSI Standard heavy hexagon nuts. Headed alloy bolts are not recommended.

Page 174

(e) It is recommended that all alloy bolts or stud bolts and accompanying nuts be threaded in accordance with ANSI B1.1 Class 2A external threads and Class 2B internal threads.

NC-3648 Reducers

Reducer fittings manufactured in accordance with the standards listed in Table NC-3132-1 shall be considered suitable for use. Where butt welding reducers are made to a nominal pipe thickness, the reducers shall be considered suitable for use with pipe of the same nominal thickness.

NC-3649 Pressure Design of Other Pressure Retaining Piping Products

Other pressure retaining piping products manufactured in accordance with the standards listed in Table NC-3132-1 shall be considered suitable for use in piping systems at the specified pressure-temperature ratings. Pressure retaining piping products not covered by the standards listed in Table NC-3132-1 and for which design equations or procedures are not given in this Subsection may be used where the design of similarly shaped, proportioned, and sized components has been proved satisfactory by successful performance under comparable service conditions. Where such satisfactory service experience exists, interpolation may be made to other sized piping products with a geometrically similar shape. In the absence of such service experience, the pressure design shall be based on an analysis consistent with the general design philosophy of this Subsection and substantiated by at least one of the following:

(a) proof tests as described in ANSI B16.9;

(b) experimental stress analysis (Appendix II).

NC-3649.1 Expansion Joints - General Requirements.

Expansion joints of the bellows, sliding, ball, or swivel types may be used to provide flexibility for piping systems. The design of the piping systems and the design, material, fabrication, examination, and testing of the expansion joints shall conform to this Subsection and shall comply with the requirements of (a) through (e) below.

(a) Piping system layout, anchorage, guiding, and support shall be such as to avoid the imposition of motions or forces on the expansion joints other than those for the absorption of which they are both suitable and intended. Bellows

expansion joints are normally not designed for absorbing torsion. Sliding expansion joints are normally not designed for absorbing bending.

In sliding and bellows expansion joints used for absorbing axial motion, the hydrostatic end force caused by fluid pressure and the forces caused by either friction resistance or spring force, or both, should be resisted by rigid end anchors, cross connections of the section ends, or other means. Where reaction to hydrostatic end forces acts on pipe, guides shall be provided to prevent buckling in any direction. For bellows expansion joints, the pipe guiding and anchorage shall conform to EJMA Standards.²⁴

(b) The expansion joints shall be installed in such locations as to be accessible for scheduled inspection and maintenance and for removal and replacement either directly or by other suitable means.

(c) Expansion joints employing mechanical seals shall be sufficiently leak-tight to satisfy safety requirements. The system designer shall specify the leak-tightness criteria for this purpose.

(d) Materials shall conform to the requirements of NC-2000, except that no sheet material in the quenched, aged, or air-hardened condition shall be used for the flexible element of a bellows joint. If heat treatment is required, it shall be performed either after welding the elements into a complete cylinder or after all forming of the bellows is completed, the only welding permissible after such treatment being that required to connect the element to pipe or end flanges.

(e) All welded joints shall comply with the requirements of NC-4800.

NC-3649.2 Bellows Expansion Joints.

Expansion joints of the bellows type may be used to provide flexibility for piping systems. The design, material, fabrication, examination, and testing of the expansion joints shall conform to this Subsection and the requirements of (a) through (f) below.

(a) The piping system layout, anchorage, guiding, and support shall be such as to avoid the imposition of motions or forces on the bellows other than those for which they have been designed.

24 Expansion Joint Manufacturers Association, 331 Madison Avenue, New York, NY 10017.

(b) In all systems containing bellows, the hydrostatic end force caused by pressure and the bellows spring force shall be accommodated by or resisted by rigid anchors, cross connections of the expansion joint ends, or other means. Where bellows are used in straight pipe sections to absorb axial motion and where the hydrostatic end force of the bellows acts on the pipe as a column, guides must be provided to prevent buckling of the pipe in any direction. The pipe guiding

Page 175

and anchorage shall conform to the requirements of the Design Specifications for the attached piping.

(c) The expansion joints shall be installed in such locations as to be accessible for scheduled inspection, where applicable.

(d) The joints shall be provided with bars or other suitable members for maintaining the proper face-to-face dimension during shipment and installation. Bellows shall not be extended or compressed to make up deficiencies in length of offset to accommodate connected piping which is not properly aligned, unless such misalignments have been specified by the system designer.

(e) The expansion joints shall be marked to show the direction of flow, if applicable, and shall be installed in accordance with this marking.

(f) Unless otherwise stated in the Design Specifications, internal sleeves shall be provided when flow velocities exceed the following values:

Air, steam, and other gases

Up to 6 in. diameter - 4 ft/sec/in. of diameter

Over 6 in. diameter - 25 ft/sec/in. of diameter

Water and other liquids

Up to 6 in. diameter - 2 ft/sec/in. of diameter

Over 6 in. diameter - 10 ft/sec/in. of diameter

NC-3649.3 Bellows Expansion Joint Materials.

Pressure retaining materials in the expansion joint shall conform to the requirements of NC-2000.

[98]

NC-3649.4 Bellows Expansion Joint Design.

Bellows may be of the unreinforced or reinforced convoluted type or of the toroidal type. The design shall conform to the requirements of NC-3000 and to those of (a) through (j) below.

(a) The circumferential membrane stresses in both the bellows and reinforcing member, due to pressure, shall not exceed the allowable stresses given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1.

(b) The sum of the bellows meridional membrane and bending stresses due to internal pressure shall not exceed a value which results in a permanent decrease in the spaces between adjacent convolutions of 7% after a pressure test of $1\frac{1}{2}$ times the Design Pressure, adjusted for temperature.

(c) The ratio of the internal pressure, at which the bellows will become unstable (squirm), to the equivalent cold service pressure shall exceed 2.25. By definition, squirm shall be considered to have occurred if under internal pressure an initially symmetrical bellows deforms, resulting in a lack of parallelism or uneven spacing of adjacent convolutions at any point on the circumference. Unless otherwise specified, this deformation shall be construed as unacceptable squirm when the ratio of the maximum convolution pitch under internal pressure to the convolution pitch before application of pressure exceeds 1.15 for unreinforced and 1.20 for reinforced bellows. In the case of universal expansion joints, which consist of two bellows joined by a cylindrical section, compliance with these criteria shall be satisfied by the entire assembly. No external restraints on the bellows shall be employed during squirm testing other than those which will exist after installation.

(1) For single joints used in axial or lateral motion, the squirm test may be performed with the bellows fixed in the straight position at the maximum length expected in service; for rotation and universal joints, the bellows shall be held at the maximum design rotation angle or offset movement. In the case of single joints subjected to rotation movement or universal joints subjected to lateral offset movement, an instability condition as previously defined may or may not appear. Instead, movement of the convolutions may occur due to the superposition of the lateral internal pressure component on the applied rotation. In such cases, that portion of the bellows deformation due to the design rotation angle or offset movement should not be included in the deformation used to define squirm.

(2) In the case of squirm tests, the equivalent cold service pressure is defined as the Design Pressure multiplied by the ratio E_c/E_R where E_c and E_R are defined as the modulus of elasticity of the bellows material at room temperature and normal service temperature, respectively.

(d) The combination of meridional membrane and bending stresses S in the bellows due to internal pressure and deflection, multiplied by a stress factor K_s ,²⁵ shall not exceed the value defined by the following equation:

$$K_s \times S = S_f$$

where

K_s	$= K_{sc} \times K_{ss}$, but not less than 1.25
K_{sc}	$=$ factor for differences in design fatigue curves at temperatures greater than 100°F
	$= 2S_c / (S_c + S_R)$
K_{ss}	$=$ factor for the statistical variation in test results
	$= 1.470 - 0.044 \times \text{number of replicate tests}$

²⁵ See Appendix II, II-1520(g).

S

= total combined meridional membrane and bending stress due to pressure and deflection, psi. The calculation of the individual stress components and their combination must be determined by the same method as used for determining S_f . In the case of single joints subjected to rotation

Page 176

movement and universal joints subjected to lateral offset movement, the increase in deflection stress caused by the lateral internal pressure component shall be included in determining the combined stress.

S_f

= total combined stress to failure at design cyclic life (number of cycles to failure) obtained from plots of stress versus cyclic life based on data from fatigue tests of a series of bellows at a given temperature (usually room temperature) evaluated by a best fit continuous curve or series of curves, psi. The S_f plot shall be parallel to the best fit curve and shall lie below all of the data points.

S_c

= basic material allowable stress value at room temperature from Section II, Part D, Subpart 1, Tables 1A and 1B, psi

S_h

= basic material allowable stress value at normal service temperature from Section II, Part D, Subpart 1, Tables 1A and 1B, psi

(e) Compliance with (a), (b), (c), and (d) above shall be demonstrated by any one of the procedures of (1), (2), or (3) below.

(1) Calculation of the individual stresses, their combination and relation to fatigue life may be performed by any analytical method based on elastic shell theory. The resulting equations must be substantiated by correlation with actual tests of a consistent series of bellows of the same basic design (unreinforced, reinforced, and toroidal bellows are considered as separate designs) by each manufacturer in order to demonstrate predictability of rupture pressure, meridional yielding, squirm, and cyclic life. A minimum of five burst tests on bellows of varying sizes, with not less than three convolutions, shall be conducted to verify that the analytical method will adequately satisfy criteria (a) and (b) above. No specimen shall rupture at less than four times its equivalent cold pressure rating. A minimum of ten squirm tests on bellows of varying diameters and number of convolutions shall be conducted to verify that the analytical method will adequately satisfy (c) above. Since column instability is most likely to occur in bellows less than 20 in. diameter, where the convoluted bellows length is greater than its diameter, the test specimens shall reflect these considerations. In the case of universal expansion joints, two additional tests shall be conducted to verify that the analytical method will adequately satisfy (c) above. The cyclic life versus combined stress plot used in evaluating NC-3649.4(d) shall be obtained from the results of at least 25 fatigue tests on bellows of varying diameters, thicknesses, and convolution profiles. These curves may be used for diameter and convolution profiles other than those tested, provided that a variation in these dimensions has been included in the correlation with test data. Each group of five such tests on varying bellows may be considered the equivalent of one replicate test in determining K_s .

(2) Individual expansion joint designs may be shown to comply by the testing of duplicate bellows. At least two test specimens are required, one to demonstrate pressure capacity in accordance with (a), (b), and (c) above and the second to demonstrate fatigue life in accordance with (d) above. In the case of rupture and fatigue tests, the specimens need not possess a duplicate number of convolutions, provided the number of convolutions is not less than three and the diameter, thickness, depth, and pitch of the specimen are identical to the part to be furnished; squirm test specimens shall possess the total number of convolutions.

(a) Any or all of the above tests of (e)(1) or (e)(2) may be conducted at room temperature, provided that cold service pressure is defined as the Design Pressure multiplied by the ratio of S_c/S_h for rupture specimens and E_c/E_h for

squirm specimens.

(b) The fatigue life of the test specimen shall exceed $K_s^{4.3}$ times the number of design cycles specified for the most significant cyclic movements. This test shall include the effect of internal pressure. If lateral and rotation movements are specified, these may be converted to equivalent axial motion for cyclic testing; the convolution deflection produced by the lateral component of the internal pressure force during the squirm test for single rotation joints and universal joints shall be added to the mechanical deflections in determining fatigue life. Where accelerated fatigue testing is employed, the deflection and number of cycles required shall be in accordance with Appendix II. Cumulative fatigue requirements can be satisfied in accordance with NC-3649.4(g) without additional testing by assuming that the slope of the fatigue curve is 4.3 and that the curve passes through the test point.

(3) An individual design may be shown to comply by a design analysis in accordance with NC-3200. The stresses at every point in the bellows shall be determined by either elastic shell theory or by a plastic analysis, where applicable. Where an elastic analysis is employed, the stress intensity values of Tables 2A, 2B, and 4, Section II, Part D, Subpart 1 and fatigue curves of Tables I-9.0 may be used to evaluate the design.

(a) The stability requirements of NC-3649.4(c) may be demonstrated by either:

(1) elastic stability calculations, provided that the ratio of the internal pressure at which the bellows is predicted to become unstable to the equivalent cold service pressure exceeds 10; or

Page 177

(2) the pressure test of NC-6230, provided that the test is conducted at $2^{1/4}$ times the equivalent cold design pressure, and single rotation and universal joints are held at their design rotation angle or offset movement during the test and the requirements of NC-3649.4(b) are not exceeded by such a test.

(f) The Certificate Holder's Data Report shall state which of the above procedures was utilized to verify the design.

(g) If there are two or more types of stress cycles which produce significant stresses, their cumulative effect shall be evaluated as stipulated in Steps 1 through 5 below.

Step 1: Designate the specified number of times each stress cycle of types 1, 2, ..., n , will be repeated during the life of the component as $n_1, n_2, \dots, n_n$ respectively.

NOTE: In determining $n_1, n_2, \dots, n_n$ consideration shall be given to the superposition of cycles of various origins which produce a total stress difference $S_1, S_2, \dots, S_n$ greater than the stress difference of the individual cycles. For example, if one type of stress cycle produces 1,000 cycles of stress difference variation from zero to +60,000 psi and another type of stress cycle produces 10,000 cycles of a stress difference variation from zero to - 50,000 psi, the two types of cycles to be considered are defined by the following parameters:

Type 1 cycle $n_1 = 1000$,

$$S_1 = (60,000 + 50,000) = 110,000 \text{ psi}$$

Type 2 cycle $n_2 = 9000$,

$$S_2 = (50,000 + 0) = 50,000 \text{ psi}$$

Step 2: For each value $S_1, S_2, \dots, S_n$ use the applicable design fatigue curve and corresponding method of analysis to determine the maximum number of stress cycles which would be allowable if this type of cycle were the only one acting. Call these values $N_1, N_2, \dots, N_n$. The fatigue curve used may be either the S_r plot defined in NC-3649.4(d) or the curve consistent with NC-3649.4(e)(2) or (3). If the fatigue curve has been developed based on a total stress difference, then the full value of $S_1, S_2, \dots, S_n$ of Step 1 must be used to determine N ; however, if the curve is based on an alternating stress, then the values $S_1, S_2, \dots, S_n$ become the alternating stresses.

Step 3: For each type of stress cycle, calculate the usage factors, $U_1, U_2, \dots, U_n$ from $U_1 = n_1/N_1, U_2 = n_2/N_2, \dots, U_n = n_n/N_n$

Step 4: Calculate the cumulative usage factor U from $U = U_1 + U_2 + \dots + U_n$

Step 5: The cumulative usage factor U shall not exceed 1.0.

(h) The Certificate Holder shall submit a report which demonstrates compliance with NC-3649.

(i) Where necessary to carry the pressure, the cylindrical ends of the bellows may be reinforced by suitable collars. The design method used to assure that the stresses generated will not cause premature failure of the bellows material or weldment shall include the attachment weld between the bellows and end connections.

(j) The spring rates of the expansion joint assembly shall be provided by the Certificate Holder. The spring rates of a bellows can be defined by several methods due to the hysteresis loop which can occur during deflection; a restoring force may be required to return the bellows to the original neutral position after deflection. When applicable, the Design Specifications shall state the maximum allowable force that can be imposed on the connecting parts or shall require the Certificate Holder to determine the maximum force necessary to deflect the bellows a given distance, such as the maximum movement to be absorbed.

[98]

NC-3650 ANALYSIS OF PIPING SYSTEMS

NC-3651 General Requirements²⁶

(a) The design of the complete piping system shall be analyzed between anchors for the effects of thermal expansion, weight, and other sustained and occasional loads. The system design shall meet the limits of NC-3650. The pressure portion of Eqs. (8) and (9) may be replaced with the expression

$$S_{LP} = B_1 \frac{2Pd^2}{D_o^2 - d^2}$$

The pressure portion of Eq. (11) may be replaced by the expression

$$S_{LP} = \frac{Pd^2}{D_o^2 - d^2}$$

where the terms are the same as in NC-3652, except

P	= P or $P_{\max}$, psi
d	= nominal inside diameter of pipe, in.

(b) When evaluating stresses in the vicinity of expansion joints, consideration must be given to actual cross-sectional areas that exist at the expansion joint.

(c) For analysis of flanged joints, see NC-3658.

NC-3652 Consideration of Design Conditions

The effects of pressure, weight, and other sustained mechanical loads must meet the requirements of Eq. (8):

26 The pressure term in Eqs. (8), (9), and (11) may not apply for bellows and expansion joints.

Page 178

$$S_{SL} = B_1 \frac{PD_o}{2t_n} + B_2 \frac{M_A}{Z} \leq 1.5S_h \quad (8)$$

(8)

B_1, B_2	= primary stress indices for the specific product under investigation [Fig. NC-3673.2(b)-1]
P	= internal Design Pressure, psi
D_o	= outside diameter of pipe, in.
t_n	= nominal wall thickness, in.
M_A	= resultant moment loading on cross section due to weight and other sustained loads, in.-lb (NC-3653.3)
Z	= section modulus of pipe, in. ³
S_h	= basic material allowable stress at Design Temperature, psi

NC-3653 Consideration of Level A and B Service Limits

NC-3653.1 Occasional Loads.²⁷

The effects of pressure, weight, other sustained loads, and occasional loads, including nonreversing dynamic loads, for which Level B Service Limits are designated, must meet the requirements of Eq. (9):

$$S_{OL} = B_1 \frac{P_{\max} D_o}{2t_n} + B_2 \left(\frac{M_A + M_B}{Z} \right) \leq 1.8 S_h \quad (9)$$

(9)

but not greater than $1.5S_y$. Terms are the same as in NC-3652, except:

$P_{\max}$	= peak pressure, psi
M_B	= resultant moment loading on cross section due to nonreversing dynamic loads.
S_y	= material yield strength at temperature consistent with the loading under consideration, psi
S_h	= material allowable stress at temperature consistent with the loading under consideration, psi

NC-3653.2 Thermal Expansion.

For Service Loadings for which Level A and B Service Limits are designated, the requirements of either Eq. (10), or Eq. (11), and Eq. (11a) must be met.

(a) The effects of thermal expansion must meet the requirements of Eq. (10):

$$S_E = \frac{iM_C}{Z} \leq S_A \quad (10)$$

(10)

Terms same as above except:

27 Design Pressure may be used if the Design Specification states that peak pressure and earthquake need not be taken as acting concurrently.

M_C	= range of resultant moments due to thermal expansion, in.-lb.; also include moment effects of anchor displacements due to nonreversing dynamic loads if anchor displacement effects were omitted from Eq. (9) (NC-3653.1)
S_A	= allowable stress range for expansion stresses (NC-3611.2), psi

i

= stress intensification factor (NC-3673.2)

(b) The effects of any single nonrepeated anchor movement shall meet the requirements of Eq. (10a):

$$\frac{iM_D}{Z} \leq 3.0S_c \quad (10a)$$

(10a)

Terms same as in NC-3653.2, except:

M_D

= resultant moment due to any single nonrepeated anchor movement (e.g., predicted building settlement), in.-lb.

(c) The effects of pressure, weight, other sustained loads, and thermal expansion shall meet the requirements of Eq. (11):

$$S_{TE} = \frac{PD_o}{4t_n} + 0.75i\left(\frac{M_A}{Z}\right) + i\left(\frac{M_C}{Z}\right) \leq (S_h + S_A) \quad (11)$$

(11)

0.75*i* shall not be less than 1.0.

(d) The effects of reversing dynamic loads must meet the requirements of Eq. (11a):

$$S_R = \frac{iM_R}{Z} \leq 2.0S_A \quad (11a)$$

(11a)

Terms same as in NC-3653.2, except:

M_R

= range of resultant moments due to inertia and anchor motion effects of reversing dynamic loads

NC-3653.3 Determination of Moments and Section Modulus

(a) For purposes of Eqs. (8), (9), (10), and (11), the resultant moment for straight through components, curved pipe, or welding elbows may be calculated as follows. Determine resultant moment:

$$M_j = [M_{xj}^2 + M_{yj}^2 + M_{zj}^2]^{1/2}$$

where

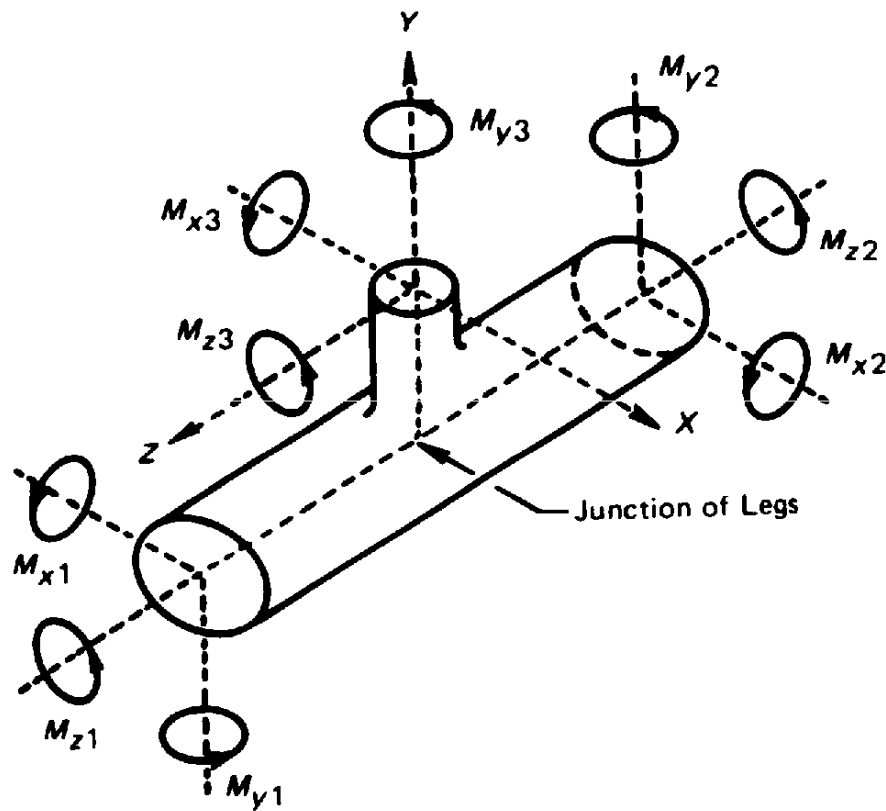
j

= A, B, C, or D which are the subscripts of M_A, M_B, M_C, M_D defined in NC-3652, NC-3653.1, and NC-3653.2

(b) When evaluating Eqs. (8) and (9) for branch connections and tees, use the procedure for branch and

Page 179

run moments given in NB-3683.1(d). When evaluating Eqs. (10), (10a), and (11), use (c) and (d) below.



**FIG. NC-3653.3-1 REDUCING OR FULL OUTLET
BRANCH CONNECTIONS OR TEES**

FIG. NC-3653.3-1 REDUCING OR FULL OUTLET BRANCH CONNECTIONS OR TEES

(c) For full outlet branch connections, calculate the resultant moment of each leg separately in accordance with (a) above. Moments are to be taken at the junction point of the legs (Fig. NC-3653.3-1).

(d) For reduced outlets, calculate the resultant moment of each leg separately in accordance with (a) above. Moments are to be taken at the junction point of the legs (Fig. NC-3653.3-1), except that for $r'_m/r < 0.5$ the branch moments at the outside surface of the run pipe may be used for the branch leg. For the reduced outlet branch:

$$M_A M_B M_C M_D = \sqrt{M_{x3}^2 + M_{y3}^2 + M_{z3}^2}$$

and

$$Z = \pi (r'_m)^2 t_s, \text{ in.}^3, \text{ except as otherwise defined in Fig. NC-3673.2(b)-1}$$

r = run pipe mean cross-sectional radius, in.

r'_m = branch mean cross-sectional radius, in.

t_s = effective branch wall thickness, in.

= lesser of T_r or iT_b

T_b = nominal branch wall thickness, in.

T_r = nominal wall thickness of run pipe, in.

For the main run outlets, use $M_A M_B$ and M_C as defined in NC-3653.3(a).

NC-3654 Consideration of Level C Service Limits

NC-3654.1 Permissible Pressure.

When Level C Service Limits [NCA-2142.4(b)(3) and NB-3113(b)] are specified, the permissible pressure shall not exceed the pressure P_a calculated in accordance with Eq. (5) of NC-3641.1, by more than 50%.

[98]

NC-3654.2 Analysis of Piping Components.

For Service Loadings for which Level C Service Limits [NCA-2142.4(b)(3) and NB-3113(b)] are designated, the requirements of (a) or (b) below shall apply.

(a) For Service Loadings for which Level C Service Limits are designated, which do not include reversing dynamic loads or have reversing dynamic loads combined with nonreversing dynamic loads, the conditions of Eq. (9) of NC-3653.1 shall be met using Service Level C coincident pressure P and moments M_{ii} which result in the maximum calculated stress. The allowable stress to be used for this condition is $2.25S_h$ but not greater than $1.8S_y$.

(b) For Service Loadings for which Level C Service Limits are designated, which include reversing dynamic loads that are not required to be combined with nonreversing dynamic loads, the requirements of NC-3655(b) shall be satisfied, using the allowable stress in NC-3656(b)(2), 70% of the allowable stress in NC-3655(b)(3), and 70% of the allowable loads in NC-3656(b)(4).

[98]

NC-3654.3 Deformation Limits.

Any deformation or deflection limits prescribed by the Design Specifications shall be considered with respect to Level C Service Limits.

[98]

NC-3655 Consideration of Level D Service Limits

If the Design Specifications specify any Service Loading for which Level D Limits are designated [NCA-2142.2(b)(4)], the requirements of (a), (b), or (c) below shall apply.

(a) For Service Loadings for which Level D Service Limits are designated, which do not include reversing dynamic loads or have reversing dynamic loads combined with nonreversing dynamic loads, the requirements of (1) and (2) below shall apply.

(1) The permissible pressure shall not exceed 2.0 times the pressure P_a calculated in accordance with Eq. (3) of NC-3641.1.

(2) The conditions of Eq. (9) of NC-3653.1 shall be met. The allowable stress to be used for this condition is $3.0 S_{Hr}$ but not greater than $2.0 S_y$.

Page 180

(b) For piping fabricated from material designated P-No. 1 through P-No. 9 in Table 2A, Section II, Part D, and limited to $D_o/t_n \leq 50$, if Level D Service Limits are designated, which include reversing dynamic loads that are not required to be combined with nonreversing dynamic loads, the requirements of (1) through (5) below shall apply.

(1) The pressure occurring coincident with the earthquake or other reversing type loading shall not exceed the Design Pressure.

(2) The sustained stress due to weight loading shall not exceed the following:

$$B_2 \frac{D_o}{2I} M_W \leq 0.5 S_m$$

where

M_W

= resultant moment due to weight effects

(3) The stress due to weight and inertial loading due to reversing dynamic loads in combination with the Level D coincident pressure shall not exceed the following:

$$B_1 \frac{P_D D_O}{2t} + B_2 \frac{D_O}{2I} M_E \leq 4.5 S_m$$

where

P_D

= the pressure occurring coincident with the reversing dynamic load

M_E

= the amplitude of the resultant moment due to the inertial loading from the earthquake, other reversing type dynamic events and weight. Earthquake and other reversing dynamic loads shall be computed from a linear elastic response spectrum analysis as defined in Appendix N-1226, except the spectrum peak broadening value Δ_{fg} in N-1226.3 shall not be less than 15% and, in place of the damping values for both large and small diameter piping systems in Table N-1230-1 for Operating Basis Earthquake and Safe Shutdown Earthquake, a value of 5 shall be used. The ground motion design input for generating the floor response spectrum to be used in the linear elastic analysis shall meet the requirements of Appendix N-1211(a) and N-1211(b). Moments and forces may be computed using a methodology other than prescribed above if the alternate methodology is demonstrated to produce results which envelope the prescribed methodology results. In the combination of loads, all directional moment components in the same direction shall be combined before determining the resultant moment. If the method of analysis is such that only magnitude without algebraic signs are obtained, the most conservative combination shall be assumed.

(4) The range of the resultant moment M_{am} and the amplitude of the longitudinal force F_{am} resulting from the anchor motions due to earthquake and other reversing type dynamic loading shall not exceed the following:

$$C_2 \frac{M_{AM} D_O}{2I} < S_1$$

$$\frac{F_{AM}}{A_M} < S_2$$

where

$$S_1 = 6S_m$$

$$S_2 = 1.0S_m$$

$$A_M = \text{cross-sectional area of metal in the piping component wall}$$

(5) Piping displacements shall satisfy Design Specification limitations.

(c) As an alternative to NC-3655(a) and (b), the rules contained in Appendix F may be used in evaluating these service loadings independently of all other Design and Service Loadings.

[98]

NC-3658 Analysis of Flanged Joints

The pressure design of flanged joints is covered by NC-3647.1. Flanged joints subjected to combinations of moment and pressure shall meet the requirements of either NC-3658.1, NC-3658.2, or NC-3658.3. In addition, the pipe-to-flange welds shall meet the requirements of NC-3651 through NC-3655 using appropriate stress intensification factors from Fig. NC-3673.2(b)-1. The following nomenclature applies for NC-3658:

P	= Design or Service Condition Pressure as defined in NCA-2140, psi
P_{eq}	= equivalent pressure to account for the moments applied to the flange joint during the Condition, psi
M_{fs}	= bending or torsional moment (considered separately) applied to the joint due to weight, thermal expansion of the piping, sustained anchor movements, relief valve steady-state thrust, and other sustained mechanical loads applied to the flanged joint during the design or service condition, in.-lb. If cold springing is used, the moment

Page 181

	may be reduced to the extent permitted by NC-3673.5.
M_{fd}	= bending or torsional moment (considered separately) as defined for M_{fs} but including dynamic loadings applied to the flanged joint during the design or service condition, in.-lb
G	= diameter at location of gasket load reaction as defined in XI-3130, in.
A_b	= total cross-sectional area of bolts at root of thread or section of least diameter under stress, sq in.
C	= bolt circle diameter, in.
S	= allowable bolt stress for the bolt material, psi
S_y	= yield strength, psi, of flange material at Design Temperature (Section II, Part D, Tables Y-1 and Y-2)
D_f	= outside diameter of raised face, in.
P_{fd}	= pressure concurrent with M_{fd} , psi

NC-3658.1 Any Flanged Joint.

Flanged joints may be analyzed and the stresses evaluated by using the methods given in Appendix XI as modified by NC-3658.1(a) or by NC-3658.1(b). Alternatively, they may be analyzed in accordance with Appendix XIII.

(a) If the flanged joint conforms to one of the standards listed in Table NC-3132-1, and if each P' as calculated by NC-3658.1(b) is less than the rated pressure at the Design or Service Temperature utilized, the requirements of NC-3658 are satisfied.

(b) The Design Pressure used for the calculation of H in Appendix XI shall be replaced by a flange design pressure

$$P' = P + P_{eq}$$

The equivalent pressure P_{eq} shall be determined by the greater of:

$$P_{eq} = 16M_{fs}/\pi G^3$$

or

$$P_{eq} = 8M_{fd}/\pi G^3$$

NC-3658.2 Standard Flanged Joints at Moderate Pressures and Temperatures.

Flanged joints conforming to ANSI B16.5, MSS SP-44, API 605, or AWWA C207 Class E [275 psi (1900 kPa)], and used where neither the Design nor Service Pressure exceeds 100 psi (690 kPa) and neither the Design nor Service Temperature exceeds 200°F (93°C), meet the requirements of NC-3658, provided the following equations are satisfied:

$$M_{fs} \leq A_b CS/4$$

and

$$M_{fd} \leq A_b CS/2$$

NC-3658.3 ANSI B16.5 Flanged Joints With High Strength Bolting.

Flanged joints using flanges, bolting, and gaskets as specified in ANSI B16.5 and using bolting material having an S value at 100°F (38°C) not less than 20,000 psi (138 MPa) may be analyzed in accordance with the following rules.

(a) Design Limits and Levels A and B Service Limits

(1) The pressure shall not exceed the rated pressure for Level A Service Limits or 1.1 times the rated pressure for Level B Service Limits.

(2) The limitations given by Eqs. (12) and (13) shall be met:

$$(12) M_{fs} \leq 3125(S_y/36,000)CA_b$$

$$(13) M_{fd} \leq 6250(S_y/36,000)CA_b$$

where the value of $S_y/36,000$ shall not be taken as greater than unity.

(b) Level C Service Limits

(1) The pressure shall not exceed 1.5 times the rated pressure.

(2) The limitation given by Eq. (17) shall be met:

$$(17) M_{fd} \leq [11,250A_b - (\pi/16) D_f^2 P_{fd}] C (S_y/36,000)$$

where the value of $S_y/36,000$ shall not be taken as greater than unity.

(c) Level D Service Limits

(1) The pressure shall not exceed 2.0 times the rated pressure.

(2) The limitation given by Eq. (17) shall be met, where P_{fd} and M_{fd} are pressures, psi, and moments, in.-lb, occurring concurrently.

(d) *Test Loadings.* Analysis for test loadings is not required.

Page 182

NC-3660 DESIGN OF WELDS

NC-3661 Welded Joints

NC-3661.1 General Requirements.

Welded joints shall be made in accordance with NC-4200.

NC-3661.2 Socket Welds²⁸

(a) Socket welded piping joints shall be limited to pipe sizes of 2 in. (DN 50) and less.

(b) Socket welds shall comply with the requirements of NC-4427.

(c) Drains and bypasses may be attached to a valve or a fitting using socket weld joints.

NC-3661.3 Fillet Welds and Partial Penetration Welds for Branch Connections²⁹

(a) Fillet welds and partial penetration welds may be used within the limitations of NC-3643.1(c).

(b)

- (b) For fillet welds, the size of the weld shall be specified on the design drawings.
- (c) For partial penetration welds, the size of the weld, the depth of the weld groove, and the groove angle shall be specified on the design drawings.

NC-3670 SPECIAL PIPING REQUIREMENTS

NC-3671 Selection and Limitations of Nonwelded Piping Joints

The type of piping joint used shall be suitable for the Design Loadings and shall be selected with consideration of joint tightness, mechanical strength, and the nature of the fluid handled.

NC-3671.1 Flanged Joints.

Flanged joints shall conform to NC-3647 and NC-3658.

NC-3671.2 Expanded or Rolled Joints.

Expanded or rolled joints may be used when experience or test (NC-3649) has demonstrated that the joint is suitable for the Design Loadings and when adequate provisions are made to prevent separation of the joint.

NC-3671.3 Threaded Joints.

Threaded joints may be used within the limitations specified in (a), (b), and (c) below.

28 Socket welds should not be used where the existence of crevices could accelerate corrosion.

29 Fillet and partial penetration welds should not be used where severe vibration is expected.

(a) All threads on piping products shall be taper pipe threads in accordance with the applicable standard listed in Table NC-3132-1. Threads other than taper pipe threads may be used for piping components where tightness of the joint depends on a seal weld or a seating surface other than the threads and when experience or test (NC-3649) has demonstrated that such threads are suitable.

(b) Threaded joints shall not be used when severe erosion, crevice corrosion, shock, or vibration is expected to occur. Size limits for steam and hot water service above 220°F (104°C) shall be as follows:

Maximum Nominal Size, in.	Maximum Pressure, psi
3	400
2	600
1	1200
3/4 and less	1500

(c) Pipe with a wall thickness less than that of standard weight of ANSI B36.10 steel pipe shall not be threaded, regardless of service. When steel pipe is threaded and used in steam service above 250 psi (1720 kPa) or water service above 100 psi (690 kPa) and 220°F (104°C), the pipe shall be seamless and at least Schedule 80.

NC-3671.4 Flared, Flareless, and Compression Joints.

Flared, flareless, and compression type tubing fittings may be used for tube sizes not exceeding 2 in. (51 mm) O.D. within the limitations of applicable standards and specifications in Table NC-3132-1 and as specified in (a) through (e) below.

(a) Fittings and their joints shall be compatible with the tubing with which they are to be used and shall conform to the range of wall thicknesses and method of assembly recommended by the manufacturer.

(b) Fittings shall be used at pressure-temperature ratings not exceeding the recommendations of the manufacturer. Service conditions, such as vibration and thermal cycling, shall be considered in the application.

(c) All threads on piping products shall be taper pipe threads in accordance with applicable standard listed in Table NC-3132-1. Exceptions are that threads other than taper pipe threads may be used for piping components where tightness of the joint depends on a seating surface other than the threads and when experience or tests (NC-3649) have demonstrated that such threads are suitable.

(d) In the absence of standards or specifications, the designer shall determine that the type of fitting selected is adequate and safe for the Design Loadings in accordance with the following requirements.

(1) The pressure design shall meet the requirements of NC-3649.

(2) Prototypes of the fittings to be used shall successfully meet performance tests (NC-3649) to determine the safety of the joint under simulated Service Loadings. When vibration, fatigue, cyclic conditions,

Page 183

low temperature, thermal expansion, or hydraulic shock are expected, the applicable conditions shall be incorporated in the test.

(e) Flareless fittings shall be of a design in which the gripping member or sleeve shall grip or bite into the outer surface of the tube with sufficient strength to hold the tube against pressure but without appreciably distorting the inside tube diameter. The gripping member shall also form a pressure seal against the fitting body.

(1) When using bite-type fittings, a spot check shall be made for adequate depth of bite and condition of tubing by disassembling and reassembling selected joints.

(2) Grip-type fittings that are tightened in accordance with manufacturer's instructions need not be disassembled for checking.

NC-3671.5 Caulked Joints.

Caulked or leaded joints shall not be used.

NC-3671.6 Brazed and Soldered Joints

(a) *Brazed Joints.* Brazed joints shall be socket type, and minimum socket depth shall be sufficient for the intended service (Fig. NC-4511-1).

(b) *Soldered Joints.* Soldered joints shall be socket type and shall be made in accordance with applicable standards listed in Table NC-3132-1.

(c) *Limitations of Brazed and Soldered Joints*

(1) Brazed socket-type joints shall not be used in systems containing flammable or toxic fluids or in areas where fire hazards are involved.

(2) Soldered socket-type joints shall be limited to systems containing nonflammable and nontoxic fluids.

(3) Soldered socket-type joints shall not be used in piping subject to mechanical or thermal shock or vibration.

(4) Brazed or soldered joints depending solely upon a fillet, rather than primarily upon brazing or soldering material between the pipe and socket, are not acceptable.

(5) Soldered joints shall be pressure and temperature rated in accordance with the applicable standards in Table NC-3132-1, except that they shall not be used at pressures in excess of 175 psi (1207 kPa) or at temperatures in excess of 250°F (121°C).

NC-3671.7 Sleeve Coupled and Other Patented Joints.

Coupling-type, mechanical gland-type, and other patented joints may be used where experience or tests have demonstrated to the satisfaction of the designer that the joint is safe for the Design Loadings and when adequate provision is made to prevent separation of the joint.

NC-3672 Expansion and Flexibility

NC-3672.1 General Requirements

(a) In addition to the design requirements for pressure, weight, and other loadings, piping systems subject to thermal expansion or contraction or to similar movements imposed by other sources shall be designed in accordance with the requirements for the evaluation and analysis of flexibility and stresses specified in this paragraph.

(b) Piping shall meet the expansion and flexibility requirements of this Subarticle except that, where Class 2 piping is connected to Class 1 piping, the requirements for expansion and flexibility for Class 1 piping shall apply to the Class 2 piping out to the first anchor on the Class 2 piping. However, the effect of expansion stresses in combination with stresses from other causes shall be evaluated in accordance with NC-3650. Other exceptions as given in the following subparagraphs shall apply.

NC-3672.2 Properties.

Thermal expansion data and moduli of elasticity shall be determined from Tables TE and TM, Section II, Part D, Subpart 2, which cover more commonly used piping materials. For materials not included in these Tables, reference shall be to authoritative source data such as publications of the National Institute of Standards and Technology.

NC-3672.3 Thermal Expansion Range.

The thermal expansion range shall be determined from Table TE, Section II, Part D, Subpart 2 as the difference between the unit expansion shown for the highest metal temperature and that for the lowest metal temperature resulting from service and shutdown conditions.

NC-3672.4 Moduli of Elasticity.

The cold and hot moduli of elasticity E_c and E_h shall be as shown in Table TM, Section II, Part D, Subpart 2 based on the temperatures established in NC-3672.3.

NC-3672.5 Poisson's Ratio.

Poisson's ratio, when required for flexibility calculations, shall be taken as 0.3 at all temperatures for all materials.

NC-3672.6 Stresses.

Calculations for the stresses shall be based on the least cross-sectional area of the pipe or fitting, using nominal dimensions at the location of local strain. Calculations for the expansion stress S_E shall be based on the modulus of elasticity at room temperature E_c .

(a) *Stress Range.* Stresses caused by thermal expansion, when of sufficient initial magnitude, relax in the hot condition as a result of local yielding or creep. A stress reduction takes place and usually appears as a stress of reversed sign when the component returns to

Page 184

the cold condition. This phenomenon is designated as self-springing of the line and is similar in effect to cold springing. The extent of self-springing depends on the material, the magnitude of the initial expansion and fabrication stress, the hot service temperature, and the elapsed time. When the expansion stress in the hot condition tends to diminish with time, the sum of the expansion strains for the hot and cold conditions during any one cycle remains substantially constant. This sum is referred to as the strain range; however, to permit convenient association with allowable stress, stress range is selected as the criterion for the thermal design of piping.

(b) *Local Overstrain.* All the commonly used methods of piping flexibility analysis assume elastic behavior of the entire piping system. This assumption is sufficiently accurate for systems in which plastic straining occurs at many points or over relatively wide regions but fails to reflect the actual strain distribution in unbalanced systems in which only a small portion of the piping undergoes plastic strain or in which, for piping operating in the creep range, the strain distribution is very uneven. In these cases, the weaker or higher stressed portions will be subjected to strain

concentrations due to elastic follow-up of the stiffer or lower stressed portions. Unbalance can be produced:

(1) by use of small pipe runs in series with larger or stiffer pipe, with the small lines relatively highly stressed;

(2) by local reduction in size or cross section, or local use of a weaker material;

(3) in a system of uniform size, by use of a line configuration for which the neutral axis or thrust line is situated close to the major portion of the line itself, with only a very small offset portion of the line absorbing most of the expansion strain.

(c) Conditions of this type shall be avoided where materials of relatively low ductility are used; if unavoidable, they shall be mitigated by the judicious application of cold spring.

(d) It is recommended that the design of piping systems of austenitic materials be approached with greater overall care as to general elimination of local stress raisers, examination, material selection, fabrication quality, and erection.

NC-3672.7 Flexibility.

Piping systems shall be designed to have sufficient flexibility to prevent pipe movements from causing failure from overstress of the pipe material or anchors, leakage at joints, or detrimental distortion of connected equipment resulting from excessive thrusts and moments. Flexibility shall be provided by changes of direction in the piping through the use of bends, loops, or offsets; or provisions shall be made to absorb thermal movements by utilizing expansion, swivel, or ball joints, or corrugated pipe.

NC-3672.8 Expansion, Swivel, or Ball Joints.

Expansion, swivel, or ball joints, if used, shall conform to the requirements and limitations of NC-3649.

NC-3673 Analysis

NC-3673.1 Method of Analysis.

All systems shall be analyzed for adequate flexibility by a structural analysis unless one of the following conditions is met:

(a) the system can be judged technically adequate by an engineering comparison with previously analyzed systems;

(b) the operating temperature of the piping system is at or below 150°F and the piping is laid out with inherent flexibility, as provided in NC-3672.7;

(c) the operating temperature of the piping system is at or below 250°F and the piping is analyzed for flexibility using simplified methods of calculation such as handbooks or charts.

[98]

NC-3673.2 Basic Assumptions and Requirements

(a) When calculating the flexibility of a piping system between anchor points, the system between anchor points shall be treated as a whole. The significance of all parts of the line and of all restraints, such as supports or guides, including intermediate restraints introduced for the purpose of reducing moments and forces on equipment or small branch lines, shall be considered.

(b) Comprehensive calculations shall take into account the flexibility factors found to exist in piping products or joints other than straight pipe. Credit may be taken where extra flexibility exists in such products or joints. Flexibility factors and stress intensification factors for commonly used piping products and joints are shown in Fig. NC-3673.2(b)-1. The stress intensification factors and flexibility factors in Fig. NC-3673.2(b)-1 shall be used unless specific experimental or analytical data exist that would warrant lower stress intensification factors or higher flexibility factors.

(c) Flexibility factors are identified herein by k with appropriate subscripts. The general definition of a flexibility factor is:

$$k = \theta_{ab} / \theta_{nom}$$

where

θ_{ab}

= rotation of end a , with respect to end b , due to

Page 185

a moment load M and in the direction of the moment M

θ_{nom}

= nominal rotation of equivalent straight pipe due to moment load M

The flexibility factor k is defined in detail for specific components in Fig. NC-3673.2(b)-1.

(d) Stress intensification factors are identified herein by i . The definition of a stress intensification factor is based on fatigue bend testing of mild carbon steel fittings and is:

$$iS = 245,000 N^{0.2}$$

where

S

= amplitude of the applied bending stress at the point of failure, psi

N

= number of cycles to failure

i

= stress intensification factor

= ratio of the bending moment producing fatigue in a given number of cycles in a straight pipe with a girth butt weld to that producing failure in the same number of cycles in the fitting or joint under consideration.

(e) For piping products or joints not listed in Fig. NC-3673.2(b)-1, flexibility or stress intensification factors shall be established by experimental or analytical means.

(f) Experimental determination of flexibility factors shall be in accordance with Appendix II, II-1900. Experimental determination of stress intensification factors shall be in accordance with Appendix II, II-2000.

(g) Analytical determination of flexibility factors shall be consistent with the definition above.

(h) Analytical determination of stress intensification factors may be based on the empirical relationship

$$i = C_2 K_2 / 2, \text{ but not less than } 1.0$$

where C_2 and K_2 are stress indices for Class 1 piping products or joints from NB-3681(a)-1, or are determined as explained below.

Analytical determination of stress intensification factors shall be correlated with experimental fatigue results. Experimental correlation may be with new test data or with test data from similar products or joints reported in literature. Finite element analyses or other stress analysis methods may be used to determine C_2 ; however, tests or established stress concentration factor data should then be used to determine K_2 .

(i) For certain piping products or joints the stress intensification factor may vary depending on the direction of the applied moment, such as in an elbow or branch connection. For these cases, the stress intensification factor used in Eqs. (10), (10a), and (11) of NC-3653.2 shall be the maximum stress intensification factor for all loading directions as determined in accordance with (f) or (h) above.

(j) Stress intensification factors determined in accordance with (f) above shall be documented in accordance with Appendix II, II-2050. The test report may be included and certified with the Design Report (NCA-3551.1 and NCA-3555) for the individual piping system or a separate report furnished (II-2050).

(k) Stress intensification factors determined in accordance with (h) above shall be documented in a report with sufficient detail to permit independent review. The review shall be performed by an engineer competent in the

applicable field of design in accordance with Appendix XXIII. The report shall be included and certified as part of the design report for the piping system (NCA-3551.1 and NCA-3555).

(l) The total expansion range as determined from NC-3672.3 shall be used in all calculations, whether or not the piping is cold sprung. Expansion of the line, linear and angular movements of the equipment, supports, restraints, and anchors shall be considered in the determination of the total expansion range.

(m) Where simplifying assumptions are used in calculations or model tests, the likelihood of underestimates of forces, moments, and stresses, including the effects of stress intensification, shall be evaluated.

(n) Dimensional properties of pipe and fittings used in flexibility calculations shall be based on nominal dimensions.

(o) When determining stress intensification factors by experimental methods, ND-3653.3(d) shall not apply. The nominal stress at the point under consideration (crack site, point of maximum stress, etc.) shall be used.

[98]

NC-3673.3 Cold Springing.

The beneficial effect of judicious cold springing in assisting a system to attain its most favorable position is recognized. Inasmuch as the life of a system under cyclic conditions depends on the stress range rather than the stress level at any one time, no credit for cold spring is allowed with regard to stresses. In calculating end thrusts and moments acting on equipment, the actual reactions at any one time, rather than their range, shall be used. Credit for cold springing is allowed in the calculations of thrusts and moments, provided the method of obtaining the designed cold spring is specified and used.

Page 186

NC-3673.4 Movements.

Movement caused by thermal expansion and loadings shall be determined for consideration of obstructions and design of proper supports.

[98]

NC-3673.5 Computing Hot and Cold Reactions

(a) In a piping system with no cold spring or an equal percentage of cold springing in all directions, the reactions of R_h and R_c in the hot and cold conditions, respectively, shall be obtained from the reaction R derived from the flexibility calculations based on the modulus of elasticity at room temperature E_c using Eqs. (14) and (15).

$$R_h = \left(1 - \frac{2}{3}C\right) \left[\frac{E_h}{E_c}\right] R \quad (14)$$

$$R_c = CR$$

$$= \left[1 - \frac{(S_h)}{(S_E)} \cdot \frac{(E_c)}{(E_h)}\right] R \quad (15)$$

(14 - 15)

whichever is greater, and with further condition that

$$\frac{(S_h)}{(S_E)} \cdot \frac{(E_c)}{(E_h)} < 1$$

where

C	= cold spring factor varying from zero for no cold spring to 1.00 for 100% cold spring
S_E	= computed expansion stress, psi [NC-3653.2(a)]
E_c	= modulus of elasticity in the cold condition, psi
E_h	= modulus of elasticity in the hot condition, psi

R	= maximum reaction for full expansion range based on E_c which assumes the most severe condition (100% cold spring, whether such is used or not), lb
R_c, R_h	= maximum reactions estimated to occur in the cold and hot conditions, respectively, lb

(b) If a piping system is designed with different percentages of cold spring in various directions, Eqs. (14) and (15) are not applicable. In this case, the piping system shall be analyzed by a comprehensive method. The calculated hot reactions shall be based on theoretical cold springs in all directions not greater than two-thirds of the cold springs as specified or measured.

[98]

NC-3673.6 Reaction Limits.

The reactions computed shall not exceed limits which the attached equipment can safely sustain.

NC-3674 Design of Pipe Supporting Elements

Supporting elements, including hangers, anchors, and sliding supports, shall be designed in accordance with the requirements of Subsection NF.

NC-3677 Pressure Relief Piping

NC-3677.1 General Requirements.

Pressure relief piping within the scope of this Subarticle shall be supported to sustain reaction forces and shall conform to the requirements of the following subparagraphs.

NC-3677.2 Piping to Pressure Relieving Safety Devices

(a) Piping that connects a pressure relief device to a piping system shall comply with all the requirements of the Class of piping of the system which it is designed to relieve.

(b) There shall be no intervening stop valves between systems being protected and their protective device or devices, except as provided for in NC-7142.

NC-3677.3 Discharge Piping From Pressure Relieving Safety Devices

(a) Discharge piping of pressure relief devices shall comply with the requirements of the Class of piping applicable to the conditions under which it operates.

(b) There shall be no intervening stop valves between the protective device or devices and the point of discharge, except as provided for in NC-7142.

(c) When discharging directly to the atmosphere, discharge shall not impinge on other piping or equipment and shall be directed away from platforms and other areas used by personnel.

(d) It is recommended that individual discharge lines be used, but if two or more reliefs are combined:

(1) the discharge piping shall be designed with sufficient flow area so as not to affect operation of the relief devices; and

(2) in no case shall the area of such common lines be less than the combined area of all lines discharging into it.

(e) Discharge lines from pressure relieving safety devices within the scope of this Subarticle shall be designed to facilitate drainage.

(f) When the umbrella or drip pan type of connection is used, the discharge piping shall be so designed as to prevent binding due to expansion movements. Drainage shall be provided to remove water collected above the safety valve seat.

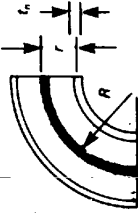
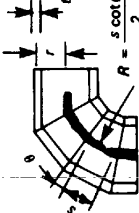
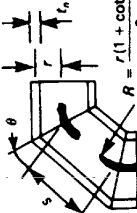
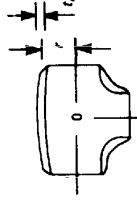
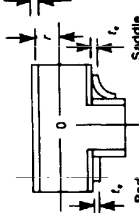
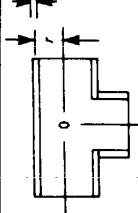
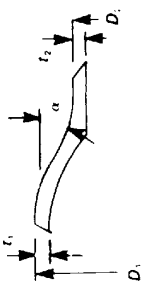
Description	Primary Stress Index		Flexibility Characteristic h	Flexibility Factor k	Stress Intensification Factor i	Sketch
	B_1	B_2				
Welding elbow or pipe bend [Note (1)]	$0.4h - 0.1 \leq 0.5$ and > 0	$\frac{1.30}{h^{2/3}}$	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Note (1)] $s < r(1 + \tan \theta)$	[Note (2)]	[Note (2)]	$\frac{st_n \cot \theta}{2r^2}$	$\frac{1.52}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Note (3)] $s \geq r(1 + \tan \theta)$	[Note (2)]	[Note (2)]	$\frac{t_n (1 + \cot \theta)}{2r}$	$\frac{1.52}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ANSI B16.9	0.5	Branch end: $B_{2b} = 0.4 \left(\frac{r}{t_n} \right)^{2/3}$	$\frac{4.4 t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
		Run end: $B_{2r} = 0.5 \left(\frac{r}{t_n} \right)^{2/3}$				
Reinforced fabricated tee [Note (5)]	0.5	[Note (2)]	$\frac{\left(\frac{t_n + t_p}{2} \right)^{3/2}}{r (t_n)^{1/2}}$	1	$\frac{0.9}{h^{2/3}} \geq 2.1$	
Unreinforced fabricated tee	0.5	[Note (2)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}} \geq 2.1$	

FIG. NC-3673.2(b)-1 STRESS INDICES, FLEXIBILITY, AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$) [Notes (1), (1), (1)]

Description	Primary Stress Index		Flexibility Factor k	Stress Intensification Factor i	Sketch
	B_1	B_2			
Branch connection [Notes (5), (6)]	0.5	Branch leg: $\left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)^{1/2} \left(\frac{T_b}{T_r}\right) \left(\frac{r'_m}{r_p}\right)$ $B_{2b} = 1.5$	1	Branch leg: $\left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)^{1/2} \left(\frac{T_b}{T_r}\right) \left(\frac{r'_m}{r_p}\right)$ $i_b = 1.5$	Fig. NC-3673.2(b)-2
		Run legs: $B_{2r} = 0.9 \left(\frac{r'_m}{t_n}\right)^{1/4}$		Run legs: $i_r = 0.4 \left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right) \geq 1.5$	
Fillet welded and partial penetration welded branch connections [Note (6)]	0.5	Branch leg: $\left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)^{1/2} \left(\frac{T_b}{T_r}\right) \left(\frac{r'_m}{r_p}\right)$ $B_{2b} = 2.25$	1	Branch leg: $\left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)^{1/2} \left(\frac{T_b}{T_r}\right) \left(\frac{r'_m}{r_p}\right) \geq 3.0$ $i_b = 4.5$	Fig. NC-3643.2(b)-2
		Run legs: $B_{2r} = 1.3 \left(\frac{r'_m}{t_n}\right)^{1/4}$		Run legs: $i_r = 0.8 \left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right) \geq 2.1$	
Girth butt weld $t_n \geq 0.237$ in.	0.5	1.0	1	1.0	
Girth butt weld $t_n < 0.237$ in.	0.5	1.0	1	$0.9 (1 + 0.094/t_n) \leq 1.9$	
Circumferential fillet welded or socket welded joints [Note (7)]	$0.75 \left(\frac{t_n}{C_x}\right) \geq 0.5$	$1.5 \left(\frac{t_n}{C_x}\right)$	1	$2.1 (t_n/C_x) \geq 1.3$	Fig. NC-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	[Note (2)]	[Note (2)]	1	2.1	Fig. NC-4511-1
30 deg. tapered transition (ANSI B16.25) $t_n < 0.237$ in.	0.5	1.0	1	$1.3 + 0.0036 \frac{D_o}{t_n} \leq 1.9$	
30 deg. tapered transition (ANSI B16.25) $t_n \geq 0.237$ in.	0.5	1.0	1	$1.3 + 0.0036 D_o/t_n \leq 1.9$	

FIG. NC-3673.2(b)-1 STRESS INDICES, FLEXIBILITY, AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$) [Notes (1), (2), (11)] (CONT'D)

FIG. NC-3673.2(b)-1 STRESS INDICES, FLEXIBILITY, AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$)
 [Notes (1), (2), (11)] (CONT'D)

Description	Primary Stress Index		Flexibility Factor k	Stress Intensification Factor i	Sketch
	B_1	B_2			
Concentric and eccentric reducers (ANSI B16.9) [Note (8)]	0.5 for $\alpha \leq 30$ deg. 1.0 for 30 deg. < $\alpha \leq 60$ deg.	1.0	1	$0.5 + 0.01 \alpha \left(\frac{D_2}{t_2} \right)^{1/2} \leq 2.0$	
Threaded pipe joint or threaded flange	[Note (2)]	[Note (2)]	1	2.3	
Corrugated straight pipe or corrugated or creased bend [Note (9)]	[Note (2)]	[Note (2)]	5	2.5	

(Notes to Fig. NC-3673.2(b)-1 appear on following page.)
 FIG. NC-3673.2(b)-1 STRESS INDICES, FLEXIBILITY, AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$) [Notes (1), (2), (11)] (CONT'D)

FIG. NC-3673.2(b)-1 STRESS INDICES, FLEXIBILITY, AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$)
[Notes (1), (2), (11)] (CONT'D)

NOTES TO FIG. NC-3673.2(b)-1:

- (1) Where flanges are attached to one or both ends, the values of k and f shall be corrected by the factor c given below.
 - (a) One end flanged, $c = h/6$
 - (b) Both ends flanged, $c = h/3$
- (2) B_1 and B_2 primary stress indices for these products are in course of preparation. In the interim, use $B_1 = 0.5$ and $B_2 = 0.75$.
- (3) Also includes single miter joints.
- (4) When $t_o > 1.5 t_n$, $h = 4.05 t_o/r$
- (5) The equation applies only if the following conditions are met.
 - (a) The reinforcement area requirements of NC-3643 are met.
 - (b) The axis of the branch pipe is normal to the surface of run pipe wall.
 - (c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe.
 - (d) The inside corner radius r_1 [Fig. NC-3673.2(b)-2] for nominal branch pipe size greater than 4 in. shall be between 10% and 50% T_r . The radius r_1 is not required for nominal branch pipe size smaller than 4 in.
 - (e) The outer radius r_2 is not less than the larger of $T_p/2$, $(T_b + Y)/2$ [Fig. NC-3673-2 sketch (c)] or $T_p/2$.
 - (f) The outer radius r_3 is not less than the larger of
 - (1) $0.002 \theta d_o$
 - (2) $2 (\sin \theta)^3$ times the offset for the configurations shown in Fig. NC-3673.2(b)-2 sketches (a) and (b).
 - (g) $R_m/T_r \leq 50$ and $r_m/R_m \leq 0.5$.
 - (h) The outer radius r_2 is not required provided an additional multiplier of 2.0 is included in the equations for branch end and run end stress intensification factors. In this case, the calculated value of f for the branch or run shall not be less than 2.1.
- (6) For checking branch leg stress: $Z = \pi(r_m)^2 T_b$.
For checking run leg stress: $Z = \pi(r_m)^2 T_r$.
- (7) In Fig. NC-4427-1(c-1) and (c-2), C_s shall be taken as X_{min} and $C_s \geq 1.25 t_n$. In Fig. NC-4427-1(c-3), $C_s \geq 0.75 t_n$. For unequal leg lengths use the smaller leg length for C_s .
- (8) The equation applies only if the following conditions are met.
 - (a) Cone angle α does not exceed 60 deg.
 - (b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.
 - (c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2 .
 - (d) For eccentric reducers, α is the maximum cone angle.
- (9) Factors shown apply to bending; flexibility factor for torsion equals 0.9.
- (10) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.
- (11) The following nomenclature applies:

r = mean radius of pipe, in. (matching pipe for tees and elbows)
 t_1 = nominal wall thickness of pipe, in. (matching pipe for tees and elbows, see Note (10))
 R = nominal bend radius of elbow or pipe bend, in.
 θ = one-half angle between adjacent miter axes, deg.
 s = miter spacing at center line, in.
 t_o = reinforced thickness, in.
 D_o = nominal outside diameter, in.
- (12) For branch connections nomenclature, refer to Figs. NC-3643.2(b)-2 and NC-3673.2(b)-2.
- (13) The flexibility factors k and stress intensification factors f and stress indices B_2 apply to bending in any plane for fittings and shall in no case be taken less than 1.0. They apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.
- (14) Primary stress indices are applicable to $D_o/t_n \leq 50$ and stress intensification factors are applicable to $D_o/t_n \leq 100$.



[98]

FIG. NC-3673.2(b)-2 BRANCH DIMENSIONS

NC-3678 Temporary Piping Systems

Prior to service of piping systems and associated equipment, certain temporary piping may be installed to accommodate cleaning by blowing out with steam or air, by acid or caustic fluid circulation, or other flushing methods. Such temporary piping shall be designed to safeguard against rupture or other failure which could become a hazard to health or safety.

NC-3690 DIMENSIONAL REQUIREMENTS FOR PIPING PRODUCTS

NC-3691 Standard Piping Products

Dimensions of standard piping products shall comply with the standards and specifications listed in Table NC-3132-1.

NC-3692 Nonstandard Piping Products

The dimensions of nonstandard piping products shall be such as to provide strength and performance equivalent to standard products, except as permitted in NC-3641.

NC-3700 ELECTRICAL AND MECHANICAL PENETRATION ASSEMBLIES

NC-3720 DESIGN RULES

(a) The design of the pressure retaining portion of electrical and mechanical penetration assemblies shall be the same as for vessels (NC-3300).

(b) For closing seams in electrical and mechanical penetration assemblies meeting the requirements of NC-4730(c), the closure head shall meet the requirements of NC-3325 using a factor $C = 0.20$. The fillet weld shall be designed using an allowable stress of 0.5S.

NC-3800 DESIGN OF ATMOSPHERIC STORAGE TANKS

NC-3810 GENERAL REQUIREMENTS

NC-3811 Acceptability

The requirements for acceptability of atmospheric storage tanks are given in the following subparagraphs.

NC-3811.1 Scope.

The design rules for atmospheric storage tanks cover vertical cylindrical flat bottom above ground³⁰ welded tanks at atmospheric pressure. These tanks may contain liquids such as refueling water, condensate, borated reactor coolant, or liquid radioactive waste. Such tanks may be within building structures, depending upon the liquid to be contained, or they may be above grade exposed to atmospheric conditions.

NC-3811.2 Design Requirements.

The design rules for atmospheric storage tanks shall conform to the design requirements of NC-3100 and NC-3300 except as they may be modified by the requirements of this Subarticle. The specific design requirements shall be stipulated in the Design Specifications.

NC-3812 Design Report

The Certificate Holder manufacturing a storage tank conforming to the design requirements of this Subarticle is required to provide a Design Report as part of his responsibility for achieving structural integrity of the tank. The Design Report shall be certified when required by NCA-3550.

NC-3820 DESIGN CONSIDERATIONS

NC-3821 Design and Service Loadings

(a) Loadings shall be identified as Design or Service, and if Service, they shall have Level A, B, C, or D Service Limits designated (NCA-2142).

(b) The provisions of NC-3110 shall apply.

(c) The stress limits given in NC-3821.5 shall be met.

NC-3821.1 Design Pressure.

The Design Pressure³¹ shall be atmospheric.

NC-3821.2 Design Temperature.

The Design Temperature shall not be greater than 200°F (93°C).

NC-3821.3 Loadings.

The requirements of NC-3111 shall be met.

NC-3821.4 Welded Joint Restrictions.

The restrictions given in (a) through (c) below on type and size of joints or welds shall apply.

(a) Tack welds shall not be considered as having any strength value in the finished structure.

30 These rules do not limit storage tanks from being installed below grade or below ground provided the tanks are not subject to external pressure resulting from earth or fill.

31 The limitation of the Design Pressure to atmospheric is not intended to preclude the use of these tanks at vapor pressure slightly above or below atmospheric within the range normally required to operate vent valves. If these pressures or vacuums exceed $\frac{1}{2}$ oz/sq in., especially in combination with large diameter tanks, the forces involved may require special consideration in the design.

**TABLE NC-3821.5-1
DESIGN AND SERVICE LIMITS**

Service Limits	Stress Limits [Notes (1), (2)]
Design and Level A	$\sigma_m \leq 1.0 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5 S$
Level B	$\sigma_m \leq 1.10 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65 S$
Level C	$\sigma_m \leq 1.5 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8 S$
Level D	$\sigma_m \leq 2.0 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4 S$

NOTES:

(a) See NC-3921.5 for definitions of symbols.

(b) These limits do not take into account either local or general buckling which might occur in thin-wall vessels.

TABLE NC-3821.5-1 DESIGN AND SERVICE LIMITS

(b) The minimum size of fillet welds shall be in accordance with NC-4246.6.

(c) All nozzle welds shall be in accordance with NC-4246.5.

NC-3821.5 Limits of Calculated Stresses for Design and Service Loadings.

Stress³² limits for Design and Service Loadings are specified in Table NC-3821.5-1. The symbols used in Table NC-3821.5-1 are defined as follows:

σ_m

= general membrane stress, psi. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

σ_L

= local membrane stress, psi. This stress is the same as σ_m except that it includes the effect of discontinuities.

σ_b

= bending stress, psi. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

S

= allowable stress value given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1, psi. The allowable stress shall correspond to the highest metal temperature at the section under consideration during the loading under consideration.

32 Stress means the maximum normal stress.

Typical examples of locations and loadings for which σ_m , σ_L , and σ_b are applicable are shown in Table XIII-1130-1, with σ considered as equivalent to P in Table XIII-1130-1.

NC-3830 BOTTOM DESIGN

NC-3831 Plate Sizes

(a) All bottom plates shall have a minimum nominal thickness of $1/4$ in. exclusive of any corrosion allowance required by the Design Specifications.

(b) Bottom plates shall be ordered of sufficient size so that, when trimmed, at least a 1 in. (25 mm) width will project beyond the outside edge of the weld attaching the bottom to the shell plate.

(c) The type of foundation used for supporting the tank shall be taken into account in the design of the bottom plates and welds. For recommended practice for construction of foundations see API-650, Appendix B.

NC-3832 Methods of Construction

Bottoms shall be built to either one of the alternative methods of construction given in NC-4246.1.

NC-3833 Shell-to-Bottom Attachment

The requirements for shell-to-bottom attachments are given in NC-4246.2.

NC-3840 SHELL DESIGN

NC-3841 Loads

(a) Thicknesses shall be computed on the basis of the specific gravity of the stored material but in no case shall the specific gravity be less than 1.00. The tension in each ring shall be computed 12 in. (305 mm) above the center line of the lower horizontal joint of the course in question. In computing these stresses, the tank diameter shall be taken as the nominal diameter of the bottom course.

(b) Isolated radial loads on tank shells, such as caused by heavy loads on platforms and elevated walkways between tanks, shall be distributed by rolled structural sections, plate ribs, or built-up members, preferably in a horizontal position.

Page 194

NC-3842 Diameters and Thicknesses of Shell Plates

(a) For method of determining minimum thicknesses³³ of shell plates, see NC-3324.3. For pressure retaining material, see NC-2121.

(b) In no case shall the nominal thickness³⁴ of shell plates be less than the following:

**Nominal Tank
Diameter,³⁵ ft**

**Nominal
Thickness, in.**

50 to 120, incl.

$$\frac{3}{16} \\ \frac{1}{4}$$

(c) The maximum nominal thickness of tank shell plates shall be $1\frac{1}{2}$ in. (38 mm).

NC-3843 Arrangement of Members

(a) The tank shell shall be designed to have all courses vertical. Unless otherwise specified, abutting shell plates at horizontal joints shall have a common vertical center line of thickness. Vertical joints in adjacent shell courses shall not be in alignment but shall be offset from each other a minimum distance of 6 in. (152 mm).

(b) Except as specified for self-supporting roofs and for tanks having the flanged roof-to-shell detail described in (c) below, tank shells shall be supplied with top angles of not less than the following sizes: tanks 35 ft (10.6 m) and smaller in diameter - $2\frac{1}{2}$ in. $\times$ $2\frac{1}{2}$ in. $\times$ $\frac{1}{4}$ in. (64 mm $\times$ 64 mm $\times$ 6 mm); tanks of more than 35 ft to 60 ft (10.6 m to 18.3 m), inclusive, in diameter - $2\frac{1}{2}$ in. $\times$ $2\frac{1}{2}$ in. $\times$ $\frac{5}{16}$ in. (64 mm $\times$ 64 mm $\times$ 8 mm); tanks larger than 60 ft (18.3 m) in diameter - 3 in. $\times$ 3 in. $\times$ $\frac{3}{8}$ in. (76 mm $\times$ 76 mm $\times$ 10 mm). The outstanding leg of the top angle may extend inside or outside the tank shell.

(c)(1) For tanks not exceeding 35 ft (10.6 m) in diameter and having supported cone roofs, the top edge of the shell may be flanged in lieu of installing a top angle. The radius of bend and the width of the flanged edge shall conform to the details of Fig. NC-4246.3-1 sketch (c).

33 Any specified corrosion allowance for the shell plates shall be added to the calculated thickness.

34 The nominal thickness of shell plates refers to the tank shell as constructed. The thicknesses specified are based on erection requirements.

35 Nominal tank diameter shall be the center line diameter of the shell plates unless otherwise stipulated in the Design Specifications.

(2) This construction may be used for any tank having a self-supporting roof if the total cross-sectional area of the junction fulfills the stated area requirements for the top angle construction. No additional member, such as an angle or bar, shall be added to the flanged roof-to-shell detail.

(d) For tanks not exceeding 35 ft (10.6 m) in diameter and having a supported flat roof, the roof plates may be flanged and butt welded to the shell. The flanged tank roof plates shall be butt welded. The inside radius of the knuckle shall not be less than $1.75t$ nor more than $8t$.

NC-3850 ROOF DESIGN

NC-3851 Types of Roofs

The types of roofs are defined in the following subparagraphs.

NC-3851.1 Supported Cone Roof.

A supported cone roof is a roof formed to approximately the surface of a right cone, with its principal support provided by either rafters on girders and columns or rafters on trusses with or without columns.

NC-3851.2 Supported Flat Roof.

A supported flat roof is a roof which is essentially flat, with its principal support provided by either rafters supported by the shell without columns or by rafters in conjunction with girders and trusses with or without columns.

NC-3851.3 Self-Supporting Cone Roof.

A self-supporting cone roof is a roof formed to approximately the surface of a right cone, supported only at its periphery.

NC-3851.4 Self-Supporting Dome Roof.

A self-supporting dome roof is a roof formed to approximately a spherical surface, supported only at its periphery.

A self-supporting dome roof is a roof formed to approximately a spherical surface, supported only at its periphery.

NC-3851.5 Self-Supporting Umbrella Roof.

A self-supporting umbrella roof is a modified dome roof so formed that any horizontal section is a regular polygon with as many sides as there are roof plates, supported only at its periphery.

NC-3852 General Roof Design Requirements

NC-3852.1 Loading Requirements.

All roofs and supporting structures shall be designed to support dead load, plus a uniform live load of not less than 25 lb/sq ft of projected area unless otherwise specified, except that tanks installed in an enclosed area, not exposed to the elements, shall be designed to support the dead load plus a uniform live load of not less than 10 lb/sq ft.

NC-3852.2 Minimum Plate Thickness.

Roof plates shall have a minimum nominal thickness of $\frac{3}{16}$ in.

Page 195

(4.8 mm). A greater thickness may be required for self-supporting roofs. Any specified corrosion allowance for the plates of self-supporting roofs shall be added to the calculated thickness. Any specified corrosion allowance for plates of supported roofs shall be added to the minimum nominal thickness.

NC-3852.3 Minimum Thickness of Supporting Members.

All internal and external structural members shall have a minimum nominal thickness, in any component, of 0.17 in.

NC-3852.4 Attachment of Roof Plates.

Roof plates shall be attached to the top angle of the tank in accordance with NC-4246.3. Roof plates of supported roofs shall not be attached to internal supporting members.

NC-3852.5 Welding of Roof Plates

(a) If the continuous fillet weld between the roof plates and the top angle does not exceed $\frac{3}{16}$ in. (4.8 mm) and the slope of the roof at the top angle attachment does not exceed 2 in./ft (16.7%), the joint may be considered to serve as an emergency venting device which, in case of excessive internal pressure, will fail before failure occurs in the tank shell joints or the shell-to-bottom joint. Failure of the roof-to-shell joint may be accompanied by buckling of the top angle.

(b) Where the weld size exceeds $\frac{3}{16}$ in. (4.8 mm) or where the slope of the roof at the top angle attachment is greater than 2 in./ft (16.7%), emergency venting devices conforming to the specifications noted in API Standard 2000³⁶ shall be provided. The Certificate Holder shall provide a suitable tank connection for the device.

(c) Roof plates shall be welded in accordance with NC-4246.4.

NC-3852.6 Allowable Stresses.³⁷

All parts of the structure shall be so proportioned that the sum of the static stresses shall not exceed the values given in (a) through (d) below.

(a) Tension

(1) in rolled steel, on net section, 20 ksi (138 MPa);

(2) in full penetration groove welds on the thinner plate area, 18 ksi (124 MPa).

(b) Compression

36 API Standard 2000, 1968 Edition, Venting Atmospheric and Low Pressure Storage Tanks, American Petroleum Institute, 1801 K Street, N.W., Washington, D.C., 20036.

37 The decrease in yield stress at Design Temperature shall be taken into account.

- (1) in rolled steel, where lateral deflection is prevented, 20.0 ksi (138 MPa);
- (2) in full penetration groove welds on the thinner plate area, 20.0 ksi (138 MPa);
- (3) in columns, on cross-sectional area, ksi; for L/r not over 120,

$$\left[1 - \frac{(L/r)^2}{34,700} \right] \frac{33Y}{FS}$$

for L/r over 120 to 131.7, inclusive:

$$\frac{\left[1 - \frac{(L/r)^2}{34,700} \right] \frac{33Y}{FS}}{1.6 - L/200r}$$

for L/r over 131.7:

$$\frac{149,000Y}{(L/r)^2 (1.6 - L/200r)}$$

where

L

= unbraced length of column, in

r

= least radius of gyration of column, in.

FS

= design factor

=

$$= \frac{5}{3} + \left[\frac{(L/r)}{350} \right] - \left[\frac{(L/r)^3}{18,300,000} \right]$$

Y

= 1.0, for structural sections or tubular sections having t/R values equal to or exceeding 0.015

= $[(200/3)(t/R)] [2 - (200/3)(t/R)]$, for tubular sections having t/R values less than 0.015

t

= thickness of tubular section, in.; $\frac{1}{4}$ in. minimum for main compression members, $\frac{3}{16}$ in. minimum for bracing and other secondary members

R

= outside radius of tubular section, in.

For main compression members, the ratio L/r shall not exceed 180. For bracing and other secondary members, the ratio L/r shall not exceed 200.

(c) Bending

(1) In tension and compression on extreme fibers of rolled shapes and built-up members with an axis of symmetry in

the plane of loading where the laterally unsupported length of compression flange is no greater than 13 times its width, the compression flange width-thickness ratio does not exceed 17, and the web depth-thickness ratio does not exceed 22.0 ksi (152 MPa).

(2) In tension and compression on extreme fibers of unsymmetrical members where the member is supported laterally at intervals no greater than 13 times its compression flange width, 20.0 ksi (138 MPa).

Page 196

(3) In tension on extreme fibers of other rolled shapes, built-up members, and plate girders, 20 ksi (138 MPa).

(4) In compression on extreme fibers of other rolled shapes, plate girders, and built-up members having an axis of symmetry in the plane of loading, the larger value, ksi, computed by the following:

$$20 - \frac{0.571}{1000} \left(\frac{l}{r} \right)^2$$

or

$$\frac{12,000}{(ld / A_f)} \leq 20$$

where

l

= unbraced length of compression flange, in.

r	= radius of gyration of section about an axis in the plane of loading, in.
d	= depth of section, in.
A_f	= area of compression flange, sq in.

Compression, ksi, on extreme fibers of other unsymmetrical sections:

$$\frac{12,000}{(ld / A_f)} \leq 20$$

(d) Shearing

(1) In fillet, plug, slot and partial penetration groove welds across throat area, 13.6 ksi.

(2) On the gross area of the webs of beams and girders when t is the thickness of the web, inches and h , the clear distance between web flanges, inches, is not more than $60t$, or when the web is adequately stiffened, 13.0 ksi.

(3) On the gross area of the webs of beams and girders, if the web is not stiffened so that h is more than $60t$, the greatest average shear V/A , ksi, shall not exceed:

$$\frac{19.5}{1 + h^2 / 7200t^2}$$

where V is the total shear, kips, and A is the gross area of the web, sq in.

NC-3853 Supported Cone Roofs - General Requirements

NC-3853.1 Slope of Roof.

The slope of the roof shall be $\frac{3}{4}$ in./ft (6.25%) or greater. If the rafters are set directly on chord girders, producing slightly varying rafter slopes, the slope of the flattest rafter shall conform to the specified roof slope.

NC-3853.2 Main Supporting Members.

Main supporting members, including those supporting the rafters, may be rolled or fabricated sections or trusses. Although these members may be in contact with the roof plates, the compression flange of a member or the top chord of a truss shall be considered to receive no lateral support from the roof plates and shall be laterally braced, if necessary, by other acceptable methods. The allowable stresses in these members shall be governed by NC-3852.6.

NC-3853.3 Design of Rafters.

Structural members, serving as rafters, may be rolled or fabricated sections but in all cases shall conform with the rules of NC-3852 through NC-3853. Rafters in direct contact with the roof plates applying the loading to the rafters may be considered to receive adequate lateral support from the friction between the roof plates and the compression flanges of the rafters, with the following exceptions:

- (a) trusses and open web joints used as rafters;
- (b) rafters having a nominal depth greater than 15 in. (381 mm);
- (c) rafters having a slope greater than 2 in./ft (16.7%).

NC-3853.4 Spacing of Rafters.

Rafters shall be spaced so that, in the outer ring, their centers shall not be more than 6.28 ft (1.9 m) apart, measured along the circumference of the tank. Spacing on inner rings shall not be greater than $5\frac{1}{2}$ ft (1.7 m).

NC-3853.5 Roof Columns.

Roof columns shall be made from structural shapes or pipe.

NC-3853.6 Attachment of Rafter Clips and Column Base Clip Guides.

Rafter clips for the outer row of rafters shall be welded to the tank shell. Column base clip guides shall be welded to the tank bottom to prevent lateral movement of column bases. All other structural attachments shall be either bolted or welded.

NC-3853.7 Welding of Roof Plates.

Roof plates shall be welded in accordance with NC-4246.4. The size of the roof to top angle weld shall be $\frac{3}{16}$ in. (4.8 mm) or less.

NC-3854 Supported Flat Roofs

NC-3854.1 General Requirements.

The use of supported flat roofs shall be limited to tanks having diameters not greater than 35 ft (10.6 m). The design of

Page 197

supported flat roofs shall be in accordance with NC-3853 except as noted below.

NC-3854.2 Main Supporting Members

- (a) Requirements of NC-3853.1 do not apply.
- (b) Supporting structural members may be either internal or external to the roof plate.
- (c) External rafters shall not be welded to the top angle or attached to the shell plate.
- (d) External rafters shall be welded to the roof plate. The weld shall be sized to carry the combined dead and live loads on the roof plate.

NC-3855 Self-Supporting Cone Roofs

NC-3855.1 Nomenclature.

The symbols used are defined as follows:

A_t	= combined cross-sectional area of roof plate, shell plate and top shell angle, sq in.
D	= nominal diameter of tank shell, ft
θ	= angle of cone elements with the horizontal, deg.
f	= tensile working stress for the material of the roof plates, shell plates, or top shell angle, whichever is the least value, at the service temperature, psi
P	= dead load of roof, plus the live load, lb/sq ft
R	= radius of curvature of roof, ft
t_r	= nominal thickness of roof plates, in.

NC-3855.2 Design Requirements.

Self-supporting cone roofs shall conform to the requirements³⁸ of (a) through (c) below.

- (a) *Slope*

Maximum $\theta = 37$ deg. (tangent = 9:12)

Minimum $\sin \theta = 0.165$ [slope 2 in./ft (16.7%)]

(b) Plate Thickness

(1) Minimum $t_r = D/400 \sin \theta$ but not less than $\frac{3}{16}$ in.

Maximum $t_r = \frac{1}{2}$ in.

(2) Self-supporting roofs having the roof plates stiffened by sections welded to the plates need not conform to the minimum thickness requirements but shall be not less than $\frac{3}{16}$ in.

38 The equations applying to self-supporting roofs provided for a uniform live load of 25 lb/sq ft.

(c) Top Angle to Roof-to-Shell Joint. The cross-sectional area of the top angle, sq in., plus the cross-sectional areas of the shell and roof plates within a distance of 16 times their thicknesses, measured from their most remote point of attachment to the top angle, shall equal or exceed:

$$\frac{D^2}{3000 \sin \theta}$$

NC-3856 Self-Supporting Dome and Umbrella Roofs

NC-3856.1 Nomenclature.

See NC-3855.1 for nomenclature.

NC-3856.2 Design Requirements.

Self-supporting dome and umbrella roofs shall conform to the requirements³⁴ of (a) through (c) below.

(a) Radius of Curvature

$R = D$ unless otherwise specified

Minimum $R = 0.80D$

Maximum $R = 1.2 D$

(b) *Plate Thickness*

(1) Minimum $t = R/200$ but not less than $\frac{3}{16}$ in.

Maximum $t = \frac{1}{2}$ in.

(2) Self-supporting roofs having the roof plates stiffened by sections welded to the plates need not conform to the minimum thickness requirements but shall be not less than $\frac{3}{16}$ in.

(c) *Top Angle to Roof-to-Shell Joint.* The cross-sectional area of the top angle, sq in., plus the cross-sectional areas of the shell and roof plates within a distance of 16 times their thicknesses, measured from their most remote point of attachment to the top angle, shall equal or exceed:

$$\frac{DR}{1500}$$

NC-3856.3 Top Angle Attachment for Self-Supporting Roofs

(a) The top angle sections for self-supporting roofs shall meet the requirements of NC-4246.4.

(b) For self-supporting roofs, the edges of the roof plates may be flanged horizontally to rest flat against the top angle to improve welding conditions.

Page 198

Table NC-3861-1
ROOF MANHOLES
See Fig. NC-3861-1; All Dimensions Are in Inches

Size of Manhole	Diameter of Neck I.D.	Diameter of Cover Plate D_C	Diameter of Bolt Circle D_B	Number of Bolts	Diameter of Gasket		Diameter of Hole in Roof Plate or Reinforcing Plate D_P	O.D. of Reinforcing Plate D
					I.D.	O.D.		
20	20	26	23½	16	21½	26	20⅝	42
24	24	30	27½	20	25½	30	24⅝	46

Table NC-3861-1 ROOF MANHOLES

NC-3860 TANK CONNECTIONS AND APPURTENANCES

NC-3861 Roof Manholes

Roof manholes shall conform to Fig. NC-3861-1 and Table NC-3861-1, except that alternative designs which provide equivalent strength are permissible if agreed to by the Owner or his designee.

NC-3862 Roof Nozzles

(a) Flanged roof nozzles shall conform to Fig. NC-3862(a)-1 and Table NC-3862(a)-1. Threaded nozzles shall conform to Fig. NC-3862(a)-2 and Table NC-3862(a)-2. Alternative designs for flanged roof nozzles and threaded nozzles can be used, provided they are of equivalent strength and agreed to by the Owner or his designee.

(b) Roof nozzles are not intended to take loads from pipe reactions. Earthquake loadings need not be considered.

NC-3863 Bottom Outlet Elbows

Bottom outlet elbows shall conform to Fig. NC-3863-1 and Table NC-3863-1.

NC-3864 Threaded Connections

Threaded piping connections shall be female and shall be tapered. The threads shall conform to the requirements for taper pipe threads included in ANSI B1.20.1.

NC-3865 Platforms, Walkways, and Stairways

Platforms, walkways, and stairways shall be in accordance with Tables NC-3865-1 through NC-3865-3.

NC-3866 Nozzle Piping Transitions

The stress limits of Table NC-3821.5-1 shall apply to all portions of nozzles which lie within the limits of reinforcement given in NC-3334, except as provided in NC-3867. Stresses in the extension of any nozzle beyond the limits of reinforcement shall be subject to the stress limits of NC-3600.

NC-3867 Consideration of Standard Reinforcement

(a) Where a nozzle-to-shell junction is reinforced in accordance with the rules of NC-3334, the stresses in this region due to internal pressure may be considered to satisfy the limits of Table NC-3821.5-1. Under these conditions, no analysis is required to demonstrate compliance for pressure induced stresses in the nozzle region.

(b) Where external piping loads are to be designed for, membrane plus bending stresses due to these loads shall be calculated in the nozzle, and membrane stresses shall be calculated in the local nozzle shell region. These stresses, in conjunction with pressure induced stresses, shall meet the limits of Table NC-3821.5-1 for $(\sigma_m \text{ or } \sigma_L) + \sigma_b$. In this case, the pressure induced stresses in the $(\sigma_m \text{ or } \sigma_L) + \sigma_b$ category may be assumed to be no greater than the limit specified for σ_m in Table NC-3821.5-1 for a given loading.

NC-3900 0-15 psi STORAGE TANK DESIGN

NC-3910 GENERAL REQUIREMENTS

NC-3911 Acceptability

NC-3911.1 Scope.

The design rules for 0-15 psi (0-103 kPa) storage tanks shall cover above ground²⁹ welded storage tanks. These tanks may contain liquids

or gases such as refueling water, condensate, borated reactor coolant, or radioactive waste. Such tanks are normally located within building structures.

FIG. NC-3861-1 ROOF MANHOLES

TABLE NC-3862(a)-1 FLANGED ROOF NOZZLES

FIG. NC-3862(a)-1 FLANGED ROOF NOZZLES

TABLE NC-3862(a)-2 SCREWED OR SOCKET WELD ROOF NOZZLES

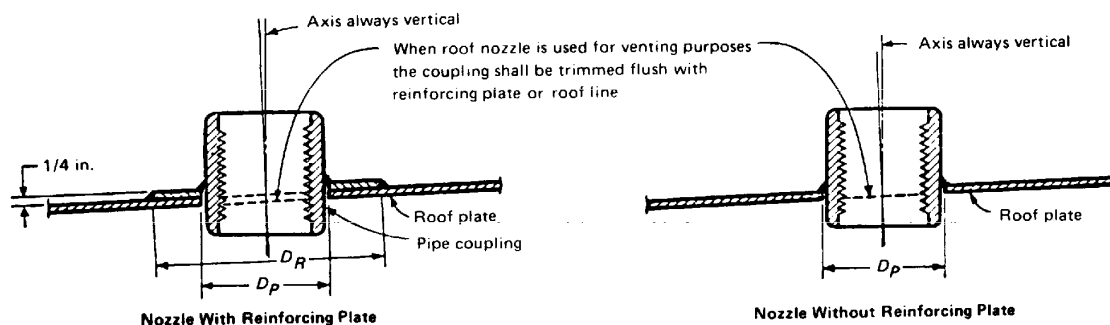


FIG. NC-3862(a)-2 SCREWED OR SOCKET WELD ROOF NOZZLES
See Table NC-3862(a)-2, NC-3864

FIG. NC-3862(a)-2 SCREWED OR SOCKET WELD ROOF NOZZLES

NC-3911.2 Design Requirements

(a) The design requirements for 0-15 psig (0-103 kPa) storage tanks shall conform to the design rules of NC-3100 and NC-3300, except where they may be modified by the requirements of this Subarticle. The specific design requirements shall be stipulated in the Design Specifications.

(b) The total liquid capacity of a tank shall be defined as the total volumetric liquid capacity below the high liquid design level. The nominal liquid capacity of a tank shall be defined as the total volumetric liquid capacity between the plane of the high liquid design level and the elevation of the tank grade immediately adjacent to the wall of the tank or such other low liquid design level as the Certificate Holder shall stipulate.

NC-3912 Design Report

The Certificate Holder of a storage tank conforming to the design requirements of this Subarticle is required to provide a Design Report as part of his responsibility

Page 202

for achieving structural integrity of the tank. The Design Report shall be certified when required by NCA-3550.

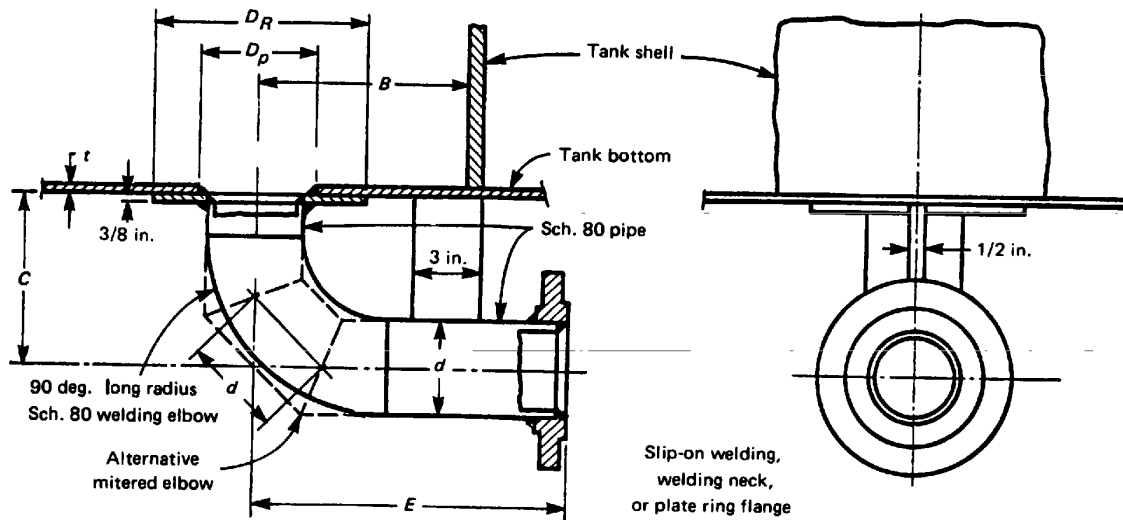
TABLE NC-3863-1
WELDED BOTTOM OUTLET ELBOW
 See Fig. NC-3863-1; All Dimensions Are in Inches

Nominal Pipe Size [Note (1)]	Distance from Center of Elbow to Shell <i>B</i>	Distance from Center of Outlet to Bottom <i>C</i>	Diameter of Hole in Tank Bottom <i>D_P</i>	O.D. of Reinforcing Plate <i>D_R</i>	Distance from Center of Elbow to Face of Outlet Flange <i>E</i>
2	7½	6	3⅛	6¼	12
3	8½	7	4¼	7¾	13
4	9½	7 ¹³ / ₁₆	5¼	9¾	14
6	11	9¾	7¾	12¾	16
8	13	12¾	9¾	16½	18

NOTE:

(1) Extra-strong pipe, refer to ANSI B36.10.

TABLE NC-3863-1 WELDED BOTTOM OUTLET ELBOW



GENERAL NOTES:

- (a) Slip-on welding and welding neck flanges shall conform to the requirements for 150 lb forged carbon steel raised face flanges as given in ANSI B16.5.
- (b) Plate ring flanges shall conform to all dimensional requirements for slip-on welding flanges, except that the extended hub on the back of the flange may be omitted.

FIG. NC-3863-1 TYPICAL WELDED BOTTOM OUTLET ELBOW
See Table NC-3863-1

FIG. NC-3863-1 TYPICAL WELDED BOTTOM OUTLET ELBOW

TABLE NC-3865-1 PLATFORMS AND WALKWAYS

-
1. All parts to be made of metal.
 2. Width of floor level (min.): 24 in.
 3. Flooring to be made of grating or nonslip material.
 4. Height of top railing above floor [Note (1)]: 42 in.
 5. Height of toeboard (min.): 3 in.
 6. Space between top of floor and bottom of toeboard (max.): $\frac{1}{4}$ in.
 7. Height of midrail: approximately one-half the distance from top of walkway to top of railing.
 8. Distance between railing posts (max.): 96 in.
 9. The completed structure shall be capable of supporting a moving concentrated load of 1000 lb, and the handrailing structure shall be capable of withstanding a load of 200 lb applied in any direction at any point on the top rail.
 10. Handrails to be on both sides of platform, discontinuing where necessary for access.
 11. At handrail openings, any space between tank and platform wider than 6 in. should be floored.
 12. Tank runways, which extend from one part of a tank to any part of an adjacent tank or to ground or other structure, shall be so supported as to permit free relative movement of the structures joined by the runway. This may be accomplished by firm attachment of runway to one tank, but with a slip joint at point of contact between runway and other tank. This is to permit either tank to settle or be disrupted by an explosion without endangering the other.
-

NOTE:

- (1) Handrail height as required by ANSI specifications. This height is mandatory in some states.

TABLE NC-3865-1 PLATFORMS AND WALKWAYS

NC-3920 DESIGN CONSIDERATIONS

NC-3921 Design and Service Loadings

(a) Conditions shall be identified as Design or Service, and if Service, they shall have Service Limits designated Level A, Level B, or Level C, or Level D (NCA-2142).

(b) The provisions of NC-3110 shall apply.

(c) The stress limits of NC-3921.6 shall be met.

³⁹ Whenever a tank is to be operated with liquid levels which at no time reach the top of the roof but is to be filled to the top of the roof during the hydrostatic test, it shall be designed for both of these maximum liquid level conditions, using in each case the density of the liquid employed. If a tank is not designed to be filled to the top of the roof, overfill protection is required.

NC-3921.1 Design Pressure

(a) The walls of the gas or vapor space and other components of the tank above the maximum liquid level³⁹ at the top of the tank shall be designed for a pressure not less than that at which the pressure relief valves are to be set⁴⁰ and for the maximum partial vacuum which can be developed in such space⁴¹ when the inflow of air, gas, or vapor through the vacuum relief valves is at its maximum specified rate. The maximum positive gage pressure for which this space is designed shall be understood to be the nominal pressure rating for the tank and shall not exceed 15 psi (103 kPa).

**TABLE NC-3865-2
STAIRWAYS**

-
1. All parts to be made of metal.
 2. Width of stairs (min.): 24 in.
 3. Angle [Note (1)] of stairway with a horizontal line (max.): 50 deg.
 4. Width of stair treads (min.): 8 in. [The run defined as the horizontal distance between the noses of successive tread pieces) and the rise of stair treads shall be such that the sum of twice the rise, plus the run, shall be not less than 24 in. nor more than 26 in. Rises shall be uniform throughout the height of the stairway.]
 5. Treads to be made of grating or nonslip material.
 6. Top railing shall join platform handrail without offset, and the height measured vertically from tread level at nose of tread shall be 30 to 34 in.
 7. Distance between railing posts (max.) measured along slope of railing: 96 in.
 8. The completed structure shall be capable of supporting a moving concentrated load of 1000 lb, and the handrailing structure shall be capable of withstanding a load of 200 lb applied in any direction at any point on the top rail.
 9. Handrails shall be on both sides of straight stairs; also, handrails shall be on both sides of circular stairs when the clearance between tank shell and stair stringer exceeds 8 in.
 10. Circumferential stairways should be completely supported on the shell of the tank, and ends of the stringers should be clear of the ground.
-

NOTE:

- (1) It is recommended that the same angle be employed for all stairways in a tank group or plant area.
-

TABLE NC-3865-2 STAIRWAYS

(b) All portions of the tank at levels below maximum liquid level shall be designed for the most severe combination of gas pressure or partial vacuum and static liquid head.

40 A suitable margin shall be allowed between the pressure normally existing in the gas or vapor space and the pressure at which the relief valves are set so as to allow for the increases in pressure caused by variations in the temperature or gravity of the liquid contents of the tank and other factors affecting the pressure in the gas or vapor space.

41 This partial vacuum shall be greater than that at which the vacuum relief valves are set to open.

Page 204

**TABLE NC-3865-3
STAIRWAY RISE, RUN, AND ANGLE RELATIONSHIPS**

Height of Rise R , in.	$2R + r = 24$ in.			$2R + r = 26$ in.		
	Width of Run, r , in.	Angle		Width of Run, r , in.	Angle	
		degrees	minutes		degrees	minutes
$5\frac{1}{4}$	$13\frac{1}{2}$	21	15	...	...	...
$5\frac{1}{2}$	13	22	56	15	20	9
$5\frac{3}{4}$	$12\frac{1}{2}$	24	43	$14\frac{1}{4}$	21	38
6	12	26	34	14	23	12
$6\frac{1}{4}$	$11\frac{1}{2}$	28	30	$13\frac{1}{2}$	24	53
$6\frac{1}{2}$	11	30	35	13	26	34
$6\frac{3}{4}$	$10\frac{1}{2}$	32	45	$12\frac{1}{2}$	28	23
7	10	35	0	12	30	15
$7\frac{1}{4}$	$9\frac{1}{2}$	38	20	$11\frac{1}{2}$	32	13
$7\frac{1}{2}$	9	39	50	11	34	18
$7\frac{3}{4}$	$8\frac{1}{2}$	42	22	$10\frac{1}{2}$	36	26
8	8	45	0	10	38	40
$8\frac{1}{4}$	$7\frac{1}{2}$	47	43	$9\frac{1}{2}$	41	0
$8\frac{1}{2}$	...	...	...	9	43	23
$8\frac{3}{4}$	...	...	...	$8\frac{1}{2}$	45	49
9	...	...	...	8	48	22

TABLE NC-3865-3 STAIRWAY RISE, RUN, AND ANGLE RELATIONSHIPS

NC-3921.2 Design Temperature.

The Design Temperature shall not be greater than 200°F (93°C).

NC-3921.3 Tank Shape.

Tank walls shall be so shaped as to avoid any pockets on the inside where gases may become trapped when the liquid level is being raised or pockets on the outside where rainwater may collect.

NC-3921.4 Loadings.

The requirements of NC-3111 shall be met.

NC-3921.5 Corrosion Allowance.

When corrosion is expected on any part of the tank wall or on any external or internal supporting or bracing members upon which the safety of the completed tank depends, additional metal thickness in excess of that required by the design computations shall be provided or some satisfactory method of protecting these surfaces from corrosion shall be employed. Such added thickness need not be the same for all zones of exposure inside and outside the tank.

NC-3921.6 Linings.

When corrosion resistant linings are attached to any element of the tank wall, including nozzles, their thickness shall not be included in the computation for the required wall thickness.

NC-3921.7 Welded Joint Restrictions.

The restrictions on type and size of joints or welds given in (a) through (c) below apply.

(a) Tack welds shall not be considered as having any strength value in the finished structure.

(b) The minimum size of fillet welds shall be in accordance with NC-4247.6.

(c) All nozzle welds shall be in accordance with NC-4244.

NC-3921.8 Limits of Calculated Stresses for Design and Service Loadings.

Stress⁴² limits for Design and Service Loadings are specified in Table NC-3921.6-1. The symbols used in Table NC-3921.6-1 are defined as follows:

σ_m	= general membrane stress, psi. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.
σ_L	= local membrane stress, psi. This stress is the same as σ_m except that it excludes the effect of discontinuities.
σ_b	= bending stress, psi. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.
S	= allowable stress value given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1, psi. The allowable stress shall correspond to the highest metal temperature at the section under consideration during the loading under consideration.

⁴² Stress means the maximum normal stress.

**TABLE ND-3921.6-1
DESIGN AND SERVICE LIMITS
FOR STEEL TANKS**

Service Limit	Stress Limits [Note (1), (2)]
Design and Level A	$\sigma_m \leq 1.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5S$
Level B	$\sigma_m \leq 1.10S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65S$
Level C	$\sigma_m \leq 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$
Level D	$\sigma_m \leq 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$

NOTES:

(1) See NC-3921.6 for definitions of symbols.

(2) These limits do not take into account either local or general buckling which might occur in thin-wall vessels.

TABLE ND-3921.6-1 DESIGN AND SERVICE LIMITS FOR STEEL TANKS

Typical examples of locations and loadings for which σ_m , σ_L , and σ_b are applicable are shown in Table XIII-1130-1, with σ in Table NC-3921.6-1 considered as equivalent to P in Table XIII-1130-1.

NC-3922 Maximum Allowable Stress Values for Tanks

NC-3922.1 Nomenclature.

The symbols used are defined as follows:

t = thickness, in., of sidewalls, roof, or bottom, including

	corrosion allowance.
c	= allowance for corrosion, in.
R	= radius of the tank wall, in.
R_1	= radius of curvature of the tank wall in a meridian plane, in.
R_2	= length, in., of the normal to the tank wall measured from the wall of the tank to its axis of revolution
T_1	= meridional unit force in the wall of the tank, lb/in. of latitudinal arc
T_2	= latitudinal unit force in the wall of the tank, lb/in. of meridional arc
S_{ts}	= maximum allowable stress for simple tension, psi (Tables 1A, 1B, and 3, Section II, Part D, Subpart 1)
S_{cs}	= maximum allowable longitudinal compressive stress, psi, for a cylindrical wall acted upon by an axial load with neither a tensile nor a compressive force acting concurrently in a circumferential direction and determined in accordance with NC-3922.3(a) for the thickness-radius ratio involved
S_{ta}	= allowable tensile stress, psi, which is lower than S_{ts} because of the presence of a coexistent compressive stress perpendicular to it
S_{ca}	= allowable compressive stress, psi, which is lower than S_{cs} because of the presence of a coexistent tensile or compressive stress perpendicular to it
S_{tc}	= computed tensile stress, psi, at the point under consideration
S_{cc}	= computed compressive stress, psi, at the point under consideration
S_t	= general symbol for indicating a tensile stress, psi, which may be either an allowable or computed value depending on the context in which the symbol is used
S_c	= general symbol for indicating a compressive stress, psi, which may be either an allowable or computed value, depending on the context in which the symbol is used
N	= ratio of the tensile stress S_t to the maximum allowable stress for simple tension S_{ts}
M	= ratio of the compressive stress S_c to the maximum allowable compressive stress S_{cs} (Fig. NC-3922.1-2)

NC-3922.2 Maximum Tensile Stresses.

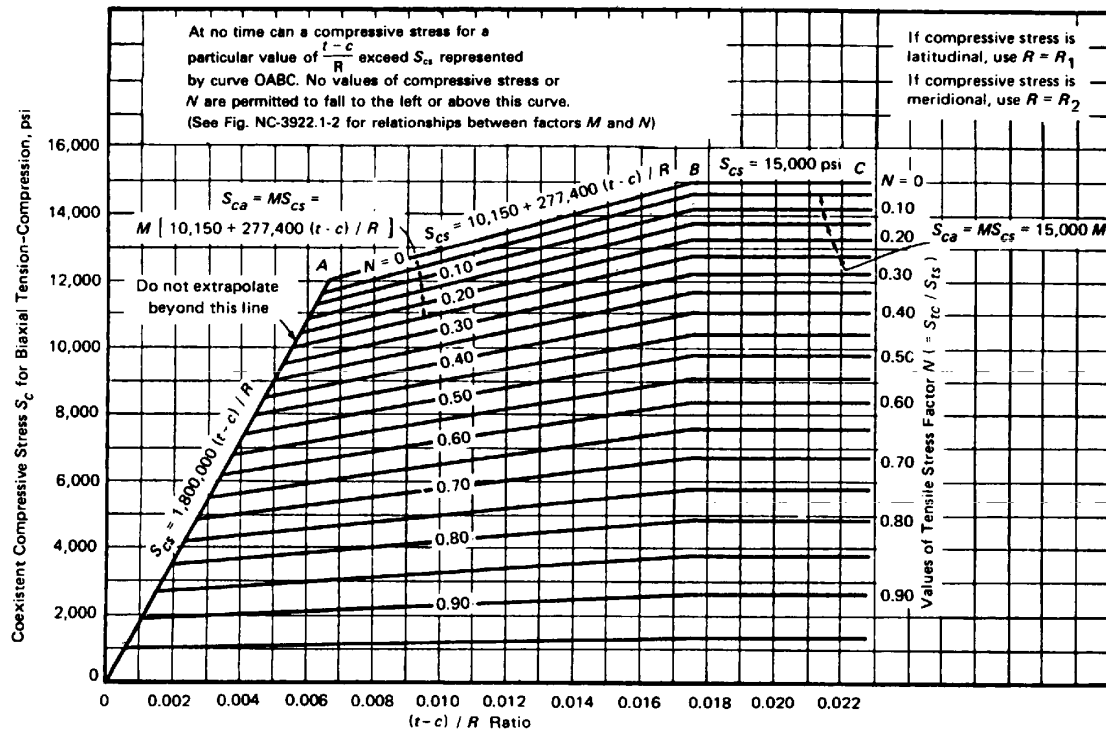
The maximum tensile stresses in the outside walls of a tank, as determined for any loadings or any concurrent combination of such loadings shall not exceed the applicable stress values determined in accordance with (a) or (b) below.

(a) If both the meridional and latitudinal unit forces T_1 and T_2 are tensile, or if one of these forces is tensile and the other is zero, the computed tensile stress S_{tc} shall not exceed the applicable value given in Tables 1A, 1B, and 3, Section

Page 206

(b) If the meridional unit force T_1 is tensile and the coexistent latitudinal unit force T_2 is compressive, or if T_2 is tensile and T_1 is compressive, the computed tensile stress S_{tc} shall not exceed a value of S_{ta} obtained by multiplying the applicable stress value given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1 by the appropriate value of N obtained from Fig. NC-3922.1-1 for the value of compressive stress ($S_c = S_{cc}$) and co-related ratio of $(t - c)/R$ involved. However, in cases where the unit force acting in compression does not exceed 5% of the coexistent tensile unit force

acting perpendicular to it, the designer may permit a tensile stress of the magnitude specified in (a) above. Section F.1 of Appendix F of API 620 Feb. 1970 Ed.⁴³ gives examples illustrating the determination of allowable tensile stress values S_{ta} . In no event shall the value of S_{ta} exceed the allowable stress for simple tension shown in Tables 1A, 1B, and 3, of Section II, Part D, Subpart 1.



**FIG. NC-3922.1-1 BIAXIAL STRESS CHART FOR COMBINED TENSION AND COMPRESSION,
30,000 psi TO 38,000 psi YIELD STRENGTH STEELS**

FIG. NC-3922.1-1 BIAXIAL STRESS CHART FOR COMBINED TENSION AND COMPRESSION, 30,000 psi TO 38,000 psi YIELD STRENGTH STEELS

NC-3922.3 Maximum Compressive Stresses.

Except as provided in NC-3933.4(b), the maximum compressive stresses in the outside walls of a tank, as determined for the loadings, shall not exceed the applicable stress values determined in accordance with (a) through (d) below.

43 Recommended Rules for Design and Construction of Large, Welded, Low-Pressure Storage Tanks, published by American Petroleum Institute, 1801 K St., N.W., Washington, D.C. 20036.

(a) If a cylindrical wall, or portion thereof, is acted upon by a longitudinal compressive force with neither a tensile nor a compressive force acting concurrently in a circumferential direction, the computed compressive stress S_{cc} shall not

exceed a value S_{cs} established for the applicable thickness-radius ratio as follows:⁴⁴

for $(t - c)/R$ values less than 0.00667:

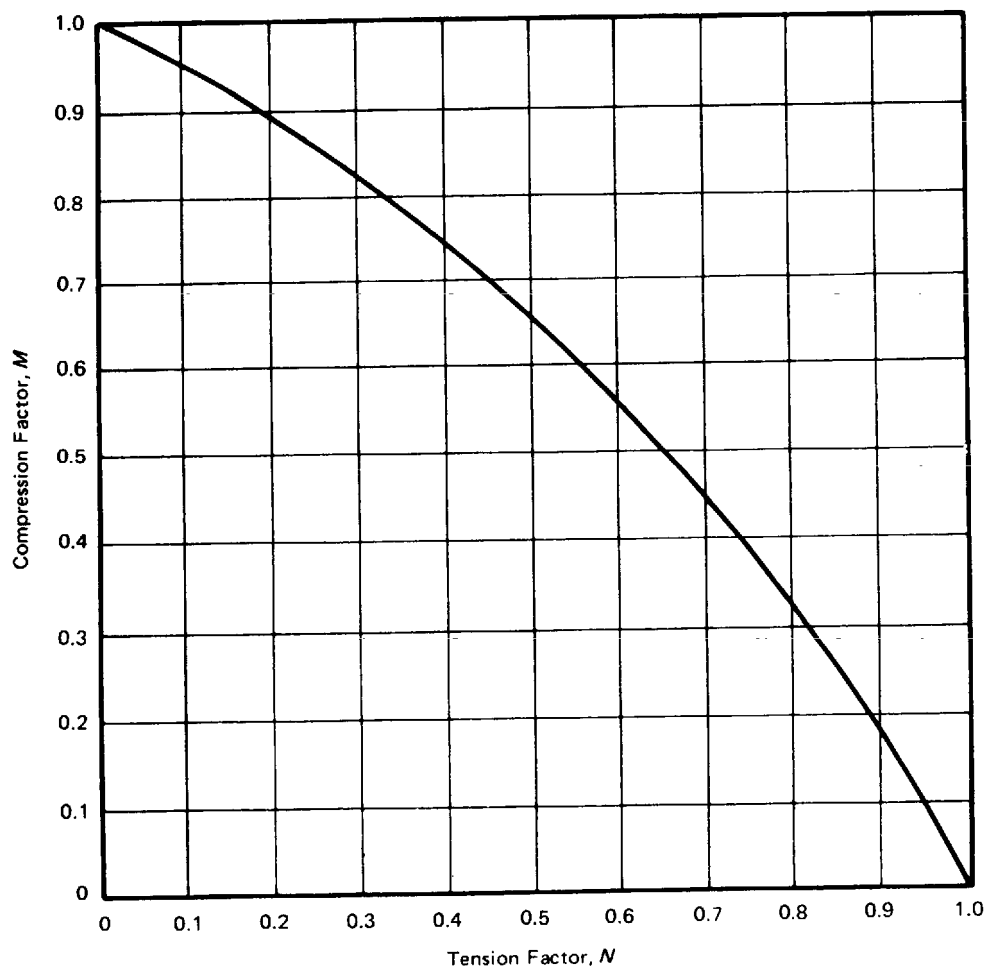
$$S_{cs} = 1,800,000 \frac{t - c}{R}$$

for $(t - c)/R$ values between 0.00667 and 0.0175:

$$S_{cs} = 10,150 + 277,400 \frac{t - c}{R}$$

for $(t - c)/R$ values greater than 0.0175:

⁴⁴ These rules do not apply when the circumferential stress on a cylindrical wall is compressive as in a cylinder acted upon by external pressure.



$$N^2 + MN + M^2 = 1$$

or

$$(S_t/S_{ts})^2 + (S_t/S_{ts})(S_c/S_{cs}) + (S_c/S_{cs})^2 = 1$$

where

$$N = S_t/S_{ts}$$

S_t = the tensile stress, at the point under consideration

S_{ts} = the maximum allowable stress for simple tension

$$M = S_c/S_{cs}$$

S_c = the compressive stress, at the point under consideration

S_{cs} = the maximum allowable longitudinal compressive stress, for a cylindrical wall acted upon by an axial load with neither a tensile nor a compressive force acting concurrently in a circumferential direction; determined in accordance with NC-3922.3(a) for the thickness to radius ratio involved

FIG. NC-3922.1-2 REDUCTION OF DESIGN STRESSES REQUIRED TO ALLOW FOR
BIAXIAL STRESSES OF OPPOSITE SIGN

FIG. NC-3922.1-2 REDUCTION OF DESIGN STRESSES REQUIRED TO ALLOW FOR BIAxIAL STRESSES OF OPPOSITE SIGN

$$S_{cs} = 15,000$$

However, the values of S_{cs} calculated as above, but with R taken as equal to R_1 when the compressive unit force under consideration is latitudinal or with R taken as equal to R_2 when the compressive unit force is meridional, form the basis for the rules given in (b), (c), and (d) below for walls of double curvature.

(b) If both the meridional and latitudinal unit forces T_1 and T_2 are compressive and of equal magnitude, the computed compressive stress S_{cc} shall not exceed a value S_{ca} established for the applicable thickness-radius ratio as follows:

for $(t - c)/R$ values less than 0.00667:

$$S_{ca} = 1,000,000 (t - c)/R$$

for $(t - c)/R$ values between 0.00667 and 0.0175:

$$S_{ca} = 5650 + 154,200 (t - c)/R$$

for $(t - c)/R$ values greater than 0.0175:

$$S_{ca} = 8340$$

(c) If both the meridional and latitudinal unit forces T_1 and T_2 are compressive but of unequal magnitude, both the larger and the smaller computed compressive stresses shall be limited to values which satisfy the following requirements:⁴⁵

$$\frac{(\text{larger stress}) + 0.8 (\text{smaller stress})}{S_{cs} \text{ determined using } R \text{ for the larger unit force}} \leq 1.0$$

$$\frac{1.8 (\text{smaller stress})}{S_{cs} \text{ determined using } R \text{ for the smaller unit force}} \leq 1.0$$

(d) If the meridional unit force T_1 is compressive and the coexistent unit force T_2 is tensile, or if T_2 is compressive and T_1 is tensile, the computed compressive stress S_{cc} shall not exceed a value of S_{ca} determined from Fig. NC-3922.1-1 by entering the computed value of N and the value of $(t - c)/R$ associated with the compressive unit stress, and reading the value of S_c which corresponds to that point. Such value of S_c will be the limiting value of S_{ca} for the given conditions.

⁴⁵ In these expressions if the unit force is latitudinal, R shall be considered to be R_1 and, if meridional, R shall be considered as equal to R_2 .

Section F.1 of Appendix F of API 620 Feb. 1970 Ed. gives examples illustrating the determination of allowable compressive stress values S_{ca} .

NC-3922.4 Maximum Shearing Stresses.

The maximum shearing stresses in welds used for attaching manways, nozzles, reinforcements, or other attachments to the walls of a tank, and in sections of manway or nozzle necks serving as reinforcement attachment, shall not exceed 80% of the applicable maximum allowable tensile stress value S_{ts} .

NC-3923 Maximum Allowable Stress Values for Structural Members

NC-3923.1 General Stress Limits.

Subject to the provisions of NC-3923.2(c), the maximum stresses in internal or external diaphragms, webs, trusses, columns, and other framing, as determined for any loadings, shall not exceed the applicable allowable stresses given in Table NC-3923.1-1.

NC-3923.2 Slenderness Ratio Limits.

The slenderness ratio (the ratio of the unbraced length l to the least radius of gyration r) for structural members in compression and for tension members other than rods shall not exceed the following values, except as provided in (a) below:

	Maximum l/r
For main compression members	120
For bracing and other secondary members in compression	200
For main tension members	240
For bracing and other secondary members in tension	300

(a) The slenderness ratio of main compression members inside of a tank may exceed 120, but not 200, provided the member is not ordinarily subject to shock or vibration loads and the unit stress under full Design Loadings does not exceed the following fraction of the stress value given in Table NC-3923.1-1 for the member's actual l/r ratio:

$$f = 1.6 - \frac{l}{200r}$$

(b) The gross and net sections of structural members shall be as determined in (1) through (5) below.

(1) The gross section of a member at any point shall be determined by summing the products of the thickness and the gross width of each element as measured normal to the axis of the member. The net

Page 209

section shall be determined by substituting for the gross width the net width which, in the case of a member having a chain of holes extending across it in any diagonal or zigzag line, shall be computed by deducting from the gross width the sum of the diameters of all holes in the chain and adding, for each gage space in the chain, the following quantity:

$$\frac{s^2}{4g}$$

Pages 210-211

TABLE NC-3923.1-1
MAXIMUM ALLOWABLE STRESS VALUES FOR STRUCTURAL MEMBERS

	Column 1 For Members Not Subject to Pressure-Imposed Loads, ksi	Column 2 For Internal Members Resisting Pressure, ksi
(a) Tension		
Rolled steel, on net section.....	18.0	[Note (1)]
Butt welds, on cross-sectional area in, or at edge of, weld ²	18.0	[Note (1)]
Bolts and other threaded parts, on net area at root of thread.....	18.0	[Note (1)]
(b) Compression		
For axially loaded structural columns, structural bracing, and structural secondary members, on gross section	$\frac{18}{1 + \frac{f^2}{18,000r^2}}$ but not to exceed 15	Same values as for Column 1
For axially loaded tubular columns, tubular bracing, and tubular secondary members, on gross section (minimum permissible thickness, $\frac{1}{4}$ in.)	$\frac{18Y}{1 + \frac{f^2}{18,000r^2}}$ but not to exceed 15Y	Same values as for Column 1
where f = unbraced length of column, in. r = corresponding least radius of gyration of column, in. R = outside radius of tubular column, in. t = thickness of tubular column, in. Y = unity (1.0) for values of t/R equal to or exceeding 0.015 Y = $\frac{2}{3} (100t/R) [2 - \frac{2}{3} (100t/R)]$, for values of t/R less than 0.015		
Butt welds, on least cross-sectional area in, or at edge of, weld (crushing)	18.0	15.0
Plate girder stiffeners, on gross section.....	18.0	15.0
(c) Bending		
Tension on extreme fibers of rolled sections, plate girders, and built-up members.....	18.0	[Note (1)]
Compression on extreme fibers of rolled sections, plate girders, and built-up members: With Id/bt not in excess of 600.....	18.0	Same as tension value ¹

**TABLE NC-3923.1-1 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES FOR STRUCTURAL MEMBERS**

	Column 1 For Members Not Subject to Pressure-Imposed Loads, ksi	Column 2 For Internal Members Resisting Pressure, ksi
With $l/d/bt$ in excess of 600	10,800.0	(600) × tension value ¹
	$l/d/bt$	$l/d/bt$
where		
l = unsupported length of the member, in., except that, for a cantilever beam not fully stayed at its outer end against translation or rotation, l shall be taken as twice the length of the compression flange		
d = depth of the member, in.		
b = width of its compression flange, in.		
t = thickness of its compression flange, in.		
Stress on extreme fibers of pins	27.0	20.0
Members subjected to both axial and bending loads shall be so proportioned that the maximum combined axial and bending stress will not exceed the permissible value for axial loading alone.		
Fiber stresses in butt welds resulting from bending shall not exceed the values prescribed for tension and compression, respec- tively. (Such values for welds in tension must be multiplied by the applicable joint efficiency.)		
(d) Shearing		
Pins and turned bolts in reamed or drilled holes.....	13.5	12.0
Unfinished bolts	10.0	8.0
Webs of beams and plate girders where h/t is not more than 60, or where web is adequately stiffened, on gross section of web	12.0	Two-thirds of tension value ¹
Webs of beams and plate girders where web is not adequately stiffened and h/t is more than 60, on gross section of web.....	18.0	Tension value ¹
	$1 + \frac{h^2}{7200t^2}$	$1 + \frac{h^2}{7200t^2}$
where		
h = clear distance between web flanges, in.		
t = thickness of the web, in.		
Fillet welds where load is perpendicular to length of weld, on section through throat ²	12.6	70% of tension value ¹
Fillet welds where load is parallel to length of weld, on section through throat ²	9.0	50% of tension value ¹
Plug welds or slot welds, on effective faying-surface area of weld ²	11.7	65% of tension value ¹
Butt welds, on least cross-sectional area in, or at edge of, weld ²	14.4	80% of tension value ¹

TABLE NC-3923.1-1 (CONT'D) MAXIMUM ALLOWABLE STRESS VALUES FOR STRUCTURAL MEMBERS

TABLE ND-3923.1-1 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES FOR STRUCTURAL MEMBERS

	Column 1 For Members Not Subject to Pressure-Imposed Loads, ksi	Column 2 For Internal Members Resisting Pressure, ksi
(e) Bearing		
Pins and turned bolts in reamed or drilled holes:		
Load applied to bolt at only one side of member connected.....	24.0	1.33 (tension value ¹)
Load approximately uniformly distributed across thickness of member connected	30.0	1.67 (tension value ¹)
Unfinished bolts:		
Load applied to bolt at only one side of member connected.....	16.0	0.9 (tension value ¹)
Load approximately uniformly distributed across thickness of member connected	20.0	1.1 (tension value ¹)

NOTES:

(1) Tables 1A, 1B, and 3, Section II, Part D, Subpart 1.

(2) All values for butt welds in tension or shear shall be multiplied by the applicable joint efficiency. These values are obtained by combining the following: a factor of 80% for shear strength of weld metal; an efficiency factor of approximately 85% for fillet welds or 80% for plug welds and slot welds; and a factor of 100% for perpendicular loading or approximately 75% for parallel loading.

TABLE NC-3923.1-1 (CONT'D) MAXIMUM ALLOWABLE STRESS VALUES FOR STRUCTURAL MEMBERS

where

s = longitudinal spacing (pitch), in., of any two successive holes
 g = transverse spacing (gage), in., of the same two holes

(2) In the case of angles, the gage for holes in opposite legs shall be the sum of the gages from the back of the angle less the thickness.

(3) In determining the net section across plug or slot welds, the weld metal shall not be considered as adding to the net area.

(4) For splice members, the thickness considered shall be only that part of the thickness of the member which has been developed by the welds or other attachments beyond the section considered.

(5) In pin connected tension members other than forged eyebars, the net section across the pinhole, transverse to the axis of the member, shall not be less than 135%, and the net section beyond the pinhole, parallel to the axis of the member, shall not be less than 90% of the net section of the body of the member. The net width of a pin connected member across the pinhole, transverse to the axis of the member, shall not exceed eight times the thickness of the member at the pin, unless lateral buckling is prevented.

(c) External structural or tubular columns and framing subject to stresses produced by a combination of wind and other applicable loads specified in NC-3921.4 may be proportioned for unit stresses 25% greater than those specified in Table NC-3923.1-1, provided the section thus required is not less than that required for all other applicable loads combined on the basis of the unit stresses specified in Table NC-3923.1-1. A corresponding increase may be applied to the allowable unit stresses in the connecting bolts or welds.

NC-3930 DESIGN PROCEDURE

NC-3931 Design of Tank Walls

(a) Free body analyses shall be made at successive levels from the top to the bottom of the tank for the purpose of determining the magnitude and character of the meridional and latitudinal unit forces which will exist in the walls of the tank at critical levels under

Page 212

all the various combinations of gas pressure or partial vacuum and liquid head to be encountered in service which may have a controlling effect on the design. To this end it will sometimes be necessary to make several analyses at a given level of the tank to establish the governing conditions of gas pressure and liquid head for that level. The thicknesses required in the main walls of the tank shall then be computed by the applicable procedures given in NC-3932.3.

(b) For tanks having points of marked discontinuity in the direction of the meridional tangent, such as occur at the juncture between a conical or dished roof or bottom and a cylindrical sidewall or at the juncture between a conical reducer and a cylindrical sidewall, the portions of the tank near such points shall be designed in accordance with the provisions of NC-3933.

NC-3932 Design of Sidewalls, Roofs, and Bottoms

NC-3932.1 Nomenclature.

The symbols used are defined as follows:

P	$= P_L + P_G$ = total pressure, psi, acting at a given level of the tank under a particular condition of loading
P_L	= pressure resulting from the liquid head at the level under consideration in the tank, psi
P_G	= gas pressure, psi, above the surface of the liquid. The maximum value, a pressure not exceeding 15 psig, is the nominal pressure rating of the tank. P_G is positive except in computations for investigating the ability of a tank to withstand a partial vacuum, where its value is negative.
T_1	= meridional unit force in the wall of the tank at the level under consideration, lb/in. of latitudinal arc. T_1 is positive when in tension.
T_2	= latitudinal unit force in the wall of the tank at the level under consideration, lb/in. of meridional arc. T_2 is positive when in tension. In cylindrical sidewalls the latitudinal unit forces are circumferential unit forces.
R_1	= radius of curvature of the tank wall in a meridian plane, at the level under consideration, in. R_1 is to be considered negative when it is on the opposite side of the tank wall from R_2 except as provided in NC-3932.2(f).
R_2	= length, in., of the normal to the tank wall at the level under consideration, measured from the wall of the tank to its axis of revolution. R_2 is always positive except as provided in NC-3932.2(f).
W	= total weight, lb, of that portion of the tank and its contents, either above the level under consideration, as in Fig. NC-3932.1-1 sketch (b) or below such level, as in Fig. NC-3932.1-1 sketch (a) which is treated as a free body in the

	computations for such level. W shall be given the same sign as P , when acting in the same direction as the pressure on the horizontal face of the free body, and the opposite sign when acting in the opposite direction.
F	= summation, lb, of the vertical components of the forces in all internal or external ties, braces, diaphragms, trusses, columns, skirts, or other structural devices or supports acting on the free body. F shall be given the same sign as P when acting in the same direction as the pressure on the horizontal face of the free body, and the opposite sign when acting in the opposite direction.
A_T	= cross-sectional area of the interior of the tank at the level under consideration, sq in.
S_{ts}	= maximum allowable stress for simple tension, psi (Tables 1A, 1B, and 3, Section II, Part D, Subpart 1)
S_{ta}	= allowable tension stress, psi, as required in NC-3922.2(b)
S_{ca}	= allowable compression stress, psi, as required in NC-3922.3
S_{tc}	= calculated tension stress, psi, at the point under consideration
S_{cc}	= calculated compression stress, psi, at the point under consideration

NC-3932.2 Computation of Unit Forces

(a) At each level of the tank selected for free body analysis as specified in NC-3931 (Fig. NC-3932.1-1) and for each condition of gas and liquid loading which must be investigated at such level, the magnitude of the meridional and latitudinal unit forces in the wall of the tank shall be calculated from Eqs.⁴⁶ (1) and (2) below, except as provided in NC-3932.6 or NC-3933:

46 (a) Eq. (2) has been derived from a summation of the components, normal to the surface, of the T_1 and T_2 forces acting on a unit area of the tank wall subjected only to a pressure P . To be technically correct, the normal to the surface components of other loads, such as metal, snow, or insulation, should be added to or subtracted from the term P . For the usual internal Design Pressure, these added loads are small compared to the pressure P , and can be omitted without significant error. When the pressure P is relatively small, including the case of a partial vacuum loading, the other load components can have a substantial effect on the calculated T_2 force and the resultant thickness.

(b) Example F.3.01 in Appendix F of API 620 Feb. 1970 Edition calculates the required roof thicknesses under a small vacuum by considering the metal, insulation, and snow loads in Eqs. (1) through (4). The designer should note that if these loads had been omitted the calculated thicknesses would have been much less than the correct values.

(c) In Eqs. (1), (3), (6), and (8), the term W is intended to include loads, such as metal weight, of significant value. At points away from the vertical center line of the roof, the value of T_2 is required for the thickness calculations of Eqs. (16), (18), and (20), and the value of P in Eqs. (2), (4), and (7) must be modified by the normal components of the added loads for the correct determination of T_2 .

$$T_1 = \frac{R_2}{2} \left(P + \frac{W + F}{A_T} \right) \quad (1)$$

$$\begin{aligned} T_2 &= R_2 \left(P - \frac{T_1}{R_1} \right) \\ &= R_2 \left[P \left(1 - \frac{R_2}{2R_1} \right) - \frac{R_2}{2R_1} \left(\frac{W + F}{A_T} \right) \right] \end{aligned} \quad (2)$$

(1 - 2)

(b) Positive values of T_1 and T_2 indicate tensile forces and negative values indicate compressive forces.

(c) It will usually be necessary to make such analyses at the level of each horizontal joint in the sidewalls, roof, and bottom of the tank and at any intermediate levels at which the center of curvature changes significantly. Moreover, the maximum total pressure, liquid head plus gas pressure which can exist at a given level will not necessarily be the governing condition for that level; sufficient analyses shall be made at each level to establish that combination of liquid head and gas pressure or partial vacuum which, in conjunction with the allowable tensile and compressive stresses, will control the design at such level. Even though a tank may normally be operated at a fixed height of liquid contents, it shall be made safe for any conditions which might develop in filling or emptying the tank.

(d) The values for a point at a horizontal distance x from the vertical axis of a roof or bottom in which the length of the horizontal semiaxis a is two times the length of the vertical semiaxis b may be determined by multiplying the length a by the factor from Table NC-3932.2(d)-1. Values for ellipsoidal shapes of other proportions shall be calculated from the following equations:

$$R_1 = \frac{b^2}{a^4} \left[\frac{a^4}{b^2} + \left(1 - \frac{a^2}{b^2} \right) x^2 \right]^{3/2} = \frac{b^2 (R_2)^3}{a^4}$$

$$R_2 = \left[\frac{a^4}{b^2} + \left(1 - \frac{a^2}{b^2} \right) x^2 \right]^{1/2}$$

(e) Equations (1) and (2) are general equations applicable to any tank having a single vertical axis of revolution and to any free body which is isolated by a horizontal plane which intersects the walls of the tank in only one circle [NC-3932.2(f)]. For shapes most commonly used, these equations reduce to the simplified equations given in (1) through (3) below for the respective shapes indicated.

(1) For a spherical tank or spherical segment of a tank:

$R_1 = R_2 = R_s$, the spherical radius of the tank or segment, and Eqs. (1) and (2) become:

$$T_1 = \frac{R_s}{2} \left(P + \frac{W+F}{A_T} \right) \quad (3)$$

$$T_2 = R_s P - T_1 \quad (4)$$

(3 - 4)

If the sphere is for gas pressure only and if $W+F/A_T$ is negligible as compared with P_G Eqs. (3) and (4) reduce to:

$$(5) T_1 = T_2 = \frac{1}{2} P_G R_s$$

(2) For a conical roof or bottom:

$$R_1 = \text{infinity, and } R_2 = \frac{R_3}{\cos \alpha}$$

where

R_3

= horizontal radius of the base of the cone at the level under consideration, in.

α

= one-half the included apex angle of the conical roof or bottom

For this condition, Eqs. (1) and (2) reduce to:

$$T_1 = \left(\frac{R_3}{2 \cos \alpha} \right) \left(P + \frac{W + F}{A_T} \right) \quad (6)$$

$$T_2 = \frac{PR_3}{\cos \alpha} \quad (7)$$

(6 - 7)

(3) For cylindrical sidewalls of a vertical tank:

$R_1 = \text{infinity}$, and $R_2 = R_c$, the radius of the cylinder, and Eqs. (1) and (2) become:

$$T_1 = \frac{R_c}{2} \left(P + \frac{W + F}{A_T} \right) \quad (8)$$

$$T_2 = PR_c \quad (9)$$

(8 - 9)

If the cylinder is for gas pressure only, and if $W+F/A_T$

Page 214

is negligible as compared with P_G Eqs. (8) and (9) reduce to:

$$(10) T_1 = \frac{1}{2} P_G R_c$$

$$(11) T_2 = P_G R_c$$

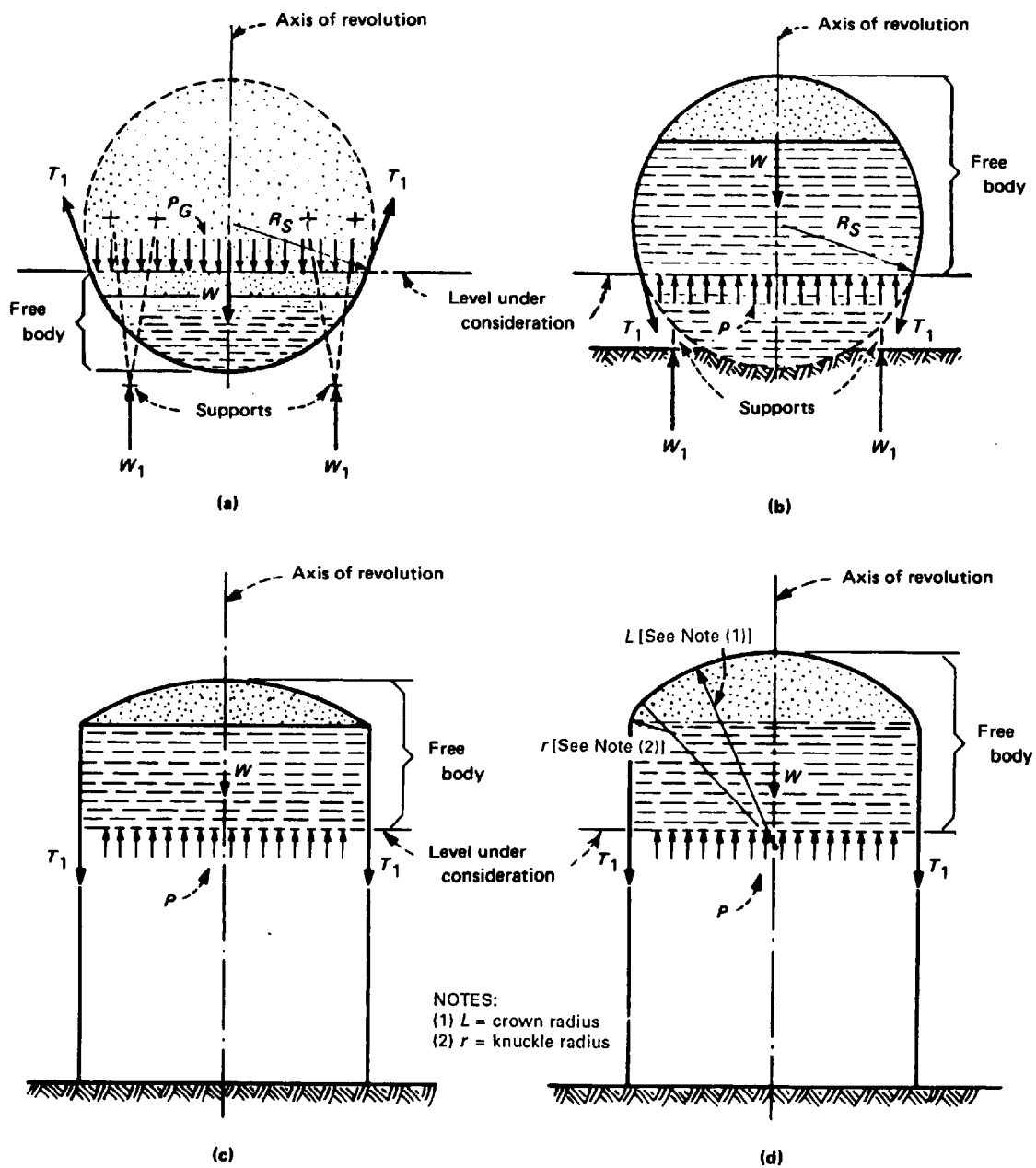


FIG. NC-3932.1-1 SOME TYPICAL FREE BODY DIAGRAMS FOR CERTAIN SHAPES OF TANKS

FIG. NC-3932.1-1 SOME TYPICAL FREE BODY DIAGRAMS FOR CERTAIN SHAPES OF TANKS

TABLE NC-3932.2(d)-1
FACTORS FOR DETERMINING VALUES OF
 R_1 AND R_2 FOR 2:1 ELLIPSOIDAL
ROOFS AND BOTTOMS

x/α	$u = R_1/\alpha$	$v = R_2/\alpha$
0.00	2.000	2.000
0.05	1.994	1.998
0.10	1.978	1.993
0.15	1.950	1.983
0.20	1.911	1.970
0.25	1.861	1.953
0.30	1.801	1.931
0.35	1.731	1.906
0.40	1.651	1.876
0.45	1.562	1.842
0.50	1.465	1.803
0.55	1.360	1.759
0.60	1.247	1.709
0.65	1.129	1.653
0.70	1.006	1.591
0.75	0.879	1.521
0.80	0.750	1.442
0.85	0.620	1.354
0.90	0.492	1.253
0.95	0.367	1.137
1.00	0.250	1.000

x = horizontal distance from point in roof or bottom to axis of revolution

α = horizontal semiaxis of elliptical cross section

$R_1 = u\alpha$

$R_2 = v\alpha$

TABLE NC-3932.2(d)-1 FACTORS FOR DETERMINING VALUES OF R_1 AND R_2 FOR 2:1 ELLIPSOIDAL ROOFS AND BOTTOMS

(f) In the case of a torispherical head shown in Fig. NC-3932.1-1(d), applicable equations for the meridional and latitudinal unit forces in the walls of the segment are as in Eqs. (12) and (13):

$$(12) T_1 = (\text{in preparation})$$

$$(13) T_2 = (\text{in preparation})$$

NC-3932.3 Required Thickness.

The thickness of the tank wall at any given level shall be not less than the largest value of t as determined for the level by the methods prescribed in (a) through (d) below. In addition, provision shall be made by means of additional metal, where needed, for the loadings other than internal pressure or possible partial vacuum enumerated in NC-3921.4 and if the tank walls have points of marked discontinuity in the direction of the meridional tangent, such as occur at the juncture between a conical or dished roof or bottom and a cylindrical sidewall, the portions of the tank near such points shall be designed in accordance with the provisions of NC-3933.

(a) If the unit forces T_1 and T_2 are both positive for the governing combination of gas pressure or partial vacuum and liquid head at a given level of the tank, the larger of the two shall be used for computing the thickness required at such level, as follows:

$$t = \frac{T_1}{S_{ts}} + c \quad \text{or} \quad t = \frac{T_2}{S_{ts}} + c \quad (14)$$

(14)

(b) If the unit force T_1 is positive and T_2 is negative for the governing combination of gas pressure or partial vacuum and liquid head at a given level of the tank, or if T_2 is positive and T_1 is negative, the thickness of tank wall required for this condition shall be determined by assuming different thicknesses until one is found for which the simultaneous values of the calculated tension stress S_{tc} and the calculated compression stress S_{cc} satisfy the requirements of NC-3922.2 (b) and NC-3922.3(d), respectively. The determination of this thickness will be facilitated by using a graphical solution such as illustrated in Appendix F, Section F.2 of API Standard 620, Feb. 1970 Edition. If the unit force acting in compression does not exceed 5% of the coexistent tensile unit force acting perpendicular to it, the designer may determine the thickness required for this condition by using the method specified in (a) above.

(c) If the unit forces T_1 and T_2 are both negative and are of equal magnitude for the governing condition of loading at a given level of the tank, the thickness of tank wall required shall be calculated using:

$$t = \frac{T_1}{S_{ca}} + c = \frac{T_2}{S_{ca}} + c \quad (15)$$

(15)

where S_{ca} has the appropriate value for the thickness-radius ratio, as required in NC-3922.3(b).

(d) If the unit forces T_1 and T_2 are both negative, but of unequal magnitude, for the governing condition of loading at a given level, the thickness of tank wall required for this condition shall be the largest of those

Page 216

thickness values, calculated by the following procedure, which show a proper correlation with the respective thickness-radius ratios involved in their calculation (Steps 2 and 4).

Step 1: Calculate the values of

$$t = \frac{\sqrt{(T' + 0.8T'')R'}}{1342} + c \quad (16)$$

(16)

and

$$t = \frac{\sqrt{T' R''}}{1000} + c \quad (17)$$

(17) using values of T' equal to the larger of the two coexistent unit forces, T'' equal to the smaller of the two unit forces, and taking R' and R'' as equal to R_1 and R_2 , respectively, if the larger unit force is latitudinal; but, conversely, taking R' and R'' as equal to R_2 and R_1 , respectively, if the larger unit force is meridional.

Step 2: Deduct the corrosion allowance from each of the two thicknesses calculated in Step 1 and check the thickness-radius ratio $(t - c)/R$ for each based on the value of R used in Eq. (16) or (17). If both thickness-radius ratios are less than 0.00667, the larger of the two thicknesses calculated in Step 1 will be the required thickness for the condition under consideration. Otherwise, proceed with Step 3.

Step 3: If one or both thickness-radius ratios determined in Step 2 exceed 0.00667, calculate the values of

$$t = \frac{T' + 0.8T''}{15,000} + c \quad (18)$$

(18)

and

$$t = \frac{T''}{8340} + c \quad (19)$$

(19)

Step 4: Deduct the corrosion allowance from each of the two thicknesses calculated in Step 3 and check the thickness-radius ratio $(t - c)/R$ for each using a value of R equal to R' as defined in Step 1 in connection with the thickness determined from Eq. (18) and a value of R equal to R_{dp} in connection with the thickness determined from Eq. (19). If both such thickness-radius ratios are greater than 0.0175, the larger of the two thicknesses calculated in Step 3 will be the required thickness for the condition under consideration. Otherwise, proceed with Step 5.

Step 5: If one or more of the thickness-radius ratios determined in Step 2 or Step 4 fall between 0.00667 and 0.0175 and the thickness involved was calculated by Eq. (16) or (18), find a thickness which satisfies the following equation:

$$\frac{10,150 (t - c) + 277,400 (t - c)^2}{R'} = T' + 0.8T'' \quad (20)$$

(20)

or, if the thickness involved was calculated by Eq. (17) or (19), find a thickness which satisfies the following equation:

$$\frac{5,650 (t - c) + 154,200 (t - c)^2}{R''} = T'' \quad (21)$$

(21)

Step 6: Make a selection of thickness from the values calculated. Calculate the values of S_{cc} for both T_1 and T_2 and check that the values of S_{cc} satisfy the requirements of NC-3922.3(c). Adjustment in the thickness may be required to make the values of S_{cc} satisfy the requirements of NC-3922.3(c).

NOTE: The procedure described in NC-3932.3(d) is predicated on the assumption that the problem is one in which biaxial compression with unit forces of unequal magnitude is the governing condition. In many cases, however, a tentative thickness will have been established previously by other design considerations and only needs to be checked for the external pressure or partial vacuum condition. In such cases, the problem is greatly simplified because the designer has only to calculate the values of S_{cc} for both T_1 and T_2 and then check to see that these values satisfy the requirements of NC-3922.3(c), as specified in Step 6 [see Section F.3 of Appendix I of API Standard 620 Feb. 1970 Edition, for examples illustrating the application of NC-3932.3(a)].

NC-3932.4 Least Permissible Thickness.

In no event shall the net thickness after fabrication of any plate subject to pressure imposed membrane stresses be less than $\frac{3}{16}$ in., exclusive of corrosion allowance. For tanks having cylindrical sidewalls with diameters from 60 ft up to but not including 120 ft, such thickness for sidewall plates shall not be less than $\frac{1}{4}$ in. exclusive of corrosion allowance.

NC-3932.5 External Pressure Limitations.

The thickness computed by the formulas and procedures specified in NC-3932, using a negative value of P_G equal to the partial vacuum for which the tank is to be designed, will ensure stability against collapse for tank surfaces of double curvature in which the meridional radius R_1 is equal to or less than R_2 or does not exceed R_2 by more than a very small amount. Data on the stability of sidewall surfaces of prolate spheroids are lacking and it is not intended that the equations and procedures be used for evaluating the stability of such surfaces or of cylindrical surfaces against external pressure. However, cylindrical sidewalls of vertical tanks designed in accordance with these rules for storage

Page 217

of liquids,⁴⁷ with the thickness of upper courses not less than specified in NC-3932.4 for the size of tank involved and with increasing thicknesses from top to bottom as required for the combined gas and liquid loadings, may safely be

subjected to a partial vacuum in the gas or vapor space not exceeding 1 oz/sq in.⁴⁸ with the operating liquid level in the tank at any stage from full to empty.

NC-3932.6 Special Considerations Applicable to Bottoms Resting Directly on Foundations

(a) *Uplift Considerations.* In the case of tanks with cylindrical sidewalls and flat bottoms, the uplift⁴⁹ from the pressure acting on the underside of the roof must not exceed the weight of the sidewalls plus the weight of that portion of the roof which is carried by the sidewalls when no uplift exists, unless such excess is counteracted by increasing the magnitude of the downward acting forces. This shall be a matter of agreement between the Certificate Holder and Owner. Similar precautions shall be taken with flat bottomed tanks of other shapes. All weights used in such calculations shall be based on net thicknesses of the materials, exclusive of corrosion allowance.

(b) *Foundation Considerations.* The type of foundation used for supporting the tank shall be taken into account in the design of bottom plates and welds. For recommended practice for construction of foundations, see API Standard 620, Feb. 1970 Edition, Appendix C.

NC-3933 Design of Roof and Bottom Knuckle Regions and Compression Rings

NC-3933.1 Nomenclature.

The symbols used are defined as follows:

w_h	= width, in., of the roof or bottom plate considered to participate in resisting the circumferential force acting on the compression ring region
w_c	= corresponding width, in., of the participating sidewall plate
t_h	= thickness, in., of the roof or bottom plate at and near the juncture of the roof or bottom and sidewalls, including corrosion allowance

⁴⁷ These rules do not contain provisions in respect to the design of cylindrical sidewalls subject to partial internal vacuum in tanks constructed for storage of gases or vapors alone.

⁴⁸ The vacuum relief valve or valves shall be set to open at a smaller partial vacuum so that the 1 oz/sq in. partial vacuum will not be exceeded when the inflow of air or gas through the valves is at its maximum specified rate.

⁴⁹ If external anchor bolts are used for resisting such uplift, it is recommended that their nominal diameter be not less than 1 in. plus a corrosion allowance of at least $\frac{1}{4}$ in. on the diameter.

t_c	= corresponding thickness, in., of the cylindrical sidewalls at and near such juncture
R_2	= length, in., of the normal to the roof or bottom at the juncture between the roof or bottom and the sidewalls, measured from the roof or bottom to the tank's vertical axis of revolution
R_c	= horizontal radius, in., of the cylindrical sidewall at its juncture with the roof or bottom
T_1	= meridional unit force in the roof or bottom of the tank at its juncture with the sidewall, lb/in. of circumferential arc
T_2	= corresponding latitudinal unit force ⁵⁰ in the roof or bottom, lb/in. of meridian arc
T_{2s}	= circumferential unit force ⁵⁰ in the cylindrical sidewall of the tank at its juncture with the roof or bottom, lb/in., measured along an element of the cylinder

α	= angle between the direction of T_1 and a vertical line. In a conical surface it is also one-half of the total vertex angle of the cone.
Q	= total circumferential force, lb, acting on a vertical cross section through the compression ring region
A_c	= net area, sq in., of the vertical cross section of metal required in the compression ring region, exclusive of all corrosion allowances
S_{ts}	= maximum allowable stress value for simple tension, psi (Tables 1A, 1B, and 3, Section II, Part D, Subpart 1)

NC-3933.2 General Requirements.

When the roof or bottom of a tank is a cone or partial sphere and is attached to cylindrical sidewalls, the membrane stresses in the roof or bottom act inward on the periphery of the sidewalls. This results in circumferential compressive forces at the juncture, which shall be resisted either by a knuckle curvature in the roof or bottom or by a limited zone at the juncture of the intersecting roof or bottom plates and sidewall plates, supplemented in some cases by an angle, a rectangular bar, or a ring girder.

50 These forces are computed by the applicable equations in NC-3932

NC-3933.3 Requirements for Knuckle Regions

(a) If a curved knuckle is provided, a ring girder or other form of compression ring shall not be used and there shall be no sudden changes in the direction of a meridional line at any point. In addition, the radius of curvature of the knuckle in a meridional plane shall not be less than 6%, and preferably not less than 12%,

Page 218

of the diameter of the sidewalls.⁵¹ Subject to the provisions of (b) below, the thickness of the knuckle at all points shall satisfy the requirements of NC-3932.

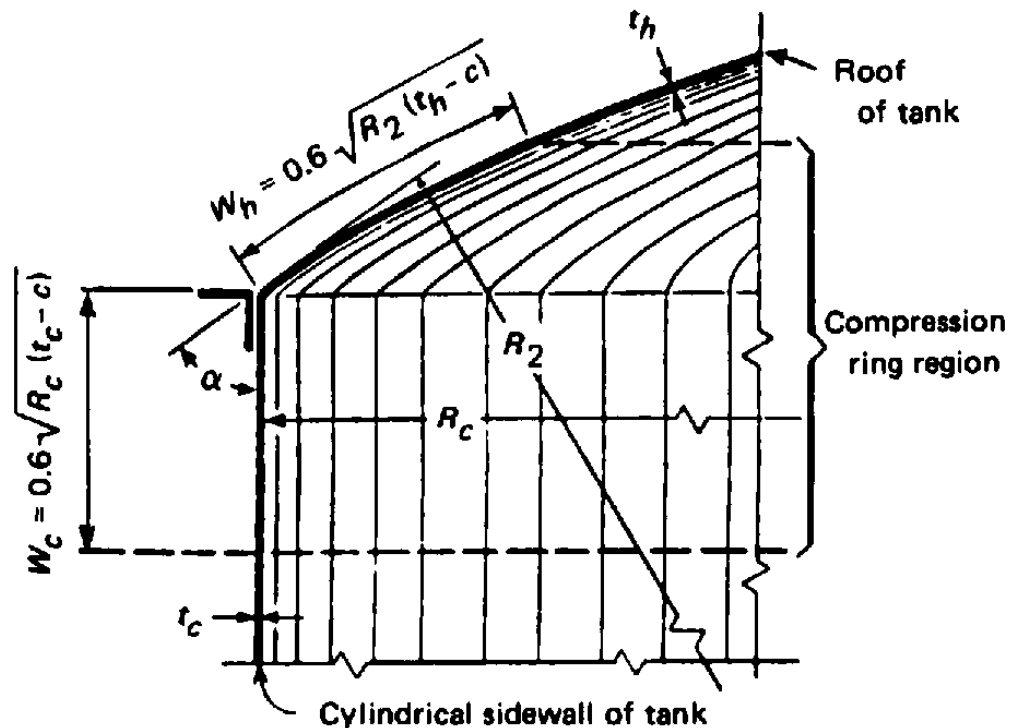


FIG. NC-3933.4(a)-1 COMPRESSION RING REGION

FIG. NC-3933.4(a)-1 COMPRESSION RING REGION

(b) Application of the equations in NC-3932.2 to levels immediately above and below a point where two surfaces of differing meridional curvature have a common meridional tangent, as at the juncture between the knuckle region and the spherically dished portion of a torispherical roof, will result in the calculation of two latitudinal unit forces, differing in magnitude and possibly in sign, at the same point. The latitudinal unit force at such a point will be between the two calculated values, depending on the geometry of the tank wall in that area.

NC-3933.4 Requirements for Compression Rings

(a) If a curved knuckle is not provided, forces shall be resisted by other means in the compression ring region of the tank walls. The zone of the tank walls at the juncture between the roof or bottom and the sidewalls includes that width of plate on each side of the juncture which is considered to participate in resisting these forces [Fig. NC-3933.4(a)-1]. The thickness of the wall plate on either side of the juncture shall not be less than the thickness needed to satisfy the requirements of NC-3932, and the widths of plate making up the compression ring region shall be computed from the following equations:

51 Use of a knuckle radius as small as 6% of the sidewall diameter will frequently require an excessively heavy thickness for the knuckle region. The thickness requirements for such region will be found more reasonable if a larger knuckle radius is used.

$$w_h = 0.6 \sqrt{R_2 (t_h - c)} \quad (22)$$

$$w_c = 0.6 \sqrt{R_c (t_c - c)} \quad (23)$$

(22 - 23)

(b) The magnitude of the total circumferential force acting on any vertical cross section through the compression ring region shall be computed as follows:

$$(24) Q = T_2 w_h + T_2 w_c - T_1 R_c \sin \alpha$$

and the net cross-sectional area provided in the compression ring region shall not be less than that found to be required by the following equation:

$$A_c = \frac{Q}{15,000} \quad \text{or} \quad \frac{Q}{S_{ts}} \quad (25)$$

(25) depending on whether the value of Q as determined by Eq. (24) is negative⁵² or positive.

NC-3933.5 Details of Compression Ring Regions

(a) If the force Q is negative, indicating compression, the horizontal projection of the effective compression ring region shall have a width in a radial direction not less than 0.015 times the horizontal radius of the tank wall at the level of the juncture between the roof or bottom and the sidewalls. If such projected width does not meet this requirement, appropriate corrective measures shall be taken as specified in this subparagraph.

⁵² Because of the discontinuities and other conditions found in a compression ring region, biaxial stress design criteria are not considered applicable for a compressive force determined as in Eq.

(24). Experience has shown that a compressive stress of the order of 15.0 ksi as indicated in Eq. (25), is permissible in this case, provided the requirements of NC-3933.5 are satisfied.

(b) Whenever the circumferential force Q determined in accordance with NC-3933.4 is of such magnitude that the area required by Eq. (25) is not provided in a compression ring region with plates of the minimum thicknesses established by the requirements of NC-3932, or when Q is compressive and the horizontal projection of the width w_h is less than specified in NC-3933.5(a), the compression ring region shall be reinforced either by thickening the roof or bottom and

sidewall plates as required to provide a compression ring region having the necessary cross-sectional area and width as determined on the basis of the thicker

plates,⁵³ or by adding an angle, a rectangular bar, or a ring girder at the juncture of the roof or bottom and sidewall plates, or by a combination of these alternatives.

(c) An angle, bar, or ring girder, if used, may be located either inside or outside of the tank⁵⁴ and shall have a cross section of such dimensions that:

(1) its area makes up the deficiency between the area A_c required by Eq. (25), and the cross-sectional area provided by the compression ring region in the walls of the tank;

(2) the horizontal width of the angle, bar, or ring girder is not less than 0.015 times the horizontal radius R_c of the tank wall at the level of the juncture of the roof or bottom and the sidewalls, except that, when the cross-sectional area to be added in an angle or bar is not more than one-half of the total area required by Eq. (25), the width requirement for this member may be disregarded, provided the horizontal projection of the width w_h of participating roof or bottom plates alone is equal to or greater than $0.015R_c$ or, with an angle or bar located on the outside of a tank, the sum of the projection of the width w_h and the horizontal width of the added angle or bar is equal to or greater than $0.015R_c$.

(3) when bracing must be provided as specified in NC-3933.5(h), the moment of inertia of the cross section about a horizontal axis shall be not less than that required by Eq. (26).

53 Note that, unless the effect of the unit forces T_2 and T_3 on the resulting increments in width of participating plate may safely be neglected, the use of thicker plates involves recomputing not only w_h and w_c but also Q and A_c for the increased plate thicknesses; hence, the design of the compression ring region in this case resolves into a trial and error procedure.

54 See Fig. NC-3933.5(d)-1 for some acceptable details of construction of compression rings.

(d) When the vertical leg of an angle ring or a vertical flange of a ring girder is located on the sidewall of the tank, it may be built into the sidewall if its thickness is not less than that of the adjoining wall plates. However, if this construction is not used, the leg, edge, or flange of the compression ring next to the tank shall make contact with the wall of the tank around the entire circumference and, except as provided in (e) below, shall be attached along both the top and bottom edges by continuous fillet welds. These welds shall be of sufficient size to transmit the portion, Q_p , of the total circumferential force Q , to the compression ring angle, bar, or girder, assuming, in the case of welds separated by the width of a leg or flange of a structural member as shown in Fig. NC-3933.5(d)-1 sketches (a) and (d), that only the weld nearest the roof or bottom is effective. The part thicknesses and weld sizes in Table NC-4247.6(d)-1 relate to dimensions in the as-welded condition before deduction of corrosion allowances, but all other part thicknesses and weld sizes referred to, in this subparagraph, relate to dimensions after deduction of corrosion allowance.

(e) If a continuous weld is not needed for strength or as a seal against corrosive elements, attachment welds along the lower edge of a compression ring on the outside of a tank may be intermittent, provided:

(1) the summation of their lengths is not less than one-half the circumference of the tank;

(2) the unattached width of tank wall between the ends of welds does not exceed eight times the tank wall thickness exclusive of corrosion allowance;

(3) the welds are of such size as needed for strength but in no case smaller than specified in Table NC-4247.6(d)-1.

(f) The projecting part of a compression ring shall be placed as close as possible to the juncture between the roof or bottom plates and the sidewall plates.

(g) If a compression ring on either the inside or outside of a tank is of such shape that liquid may be trapped, it shall be provided with adequate drain holes uniformly distributed along its length. Similarly, if the shape of a compression ring on the inside of a tank is such that gas would be trapped on the underside thereof when the tank is being filled with liquid, adequate vent holes shall be provided along its length. Where feasible, such drain or vent holes shall be not less than $\frac{3}{4}$ in. (19 mm) in diameter.

(h) The projecting part of a compression ring without an outer vertical flange need not be braced, provided the width of such projecting part in a radial vertical plane does not exceed 16 times its thickness. With this exception, the horizontal part of the compression ring shall be braced at intervals around the circumference of the tank with brackets or other

suitable members securely attached to both the ring and the tank wall to prevent such part of the ring from buckling laterally. When such bracing is required, the moment of inertia of the cross section of the angle, bar, or ring girder about a horizontal axis shall be not less than that calculated to be required by the following equation:⁵⁵

$$I_1 = \frac{1.44 Q_p R_c^2}{29,000,000 k} = 5 \frac{Q_p R_c^2}{k} \times 10^{-8} \quad (26)$$

(26)

where

I_1

= required moment of inertia, in.⁴, for the cross section of a steel compression ring with respect to a horizontal axis through the centroid of the section, not taking credit for any portion of the tank wall, except that, in the case of an angle ring whose vertical leg is attached to or forms a part of the tank wall, the moment of inertia of only the horizontal leg shall be considered, and it shall be figured with respect to a horizontal axis through the centroid of such leg⁵⁴

⁵⁵ Note that the value required for I as calculated from Eq. (26) is not applicable for materials other than steel.

Q_p

= that portion of the total circumferential force Q , lb, [Eq. (24)] which is carried by the compression ring angle, bar, or girder, as computed from the ratio of the cross-sectional area of the compression ring to the total area of the compression zone

R_c

= horizontal radius, in., of the cylindrical sidewall of the tank at its juncture with the roof or bottom

k

= a constant whose value depends on the magnitude of the angle θ , subtended at the central axis of the tank by the space between adjacent brackets, or other supports, which value shall be determined from the following tabulation in which n is the number of brackets or other supports evenly spaced around the circumference of the tank

Some Values for k Based on n, θ

n	30	24	20	18	15	12
θ , deg.	12	15	18	20	24	30
k	186.6	119.1	82.4	66.6	45.0	29.1
n	10	9	8	6	5	4
θ , deg.	36	40	45	60	72	90
k	20.0	16.0	12.5	6.7	4.4	2.6

In no case shall θ be larger than 90 deg.

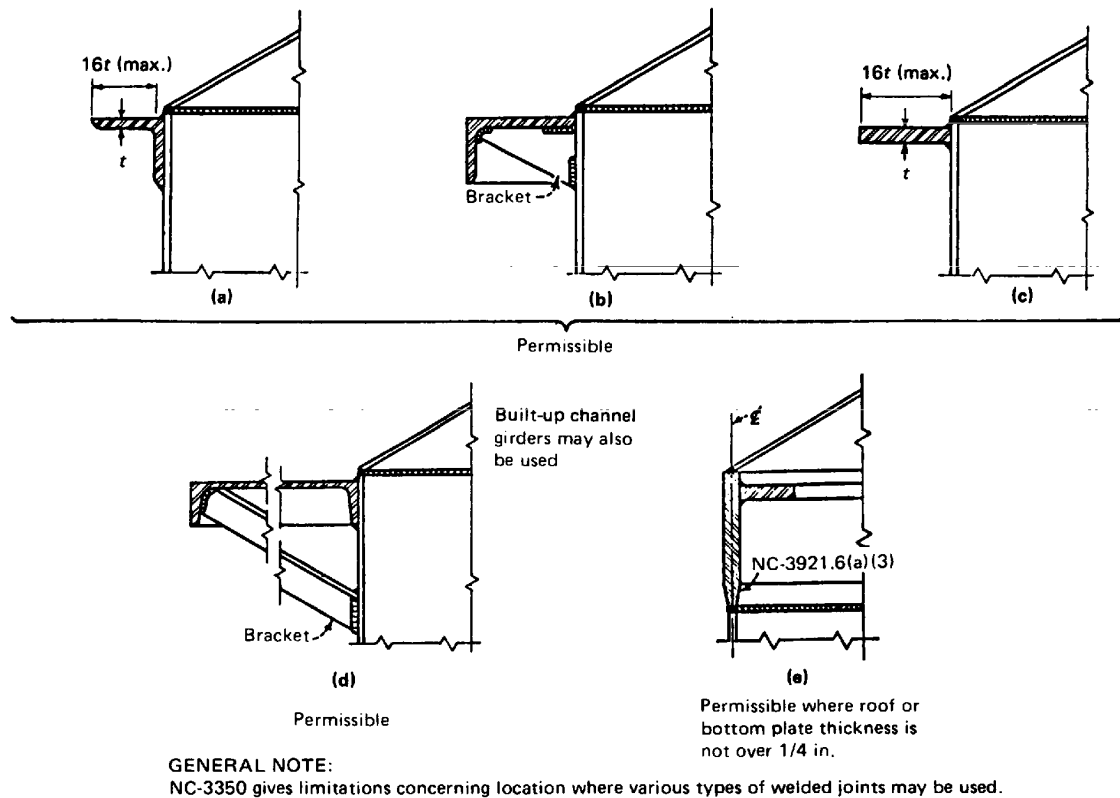


FIG. NC-3933.5(d)-1 PERMISSIBLE DETAILS OF COMPRESSION RING

FIG. NC-3933.5(d)-1 PERMISSIBLE DETAILS OF COMPRESSION RING

NC-3934 Nozzle Piping Transitions

The stress limits of Table NC-3921.6-1 shall apply to all portions of nozzles which lie within the limits

Page 221

of reinforcement given in NC-3334, except as provided in NC-3935. Stresses in the extension of any nozzle beyond the limits of reinforcement shall be subject to the stress limits of NC-3600.

NC-3935 Consideration of Standard Reinforcement

(a) Where a nozzle-to-shell junction is reinforced in accordance with the rules of NC-3334, the stresses in this region due to internal pressure may be considered to satisfy the limits of Table NC-3921.6-1. Under these conditions, no analysis is required to demonstrate compliance for pressure induced stresses in the nozzle region.

(b) Where external piping loads are to be designed for, membrane plus bending stresses due to these loads shall be calculated in the nozzle, and membrane stresses shall be calculated in the local nozzle-to-shell region. These stresses, in conjunction with pressure induced stresses, shall meet the limits of Table NC-3921.6-1 for $(\sigma_m \text{ or } \sigma_L) + \sigma_b$. In this case the pressure induced stresses in the $(\sigma_m \text{ or } \sigma_L) + \sigma_b$ category may be assumed to be no greater than the limit specified for σ_m in Table NC-3921.6-1 for a given condition.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NC-4000

ARTICLE NC-4000 FABRICATION AND INSTALLATION

Page 223

NC-4100 GENERAL REQUIREMENTS

NC-4110 INTRODUCTION

(a) Components, parts, and appurtenances shall be fabricated and installed in accordance with the rules of this Article and shall be manufactured from materials which meet the requirements of NC-2000.

(b) Vessels designed to the requirements of NC-3200 shall meet the requirements of this Article except for NC-4240 and NC-4433. In this case, the requirements of NC-4260 apply.

(c) Atmospheric and 0-15 psig (0-103 kPa) storage tanks shall be fabricated in accordance with the rules of this Article.

NC-4120 CERTIFICATION OF MATERIALS AND FABRICATION BY COMPONENT CERTIFICATE HOLDER

NC-4121 Means of Certification

The Certificate Holder for an item shall certify, by application of the appropriate Code symbol and completion of the appropriate Data Report in accordance with NCA-8000, that the materials used comply with the requirements of NC-2000 and that the fabrication or installation complies with the requirements of this Article.

NC-4121.1 Certification of Treatments, Tests, and Examinations.

If the Certificate Holder or Subcontractor performs treatments, tests, repairs, or examinations required by other Articles of this Subsection, the Certificate Holder shall certify that this requirement has been fulfilled (NCA-3862). Reports of all required treatments and of the results of all required tests, repairs, and examinations performed shall be available to the Inspector.

NC-4121.2 Repetition of Tensile or Impact Tests.

If during the fabrication or installation of the item the material is subjected to heat treatment that has not been covered by treatment of the test coupons (NC-2200) and that may reduce either tensile or impact properties below the required values, the tensile and impact tests shall be repeated by the Certificate Holder on test specimens taken from test coupons which have been taken and treated in accordance with the requirements of NC-2000.

NC-4121.3 Repetition of Surface Examination After Machining.

During the fabrication or installation of an item, if materials for pressure containing parts are machined, then the Certificate Holder shall reexamine the surface of the material in accordance with NC-2500 when:

(a) the surface was required to be examined by the magnetic particle or liquid penetrant method in accordance with NC-2500; and

(b) the amount of material removed from the surface exceeds the lesser of $\frac{1}{8}$ in. (3.2 mm) or 10% of the minimum required thickness of the part.

NC-4122 Materials Identification

(a) Material for pressure retaining parts shall carry identification markings which will remain distinguishable until the component is assembled or installed. If the original identification markings are cut off or the material is divided, either the marks shall be transferred to the parts cut or a coded marking shall be used to ensure identification of each piece of material during subsequent fabrication or installation. In either case, an as-built sketch or a tabulation of materials shall be made identifying each piece of material with the Certified Material Test Report, where applicable, and the coded marking. For studs, bolts, nuts, and heat exchanger tubes, it is permissible to identify the Certified Material Test Reports for material in each component in lieu of identifying each piece of material with the

Page 230

Certified Material Test Report and the coded marking. Material supplied with a Certificate of Compliance and welding and brazing materials shall be identified and controlled so that they can be traced to each component or installation of a piping system, or else a control procedure shall be employed which ensures that the specified materials are used.

(b) Material from which the identification marking is lost shall be treated as nonconforming material until appropriate tests or other verifications are made and documented to assure material identification. Testing is required unless positive identification can be made by other documented evidence. The material may then be remarked upon establishing positive identification.

NC-4122.1 Marking Materials.

Material shall be marked in accordance with NC-2150.

NC-4123 Examinations

Visual examination activities that are not referenced for examination by other specific Code paragraphs, and are performed solely to verify compliance with requirements of NC-4000, may be performed by the persons who perform or supervise the work. These visual examinations are not required to be performed by personnel and procedures qualified to NC-5100 and NC-5500, respectively, unless so specified.

NC-4125 Testing of Welding and Brazing Materials

All welding and brazing materials shall meet the requirements of NC-2400.

NC-4130 REPAIR OF MATERIAL

Material originally accepted on delivery in which defects exceeding the limits of NC-2500 are known or discovered during the process of fabrication or installation is unacceptable. The material may be used, provided the condition is corrected in accordance with the requirements of NC-2500 for the applicable product form, except that:

- (a) the limitation on the depth of the weld repair does not apply;
- (b) the time of examination of the weld repairs to weld edge preparations shall be in accordance with NC-5130;
- (c) radiographic examination is not required for weld repairs to seal membrane material when the material thickness is $\frac{1}{4}$ in. (6 mm) or less;
- (d) radiographic examination is not required for welded repairs in material used in storage tanks, provided that the welded joints in these materials are not required to be radiographed, the extent of the welded repair does not exceed 10 sq in. of the surface area, and the magnetic particle or liquid penetrant examination of the repair is made as required by NC-2539.4.

NC-4200 FORMING, CUTTING, AND ALIGNING

NC-4210 CUTTING, FORMING, AND BENDING

NC-4211 Cutting

Materials may be cut to shape and size by mechanical means, such as machining, shearing, chipping, or grinding, or by thermal cutting.

NC-4211.1 Preheating Before Thermal Cutting.

When thermal cutting is performed to prepare weld joints or edges, to remove attachments or defective material, or for any other purpose, consideration shall be given to preheating the material, using preheat schedules such as suggested in Appendix D.

NC-4212 Forming and Bending Processes

Any process may be used to hot or cold form or bend pressure retaining materials, including weld metal, provided the required dimensions are attained (see NC-4214 and NC-4220), and provided the impact properties of the materials, when required, are not reduced below the minimum specified values, or they are effectively restored by heat treatment following the forming operation. *Hot forming* is defined as forming with the material temperature higher than 100°F (56°C) below the lower transformation temperature of the material. When required, the process shall be qualified for impact properties as outlined in NC-4213. When required, the process shall be qualified to meet thickness requirements as outlined in NC-4223.1.

NC-4213 Qualification of Forming Processes for Impact Property Requirements

When impact testing is required by the Design Specifications, a procedure qualification test shall be conducted using specimens taken from materials of the same specification, grade or class, heat treatment, and with similar impact properties, as required for the material in the component. These specimens shall be

Page 231

subjected to the equivalent forming or bending process and heat treatment as the material in the component. Applicable tests shall be conducted to determine that the required impact properties of NC-2300 are met after straining.

NC-4213.1 Exemptions.

Procedure qualification tests are not required for material listed in (a) through (f) below:

- (a) hot formed material, such as forgings, in which the hot forming is completed by the Material Manufacturer prior to removal of the impact test specimens;
- (b) hot formed materials represented by test coupons required in either NC-2211 or NC-4121.2 which have been subjected to heat treatment representing the hot forming procedure and the heat treatments to be applied to the parts;
- (c) materials which do not require impacts in accordance with NC-2300;
- (d) materials which have a final strain less than 0.5%;
- (e) material where the final strain is less than that of a previously qualified procedure for that material;
- (f) material from which the impact testing required by NC-2300 is performed on each heat and lot, as applicable, after forming.

NC-4213.2 Procedure Qualification Test.

The procedure qualification test shall be performed in the manner stipulated in (a) through (f) below.

- (a) The tests shall be performed on three different heats of material, both before straining and after straining and heat treatment, to establish the effects of the forming and subsequent heat treatment operations.
- (b) Specimens shall be taken in accordance with the requirements of NC-2000 and shall be taken from the tension side of the strained material.
- (c) The percent strain shall be established by the following equations:
for cylinders:

$$\% \text{ strain} = \frac{50t}{R_f} \left(1 - \frac{R_f}{R_o} \right)$$

for spherical or dished surfaces:

$$\% \text{ strain} = \frac{75t}{R_f} \left(1 - \frac{R_f}{R_o} \right)$$

for pipe:

$$\% \text{ strain} = \frac{100r}{R}$$

where

t	= nominal thickness, in.
R_f	= final radius to center line of shell, in.
R_o	= original radius (equal to infinity for a flat part), in.
R	= nominal bending radius to the center line of the pipe, in.
r	= nominal radius of the pipe, in.

(d) The procedure qualification shall simulate the maximum percent surface strain, employing a bending process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient C_v test specimens shall be taken from each of the three heats of material to establish a transition curve showing both the upper and lower shelves. On each of the three heats, tests consisting of three impact specimens shall be conducted at a minimum of five different temperatures distributed throughout the transition region. The upper and lower shelves may be established by the use of one test specimen for each shelf. Depending on the product form, it may be necessary to plot the transition curves using both the lateral expansion and energy level data (NC-2300). In addition, drop weight tests shall be made when required by NC-2300.

(f) Using the results of the impact test data from each of three heats, taken both before and after straining, determine either:

(1) the maximum change in NDT temperature along with:

(a) the maximum change of lateral expansion and energy at the temperature under consideration; or

(b) the maximum change in temperature at the lateral expansion and energy levels under consideration; or

(2) where lateral expansion is the acceptance criteria (NC-2300), either the maximum change in temperature or the maximum change in lateral expansion.

NC-4213.3 Acceptance Criteria for Formed Material.

To be acceptable, the formed material used in the component shall have impact properties, before forming, sufficient to

NC-4213.4 Requalification.

A new procedure qualification test is required when any of the changes in (a), (b), or (c) below are made.

(a) The actual postweld heat treatment time at temperature is greater than previously qualified considering NC-2211. If the material is not postweld heat treated, the procedure must be qualified without postweld heat treatment.

(b) The maximum calculated strain of the material exceeds the previously qualified strain by more than 0.5%.

(c) Where preheat over 250°F (121°C) is used in the forming or bending operation but not followed by a subsequent postweld heat treatment.

NC-4214 Minimum Thickness of Fabricated Material

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of NC-2124 and NC-3000, the material may be repaired in accordance with NC-4130.

NC-4220 FORMING TOLERANCES

NC-4221 Tolerance for Vessel Shells

Cylindrical, conical, or spherical shells of a completed vessel, except formed heads covered by NC-4222, shall meet the requirements of the following subparagraphs at all cross sections.

NC-4221.1 Maximum Difference in Cross-Sectional Diameters.

The difference in inches between the maximum and minimum diameters at any cross-section shall not exceed the smaller of $(D + 50)/200$ and $D/100$, where D is the nominal inside diameter, in., at the cross section under consideration. The diameters may be measured on the inside or outside of the vessel. If measured on the outside, the diameters shall be corrected for the plate thickness at the cross section under consideration (Fig. NC-4221.1-1). When the cross section passes through an opening, the permissible difference in inside diameters given herein may be increased by 2% of the inside diameter of the opening.

NC-4221.2 Maximum Deviation From True Theoretical Form for External Pressure.

Vessels designed for external pressure shall meet the tolerances given in (a) through (e) below.

(a) The maximum plus or minus deviation from the true circular form of cylinders or the theoretical form of other shapes, measured radially on the outside or inside of the component, shall not exceed the maximum permissible deviation obtained from Fig. NC-4221.2(a)-1. Measurements shall be made from a segmental circular template having the design inside or outside radius depending on where the measurements are taken and a chord length equal to twice the arc length obtained from Fig. NC-4221.2(a)-2. For Fig. NC-4221.2(a)-1, the maximum permissible deviation e need not be less than $0.3t$. For Fig. NC-4221.2(a)-2, the arc length need not be greater than $0.30D_o$. Measurements shall not be taken on welds or other raised parts.

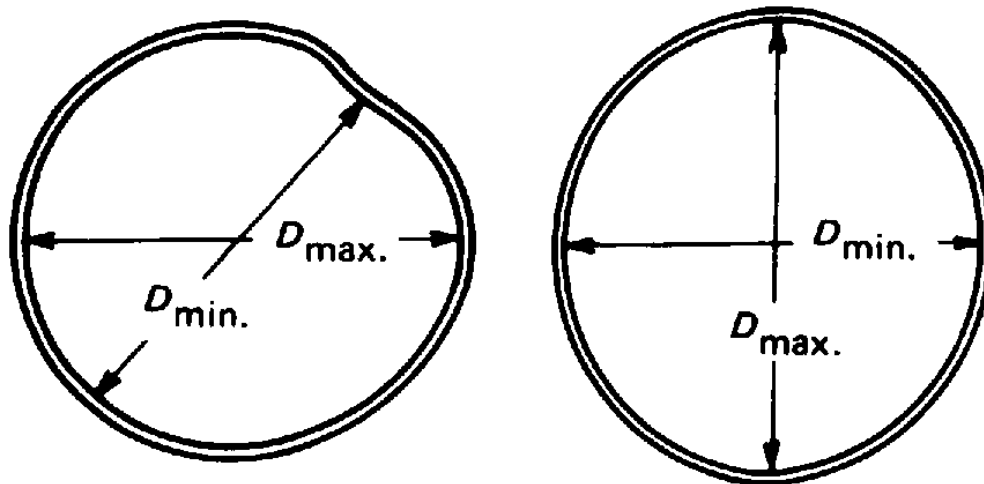


FIG. NC-4221.1-1 MAXIMUM DIFFERENCE IN CROSS-SECTIONAL DIAMETERS

FIG. NC-4221.1-1 MAXIMUM DIFFERENCE IN CROSS-SECTIONAL DIAMETERS

(b) The value of t , in., at any cross section is the nominal plate thickness less corrosion allowance for sections of constant thickness and the nominal thickness of the thinnest plate less corrosion allowance for sections having plates of more than one thickness.

(c) The value of L in Figs. NC-4221.2(a)-1 and NC-4221.2(a)-2 is determined by (1), (2), and (3) below.

(1) For cylinders, L is as given in NC-3133.2.

(2) For cones, L is the axial length of the conical section if no stiffener rings are used or, if stiffener rings are used, the axial length from the head bend line at the large end of the cone to the first stiffener ring, with D_o taken as the outside diameter in inches of the cylinder at the large end of the cone.

(3) For spheres, L is one-half of the outside diameter D_o in.

(d) The dimensions of a completed vessel may be brought within the requirements by any process which will not impair the strength of the material.

(e) Sharp bends and flat spots shall not be permitted unless provision is made for them in the design.

NC-4221.3 Deviations From Tolerances.

Deviations from the tolerance requirements stipulated in NC-4221.1 and NC-4221.2 are permitted, provided the drawings are modified and reconciled with the design calculations.

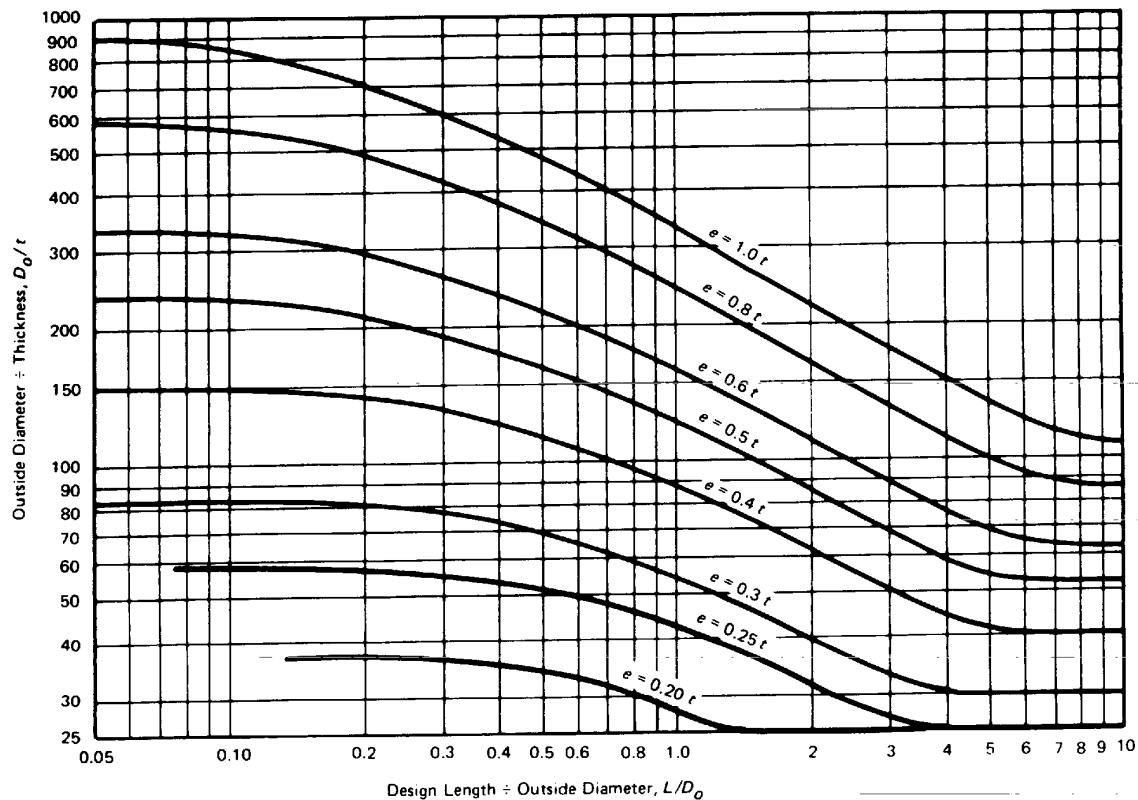


FIG. NC-4221.2(a)-1 MAXIMUM PERMISSIBLE DEVIATION e FROM A TRUE CIRCULAR FORM

FIG. NC-4221.2(a)-1 MAXIMUM PERMISSIBLE DEVIATION e FROM A TRUE CIRCULAR FORM

NC-4221.4 Tolerance Deviations for Vessel Parts Fabricated From Pipe.

Vessel parts subjected to either internal or external pressure and fabricated from pipe, meeting all other requirements of this Subsection, may have variations of diameter and deviations from circularity permitted by the specification for such pipe.

NC-4221.5 Localized Thin Areas.

Localized thin areas are permitted if the adjacent areas surrounding each have sufficient thickness to provide the necessary reinforcement according to the rules for reinforcement in NC-3330.

NC-4222 Tolerances for Formed Vessel Heads

The tolerance for formed vessel heads shall be as set forth in the following subparagraphs.

NC-4222.1 Maximum Difference in Cross-Sectional Diameters.

The skirt or cylindrical end of a formed head shall be circular to the extent that the difference in inches between the maximum and minimum diameters does not exceed the lesser of $(D + 50)/200$ and $(D + 12)/100$, where D is the nominal inside diameter, in., and shall match the cylindrical edge of the adjoining part within the alignment tolerance specified in

NC-4222.2 Deviation From Specified Shape

(a) The inner surface of a torispherical or ellipsoidal head shall not deviate outside the specified shape by more than $1\frac{1}{4}\%$ of D , nor inside the specified shape by more than $\frac{5}{8}\%$ of D , where D is nominal inside diameter of the vessel. Such deviations shall be measured perpendicular to the specified shape and shall not be abrupt. The knuckle radius shall not be less than specified. For 2:1 ellipsoidal heads, the knuckle radius may be considered to be 17% of the diameter of the vessel.

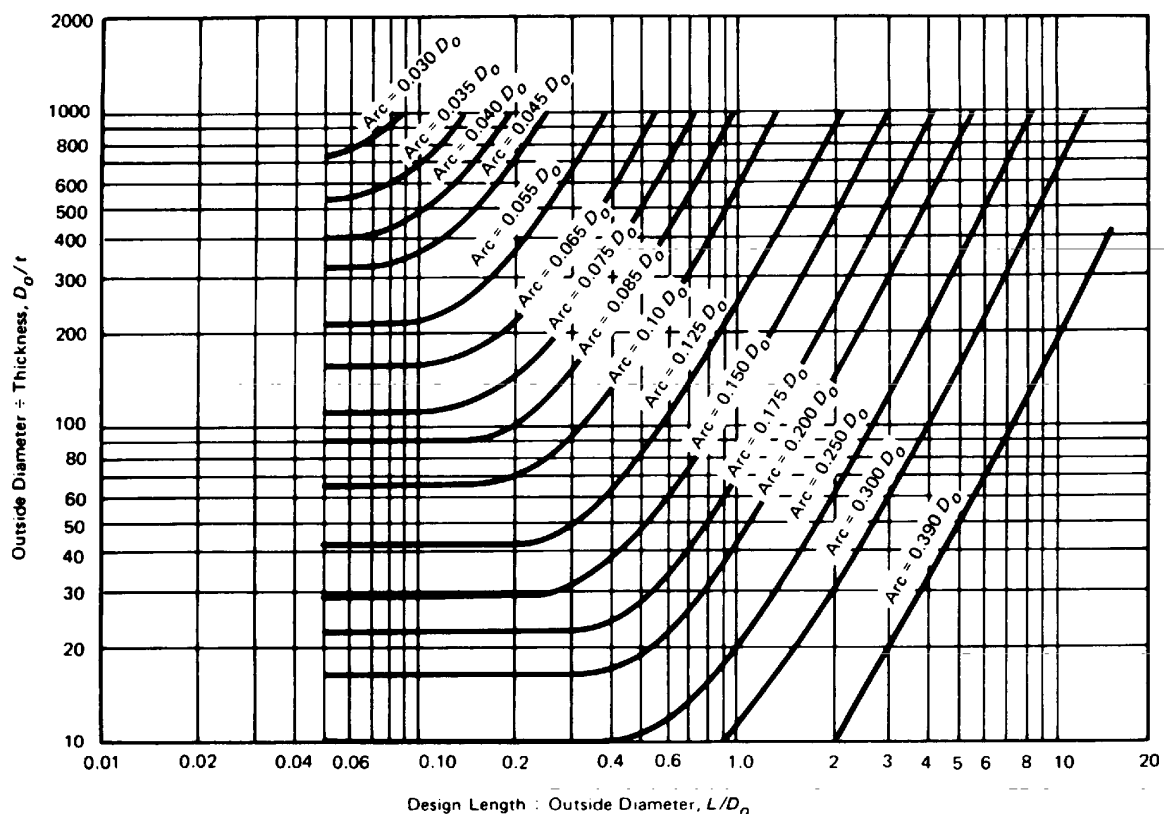


FIG. NC-4221.2(a)-2 MAXIMUM ARC LENGTH FOR DETERMINING PLUS OR MINUS DEVIATION

FIG. NC-4221.2(a)-2 MAXIMUM ARC LENGTH FOR DETERMINATION PLUS OR MINUS DEVIATION

(b) Hemispherical heads and any spherical portion of a formed head shall meet the local tolerances for spheres as given in NC-4221.2, using L as the outside spherical radius in inches and D_o as 2 times L .

(c) Deviation measurements shall be taken on the surface of the base material and not on welds.

NC-4223 Tolerances for Formed or Bent Piping

The tolerances for formed or bent piping shall be as set forth in the following subparagraphs.

NC-4223.1 Minimum Wall Thickness

(a) In order to assure that the wall thickness requirements of the design calculations are met, the actual thickness shall be measured, or the process shall be qualified by demonstrating that it will maintain the required wall thickness.

(b) As an alternate to (a) above, the requirements of Table NC-3642.1(b)-1 shall be followed.

NC-4223.2 Ovality Tolerance.

Unless otherwise justified by the design calculations, the ovality of piping after bending shall not exceed 8% as determined by

$$100 \times (D_{\max} - D_{\min})/D_o$$

where

D_o = the nominal pipe outside diameter, in.

$D_{\min}$ = the minimum outside diameter after bending or forming, in.

$D_{\max}$ = the maximum outside diameter after bending or forming, in.

Page 235

NC-4224 Tolerances for Storage Tanks

The horizontal circular cross section of storage tanks shall be sufficiently true to round so that the difference between the maximum and minimum diameters measured inside or outside at any section in a cylindrical wall shall not exceed 1% of the average diameter or 12 in. (305 mm), whichever is less, measured 6 ft (1.8 m) or one plate width from the top and bottom juncture, respectively, if these junctures are of a type which offers serious restraint when the tank is filled or under the specified maximum vapor pressure. At any section in a sidewall having double curvature, this difference in diameter shall not exceed $\frac{1}{2}\%$ of the average diameter or 6 in., whichever is less.

NC-4224.1 Maximum Difference in Cross-Sectional Diameters for Tanks of Double Curvature.

For tanks of double curvature, the meridian curvature of the plate surface shall not deviate from the design shape by more than $\frac{1}{2}\%$ of the radius, measured radially, and shall not show abrupt changes. Plate surfaces shall merge smoothly into the adjoining surfaces in all directions. Local inward deviations, such as flat spots, shall be limited by NC-4224.2.

NC-4224.2 Local Inward Deviations.

Local inward deviations, such as flat spots, if present on wall or bottom surfaces having double curvature, shall not be greater than the plate thickness, and shall not have a diameter d greater than $\sqrt{8Rt}$, where R is the radius of the tank and t is the thickness of the plate involved. R shall be taken as R_1 , with d being the chord in a meridional direction, and as R_2 , with d being the chord in a latitudinal direction.

NC-4224.3 Tolerance Measurements.

The tolerance measurements are given for a tank while empty and shall be taken with a steel tape, making corrections for temperature, sag, and wind.

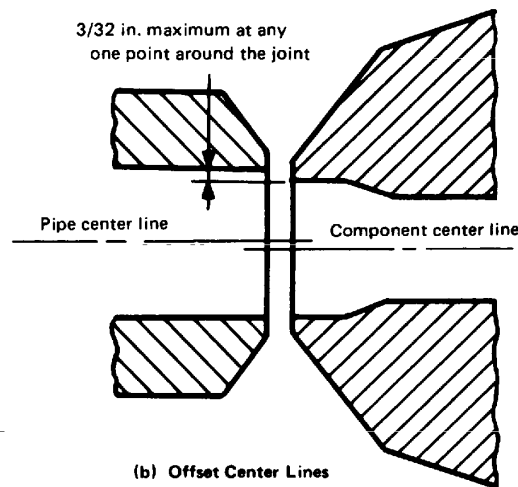
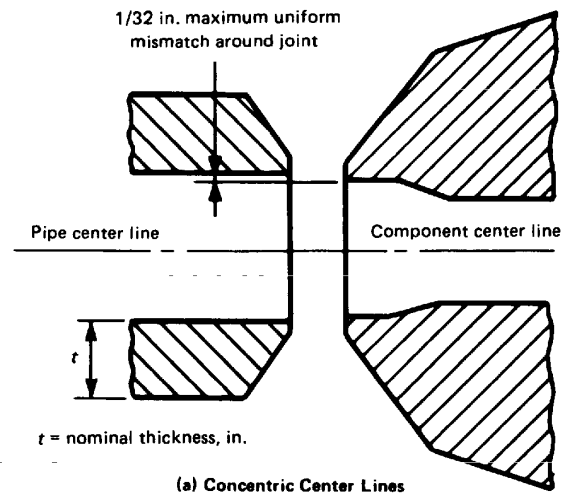
NC-4230 FITTING AND ALIGNING

NC-4231 Fitting and Aligning Methods

Parts that are to be joined by welding may be fitted, aligned, and retained in position during the welding operation by the use of bars, jacks, clamps, tack welds, or temporary attachments.

NC-4231.1 Tack Welds.

Tack welds used to secure alignment shall either be removed completely when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified welders using qualified welding procedures. When tack welds are to become part of the finished weld, they shall be visually examined and defective tack welds removed.



GENERAL NOTE:

The weld end transitions are typical and are not intended as requirements. Refer to NC-4250 for weld end transition requirements.

FIG. NC-4233-1 BUTT WELD ALIGNMENT AND MISMATCH TOLERANCES FOR UNEQUAL I.D. AND O.D. WHEN COMPONENTS ARE WELDED FROM ONE SIDE AND FAIRING IS NOT PERFORMED

TABLE NC-4232(a)-1 MINIMUM ALLOWABLE OFFSET IN FINAL WELDED JOINTS

NC-4232 Alignment Requirements When Components Are Welded From Two Sides

(a) Alignment of sections which are welded from two sides shall be such that the maximum offset of the finished weld will not be greater than the applicable amount listed in Table NC-4232(a)-1, where t is the nominal thickness of the thinner section at the joint.

(b) Joints in spherical vessels, joints within heads and joints between cylindrical shells and hemispherical heads shall meet the requirements in Table NC-4232(a)-1 for longitudinal joints.

NC-4232.1 Fairing of Offsets.

Any offset within the allowable tolerance provided above shall be faired to at least 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld.

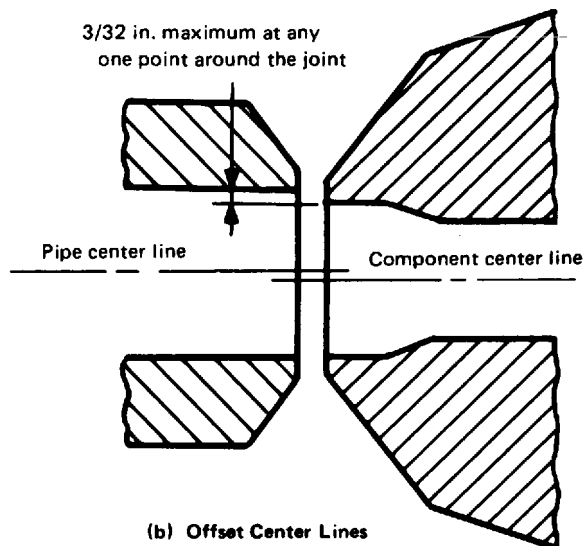
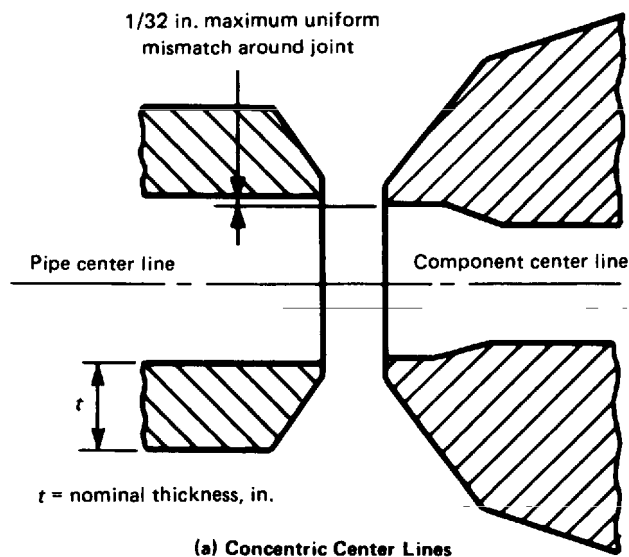
NC-4233 Alignment Requirements When Inside Surfaces Are Inaccessible

(a) When the inside surfaces of items are inaccessible for welding or fairing in accordance with NC-4232, alignment of sections shall meet the requirements of (1) and (2) below.

(1)(a) For circumferential joints the inside diameters shall match each other within $\frac{1}{16}$ in. (1.6 mm) When the items are aligned concentrically, a uniform mismatch of $\frac{1}{32}$ in. (0.8 mm) all around the joint can result, as shown in Fig. NC-4233-1 sketch (a). However,

Page 236

other variables not associated with the diameter of the item often result in alignments that are offset rather than concentric. In these cases, the maximum misalignment at any one point around the joint shall not exceed $\frac{3}{32}$ in. (2.4 mm), as shown in Fig. NC-4233-1 sketch (b). Should tolerances on diameter, wall thickness, out-of-roundness, etc., result in inside diameter variation which does not meet these limits, the inside diameters shall be counterbored, sized, or ground to produce a bore within these limits, provided the requirements of NC-4250 are met.



GENERAL NOTE:

The weld end transitions are typical and are not intended as requirements. Refer to NC-4250 for weld end transition requirements.

FIG. NC-4233-1 BUTT WELD ALIGNMENT AND MISMATCH TOLERANCES FOR UNEQUAL I.D. AND O.D. WHEN COMPONENTS ARE WELDED FROM ONE SIDE AND FAIRING IS NOT PERFORMED

FIG. NC-4233-1 BUTT WELD ALIGNMENT AND MISMATCH TOLERANCES FOR UNEQUAL I.D. AND O.D. WHEN COMPONENTS ARE WELDED FROM ONE SIDE AND FAIRING IS NOT PERFORMED

(1)(b) Offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(2) For longitudinal joints the misalignment of inside surfaces shall not exceed $\frac{3}{32}$ in. (2.4 mm), and the offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(b) Single welded joints may meet the alignment requirements of (1) and (2) above in lieu of the requirements of NC-4232.

NC-4240 REQUIREMENTS FOR WELD JOINTS IN COMPONENTS¹

NC-4241 Category A Weld Joints in Vessels and Longitudinal Weld Joints in Other Components

Category A weld joints in vessels and longitudinal weld joints in other components shall be full penetration butt joints. Joints that have been welded from one side with backing that has been removed, and those welded from one side without backing, are acceptable as full penetration welds provided the weld root side of the joints meet the requirements of NC-4424.

NC-4242 Category B Weld Joints in Vessels and Circumferential Weld Joints in Other Components

Category B weld joints in vessels and circumferential weld joints in other components shall be full penetration butt joints, except that piping 2 in. nominal pipe size (DN 50) and smaller may be socket welded. Joints prepared with opposing lips to form an integral backing ring and joints with backing strips which are not later removed are acceptable, provided the requirements of NC-3352.2 are met.

¹ See NC-4246 and NC-4247 for special weld joint requirement in storage tanks

NC-4243 Category C Weld Joints in Vessels and Similar Weld Joints in Other Components

Category C weld joints in vessels and similar weld joints in other components shall be full penetration joints, as shown in Figs. NC-4243-1 and NC-4243-2, except that socket welded flanges of 2 in. nominal pipe size and less and slip-on flanges may be used.

NC-4243.1 Flat Heads and Tubesheets With Hubs.

Hubs for butt welding to the adjacent shell, head, or other pressure part, as in Fig. NC-4243.1-1, shall not be machined from rolled plate. The component having the hub shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material, in a direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension test specimen, subsize if necessary, taken in this direction and as close to the hub as is practical.² In no case shall the height of the hub be less than 1.5 times the thickness of the pressure part to which it is welded.

NC-4244 Category D Weld Joints in Vessels and Branch and Piping Connection Weld Joints in Other Components

Category D weld joints in vessels and similar weld joints in other components shall be welded using one of the details of (a) through (e) below.

(a) *Butt Welded Nozzles and Branch Piping Connections.* Nozzles and branch piping connections shall be attached by full penetration butt welds through the wall of the component, nozzle, or branch as shown in Fig. NC-4244(a)-1. Backing strips, if used, may be left in place.

(b) *Corner Welded Nozzles and Branch Piping Connections.* Nozzles and branch piping connections shall be joined to the component by full penetration welds through the wall of the component, nozzle, or branch similar to those shown in Fig. NC-4244(b)-1. When complete joint penetration cannot be verified by visual examination or other means permitted, backing strips or equivalent shall be used with full penetration welds deposited from only one side. Backing strips, if used, may be left in place.

2 One test specimen may represent a group of forgings, provided they are of the same nominal dimensions, from the same heat of material and the same heat treatment lot, and forged in the same manner.

(c) *Deposited Weld Metal of Opening for Nozzles and Branch Piping Connections.* Nozzles and branch

Page 238

piping connections shall be joined to the component by full penetration weld to built-up weld deposits applied to the component, nozzle, or branch as shown in Fig. NC-4244(c)-1. Backing strips, if used, may be left in place. Fillet welds shall be used only to provide a transition between the parts joined or to provide a seal. The fillet welds, when used, shall be finished by grinding to provide a smooth surface having a transition radius at its intersection with either part being joined.

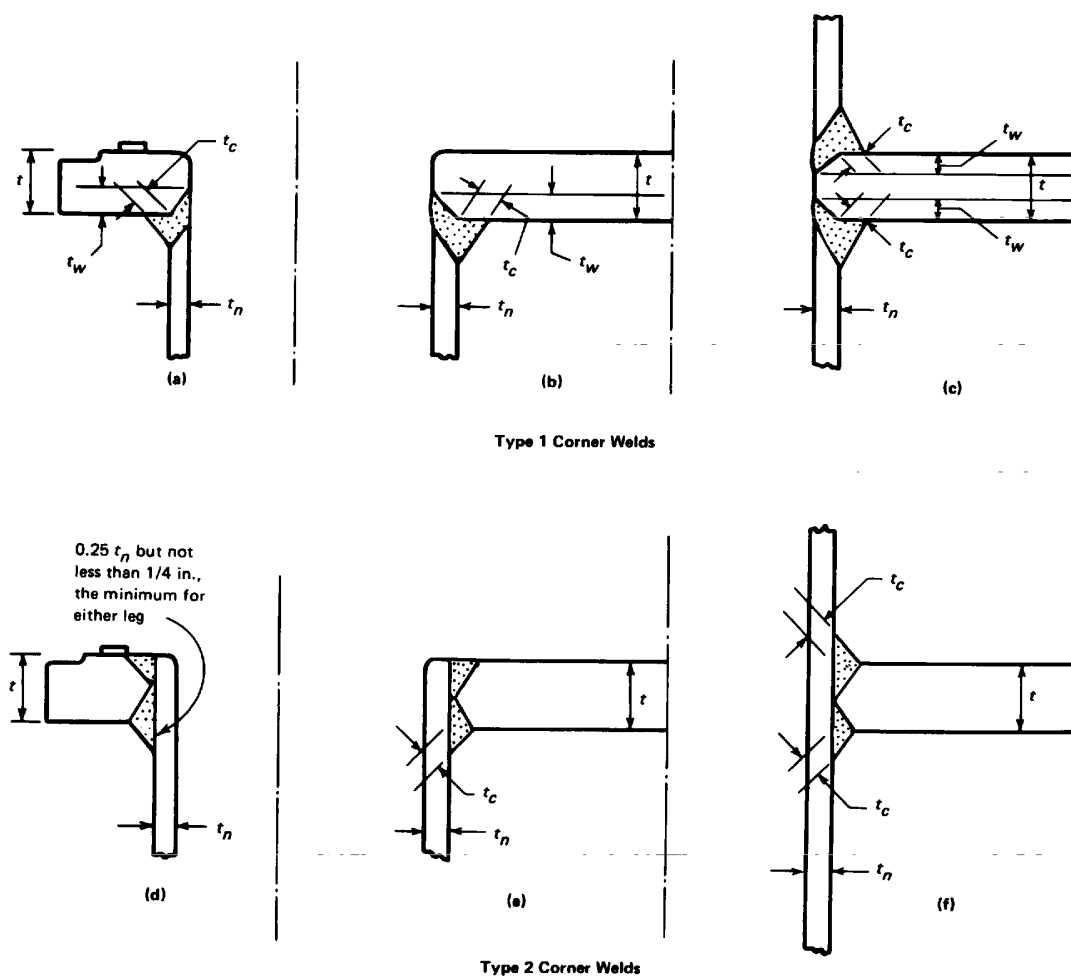


FIG. NC-4243-1 ACCEPTABLE FULL PENETRATION WELD DETAILS FOR CATEGORY C JOINTS
For Definitions of Nomenclature, See NC-3358.3(e)(1)

FIG. NC-4243-1 ACCEPTABLE FULL PENETRATION WELD DETAILS FOR CATEGORY C JOINTS

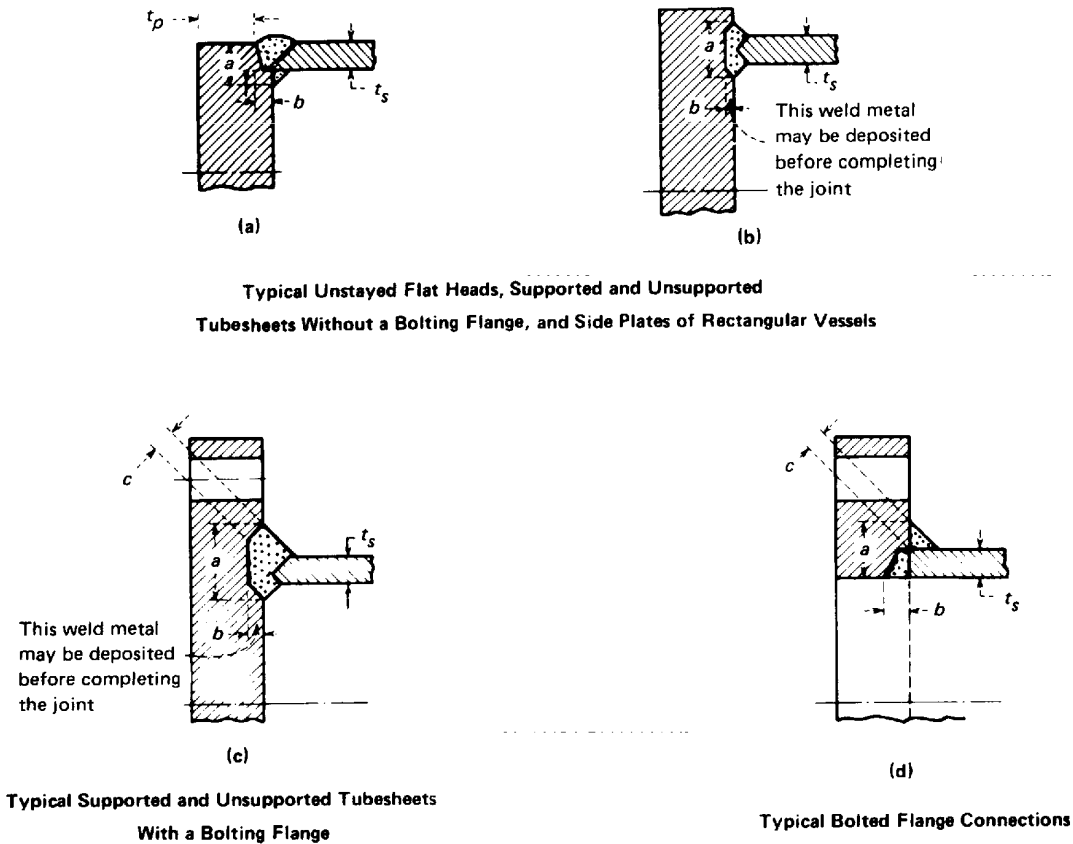


FIG. NC-4243-2 ATTACHMENT OF PRESSURE PARTS TO PLATES TO FORM A CORNER JOINT
For Definitions of Nomenclature, See NC-3358.3(e)(2)

FIG. NC-4243-2 ATTACHMENT OF PRESSURE PARTS TO PLATES TO FORM A CORNER JOINT

(d) *Partial Penetration Welded Nozzles and Branch Piping Connections.* Partial penetration welds in components and branch piping connections, shall meet the weld design requirements of NC-3352.4(d) and NC-3359. Nozzles shall be attached as shown in Fig. NC-4244(d)-1. Reinforcing plates of nozzles attached to the outside of a vessel shall be provided with at least one telltale hole, maximum size $\frac{1}{4}$ in. pipe tap, that may be tapped for a preliminary compressed air and soapsuds test for tightness of welds. These telltale holes may be left open or may be plugged when the vessel is in service. If the holes are plugged, the plugging material used shall not be capable of sustaining pressure between the reinforcing plate and the vessel wall.

3 Written and illustrated with internal threads but also applicable to externally threaded and socket or butt welded fittings

(e) *Attachment of Fittings With Internal Threads.*³ Internally threaded fittings shall be attached by a full penetration groove weld or for 3 in. nominal pipe size (DN 80) and less, by two fillet or partial penetration welds, one on each face of the vessel wall, or by a fillet groove weld from the outside only as shown in Fig. NC-4244(e)-1 sketch (c-3). Internally threaded fitting and bolting pads not exceeding 3 in. nominal pipe size (DN 80), as shown in Fig. NC-4244(e)-2, may be attached to components having a wall thickness

not greater than $\frac{3}{8}$ in. (10 mm) by a fillet weld deposited from the outside only. The design requirements of NC-3352.4 (e) shall be met for all components.

NC-4245 Complete Joint Penetration Welds

Complete joint penetration is considered to be achieved when the acceptance criteria for the examinations specified by this Subsection have been met. No other examination is required to assess that complete penetration has been achieved.

NC-4246 Atmospheric Storage Tank Special Joints

Requirements for special joints for atmospheric storage tanks are given below.

NC-4246.1 Bottom Plates.

Bottoms shall be built to either one of the alternative methods of construction given in (a) and (b) below.

(a) Lap welded bottom plates shall be reasonably rectangular and square edged. Three plate laps in tank bottoms shall not be closer than 12 in. (305 mm) from each other and also from the tank shell. Bottom plates need be welded on the top side only with a continuous full fillet weld on all seams [Fig. NC-4246.1(a)-1]. The plates under the bottom ring shell connection shall have the outer ends of the joints fitted and lap welded to form a smooth bearing for the shell plates as shown in Fig. NC-4246.1(a)-1.

(b) Butt welded bottom plates shall have the parallel edges prepared for butt welding with either square or V-grooves. If square grooves are employed, the root opening shall be not less than $\frac{1}{4}$ in. The butt welds shall be made by applying a backing strip $\frac{1}{8}$ in. (3.2 mm) thick or heavier by tack welding to the underside of the plate [Fig. NC-4246.1(a)-1]. A metal spacer shall be used, if necessary, to maintain the root opening between the adjoining plate edges. The Certificate Holder may submit other methods of butt welding the bottom for the Owner's approval. Three plate joints in tank bottoms shall not be closer than 12 in. (305 mm) from each other and also from the tank shell.

NC-4246.2 Shell-to-Bottom Attachment.

The attachment between the bottom edges of the lowest course shell plate and the bottom plate shall be a continuous full wall thickness weld with a cover fillet on each side of shell plate [Fig. NC-4246.1(a)-1] or, for tanks not exceeding 35 ft (10.6 m) in diameter, the bottom plates may be flanged and butt welded to the bottom shell course. The flanged tank bottom plates shall be butt welded and have a thickness equal to the thickness of the bottom shell course. The inside radius of the bend shall be neither less than $1.75t$ nor more than $3t$.

NC-4246.3 Roof-to-Sidewall Attachment.

Roof plates shall be attached to the top angle of the tank with a continuous fillet weld on the top side only (Fig. NC-4246.3-1). Roof plates of supported cone roofs shall not be attached to the supporting members. For cone roofs the fillet weld shall be $\frac{3}{16}$ in. (4.8 mm) or smaller.

NC-4246.4 Roof Plates.

Roof plates shall be attached at least by a continuous full fillet lap joint on the top side (Fig. NC-4246.3-1). The top angle sections for self supporting roofs shall be joined by full penetration butt welds.

NC-4246.5 Nozzle, Manhole, and Bottom Outlet.

Nozzles, manholes, and outlets shall be attached by full fillet welds as shown in Figs. NC-4246.5-1 through NC-4246.5-4.

NC-4246.6 Flanges to Roof Nozzles, Manholes, and Bottom Outlets.

Flanges to roof nozzles, manholes, and bottom outlets shall be attached by fillet welds as shown in Figs. NC-4246.5-1, NC-4246.5-2, and NC-4246.5-4.

NC-4246.7 Special Requirements.

Special weld requirements for storage tanks are given in (a) through (d) below.

(a) The minimum size of fillet welds shall be as follows: plates $\frac{3}{16}$ in. (4.8 mm) thick, full fillet welds; plates over $\frac{3}{16}$ in. (4.8 mm) thick, not less than one-third the thickness of the thinner plate at the joint, with a minimum of $\frac{3}{16}$ in. (4.8 mm).

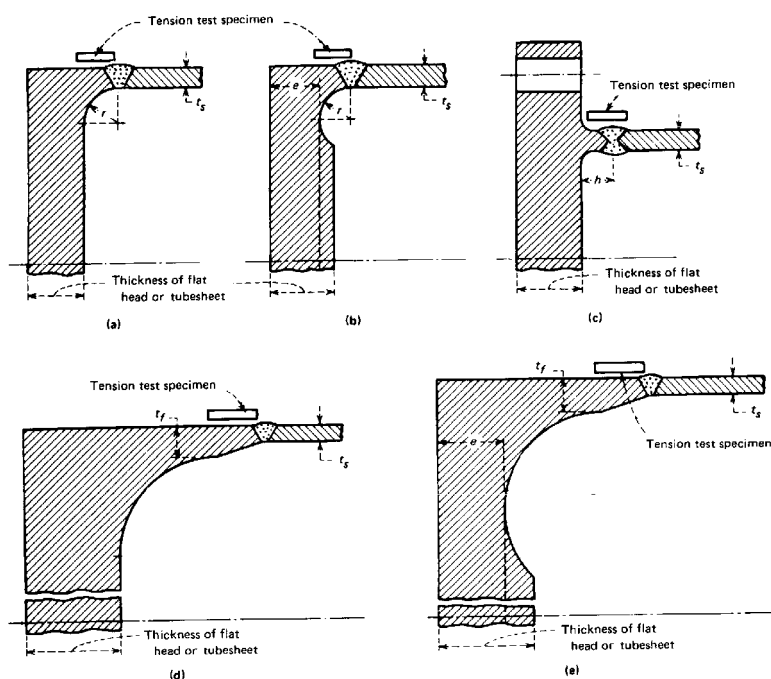
(b) Lap welded joints, as tack welded, shall be lapped not less than five times the nominal thickness of the thinner plate joined; but in the case of double welded lap joints the lap need not exceed 2 in. (51 mm), and in the case of single welded lap joints the lap need not exceed 1 in. (25 mm).

(c) For plates over $\frac{1}{2}$ in. (13 mm) thick in the sidewalls, roof, or bottom of the tank, if the thickness of two adjacent plates which are to be butt welded together differs more than $\frac{1}{8}$ in. (3.2 mm), the thicker plate shall be trimmed to a smooth taper extending for a distance at least three times the offset between the abutting surfaces so that the adjoining edges will be approximately the same thickness (Fig. NC-3361-1). The length of the required taper may include the width of the weld.

(d) Top angle sections for self-supporting roofs shall be joined by full penetration butt welds.

Page 241

Page 242



GENERAL NOTE:

Not permissible if machined from rolled plate. The tension test specimen may be located, when possible, inside the forged hub, instead of outside, as shown.

FIG. NC-4243.1-1 TYPICAL FLAT HEADS AND SUPPORTED AND UNSUPPORTED TUBESHEET WITH HUBS
For Definitions of Nomenclature, See NC-3358.4

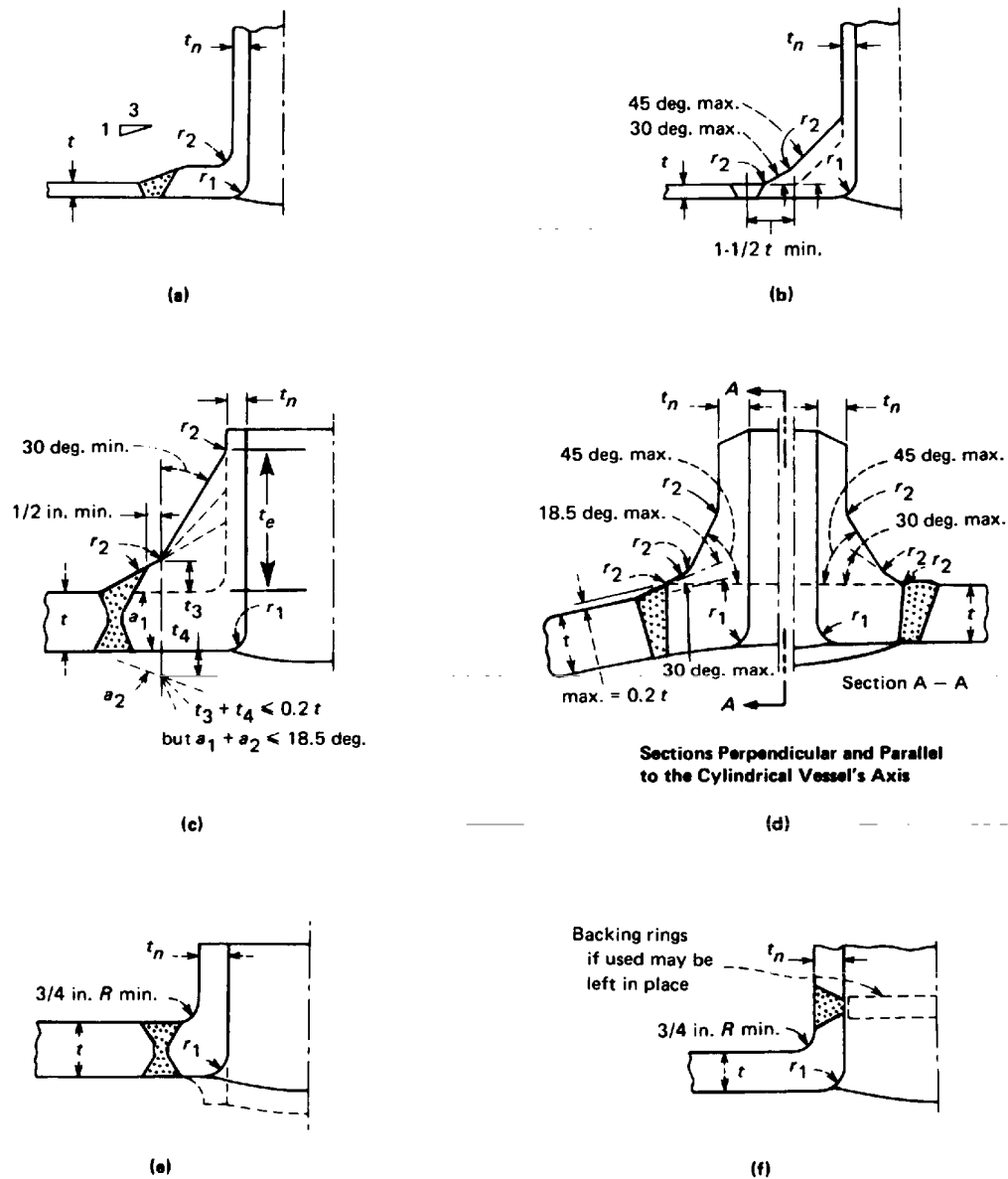


FIG. NC-4244(a)-1 NOZZLES, BRANCH, AND PIPING CONNECTIONS JOINED BY FULL PENETRATION BUTT WELDS
For Definition of Symbols, See NC-3352.4(a)

FIG. NC-4244(a)-1 NOZZLES, BRANCH, AND PIPING CONNECTIONS JOINED BY FULL PENETRATION

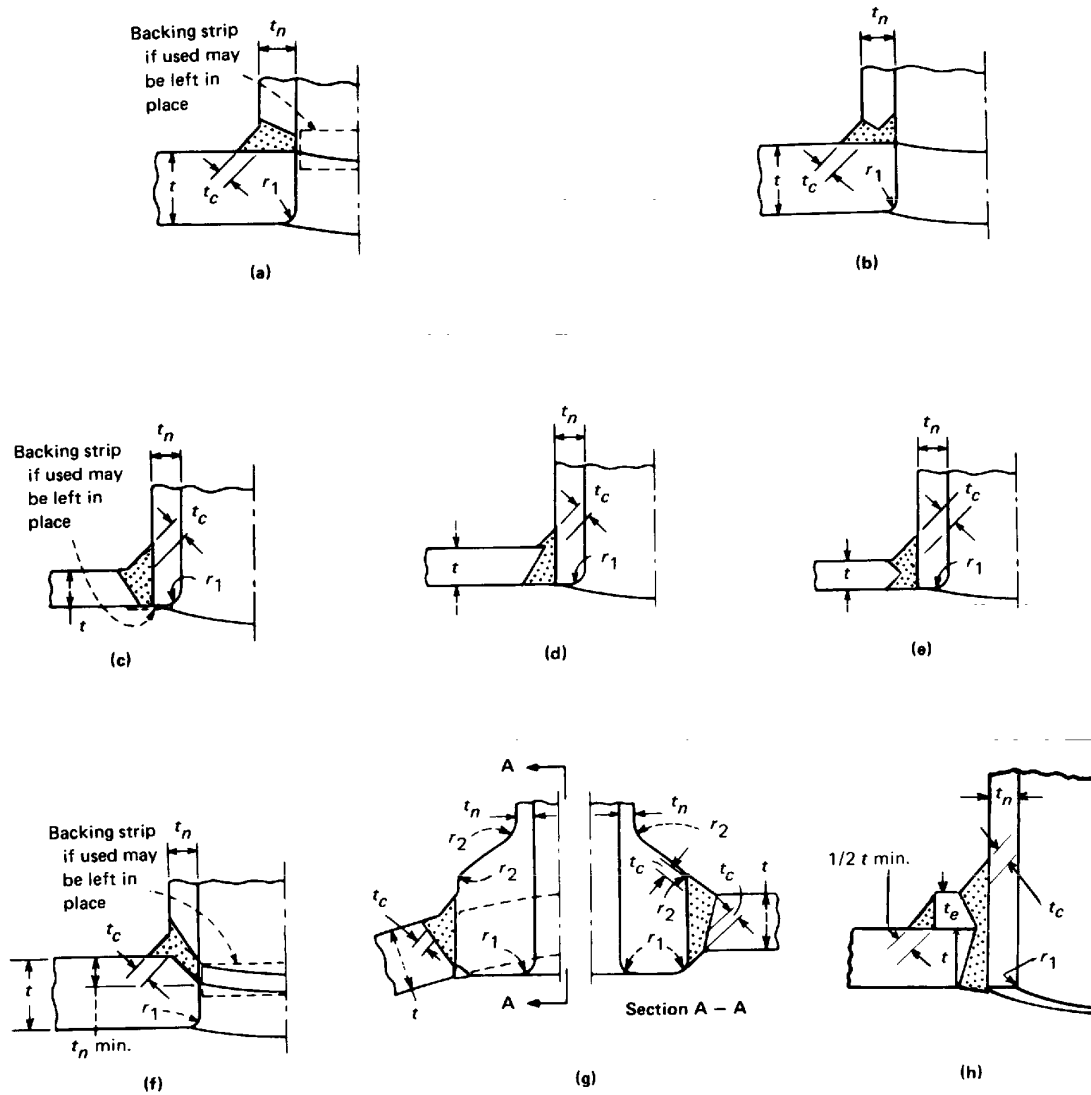


FIG. NC-4244(b)-1 NOZZLES AND BRANCH AND PIPING CONNECTIONS JOINED BY FULL PENETRATION CORNER WELDS
For Definition of Symbols, See NC-3352.4(b)

FIG. NC-4244(b)-1 NOZZLES AND BRANCH AND PIPING CONNECTIONS JOINED BY FULL PENETRATION CORNER WELDS

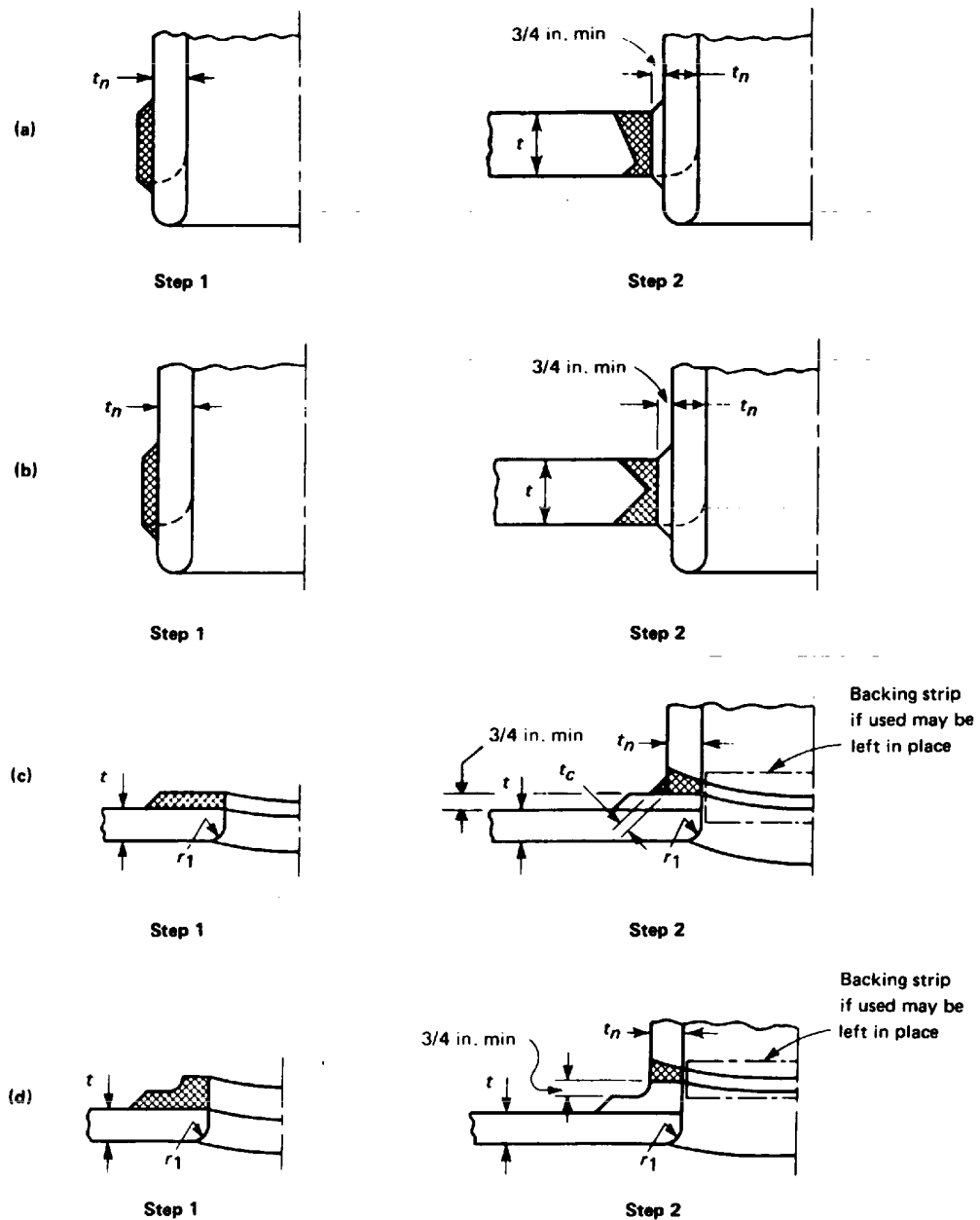


FIG. NC-4244(c)-1 DEPOSITED WELD METAL USED AS REINFORCEMENT OF OPENINGS FOR NOZZLES AND BRANCH AND PIPING CONNECTIONS
 For Definition of Symbols, See NC-3352.4(c)

FIG. NC-4244(c)-1 DEPOSITED WELD METAL USED AS REINFORCEMENT OF OPENINGS FOR NOZZLES

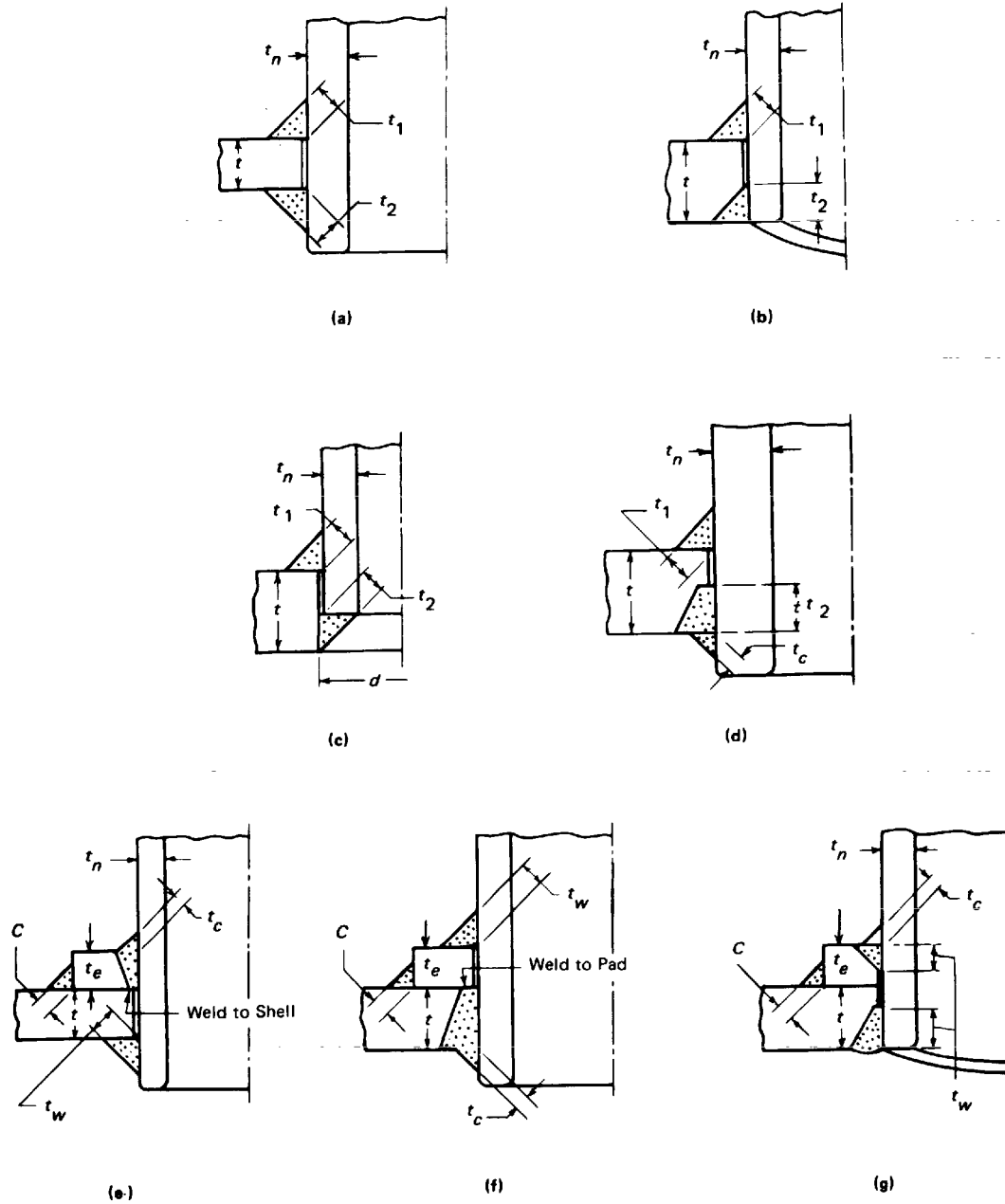


FIG. NC-4244(d)-1 SOME ACCEPTABLE TYPES OF WELDED NOZZLES AND
BRANCH AND PIPING CONNECTIONS
For Definition of Symbols, See NC-3352.4(d)

FIG. NC-4244(d)-1 SOME ACCEPTABLE TYPES OF WELDED NOZZLES AND BRANCH AND PIPING CONNECTIONS

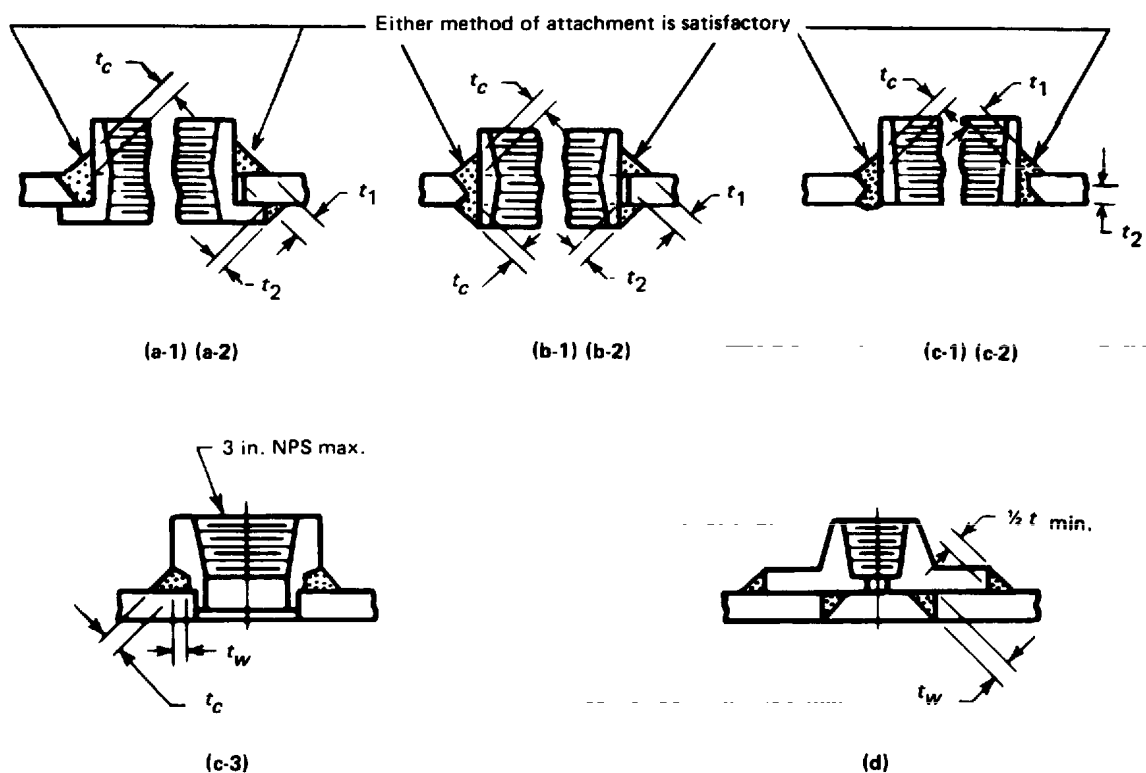


FIG. NC-4244(e)-1 SOME ACCEPTABLE TYPES OF WELDED NOZZLES
For Definition of Symbols, See NC-3352.4(e)

FIG. NC-4244(e)-1 SOME ACCEPTABLE TYPES OF WELDED NOZZLES

NC-4246.8 Other Weld Joints.

The fabrication requirements for weld joints not specifically covered by NC-4246, such as sidewall weld joints and nozzle-to-flange weld joints, are the same as given in NC-4240 for Category A, B, and C weld joints for vessels.

NC-4247 0-15 psi (0-103 kPa) Storage Tank Special Joints

Requirements for special joints for 0-15 psi (0-103 kPa) storage tanks are given below.

NC-4247.1 Bottoms.

All welds in flat bottoms supported directly on foundations shall be single full fillet lap joints as a minimum. For other bottoms, all welds shall be butt welds.

NC-4247.2 Bottom-to-Sidewall.

All welds shall meet the design requirements of NC-3933. Flat bottoms shall be attached to sidewalls by full penetration welds and fillet welds on each side as a minimum.

NC-4247.3 Roof-to-Sidewall.

Roof-to-sidewall joints shall be in accordance with the design requirements of NC-3933. The joints shall have continuous full fillet welds as a minimum.

NC-4247.4 Roofs.

Roofs shall be in accordance with the design requirements of NC-3933 and shall meet the requirements of NC-4241.

NC-4247.5 Nozzles.

Nozzle welds shall meet the requirements of NC-4244.

NC-4247.6 Special Requirements.

Special weld requirements for storage tanks are given in (a) through (d) below.

(a) The minimum size of fillet welds shall be as follows: plates $\frac{3}{16}$ in. (4.8 mm) thick, full fillet welds; plates over $\frac{3}{16}$ in. (4.8 mm) thick, not less than one-third the thickness of the thinner plate at the joint, with a minimum of $\frac{3}{16}$ in. (4.8 mm).

(b) Lap welded joints, as tack welded, shall be lapped not less than five times the nominal thickness of the thinner plate joined; but in the case of double welded lap joints the lap need not exceed 2 in. (51 mm), and in the case of single welded lap joints the lap need not exceed 1 in. (25 mm).

Page 247

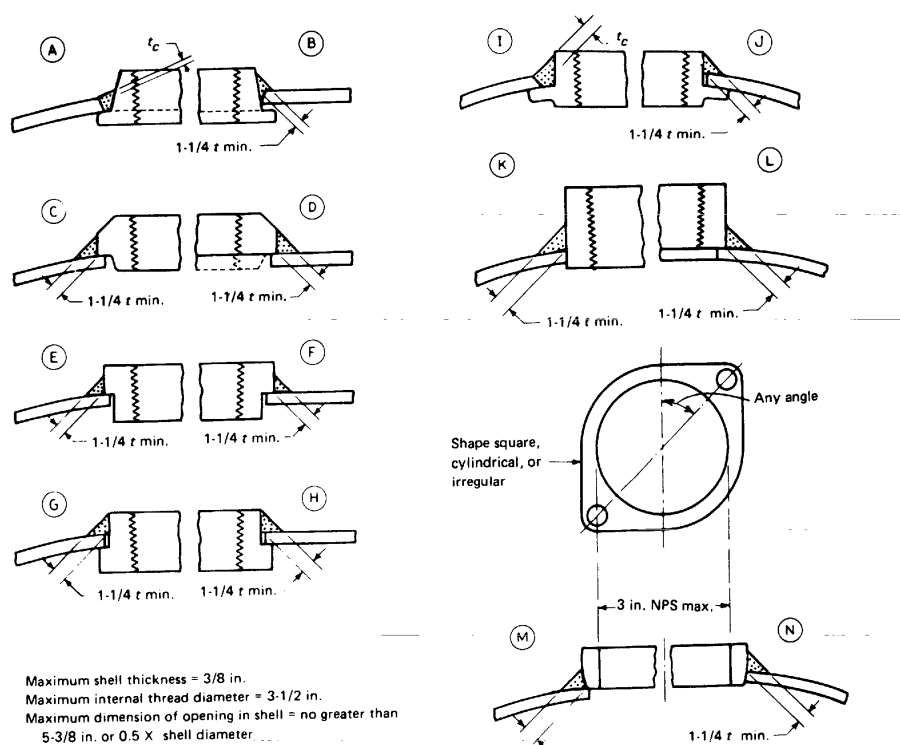


FIG. NC-4244(e)-2 SOME ACCEPTABLE TYPES OF SMALL FITTINGS
For Definitions of Nomenclature, See NC-3352.4(e)

FIG. NC-4244(e)-2 SOME ACCEPTABLE TYPES OF SMALL FITTINGS

(c) For plates over $\frac{1}{2}$ in. (13 mm) thick in the sidewalls, roof, or bottom of the tank, if the thickness of two adjacent plates which are to be butt welded together differs more than $\frac{1}{8}$ in. (3.2 mm), the thicker plate shall be trimmed to a smooth taper extending for a distance at least three times the offset between the abutting surfaces so that the adjoining edges will be approximately the same thickness (Fig. NC-3361-1). The length of the required taper may include the width of the weld.

(d) The size of any weld along either edge of a compression ring shall not be less than the thickness of the thinner of the two parts joined or $\frac{1}{4}$ in. (6 mm), whichever is less, nor shall the size of the corner welds between the shell and a girder bar, such as shown in Fig. NC-3933.5(d)-1 sketches (d) and (e), or between the horizontal and vertical members of a compression ring assembly, such as shown in sketches (f) and (i), be less than the applicable value specified in Table NC-4247.6(d)-1.

NC-4247.7 Other Weld Joints.

The fabrication requirements for weld joints not specifically covered by NC-4247, such as sidewall weld joints and nozzle-to-flange weld joints, are the same as given in NC-4240 for Category A, B, and C weld joints for vessels.

Page 248

Page 249

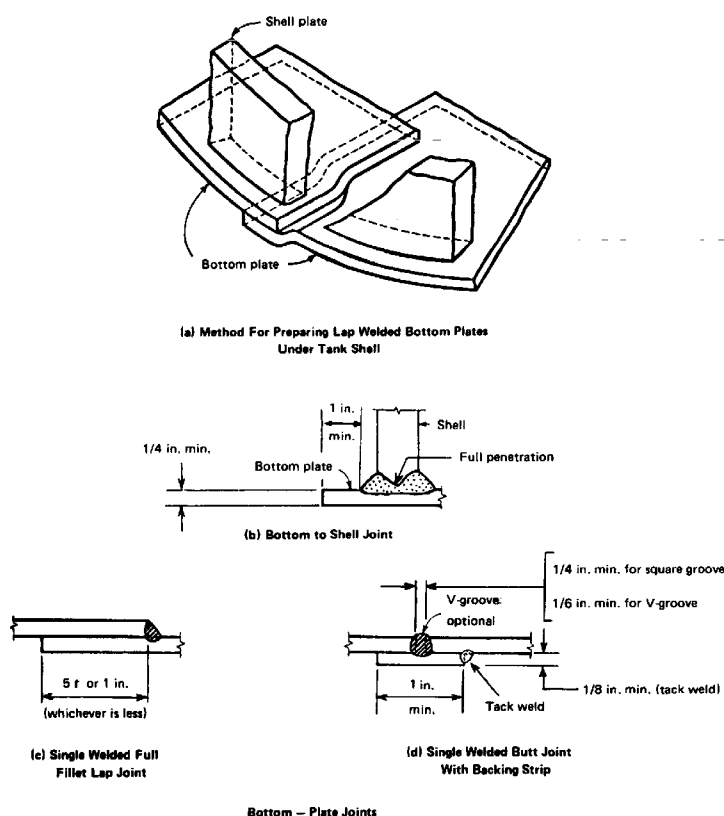
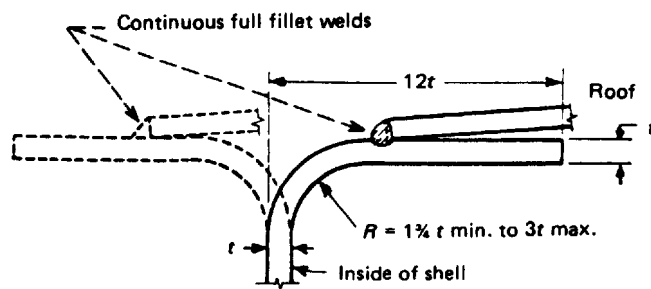
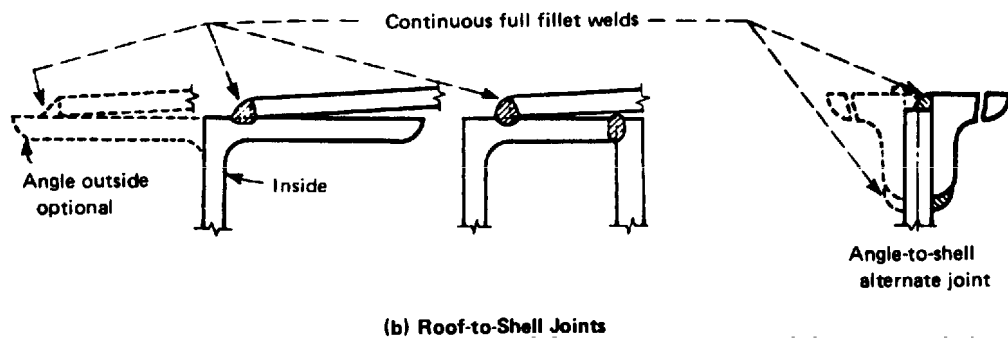
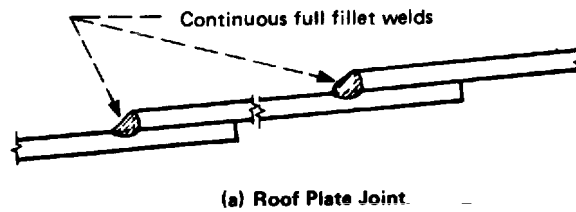


FIG. NC-4246.1(a)-1 TYPICAL BOTTOM AND BOTTOM-TO-SHELL JOINTS



(c) Alternate Roof-to-Shell Joint [Subject to Limitations of NC-3843(c)]

FIG. NC-4246.3-1 TYPICAL ROOF AND ROOF-TO-SHELL JOINTS

FIG. NC-4246.3-1 TYPICAL ROOF AND ROOF-TO-SHELL JOINTS

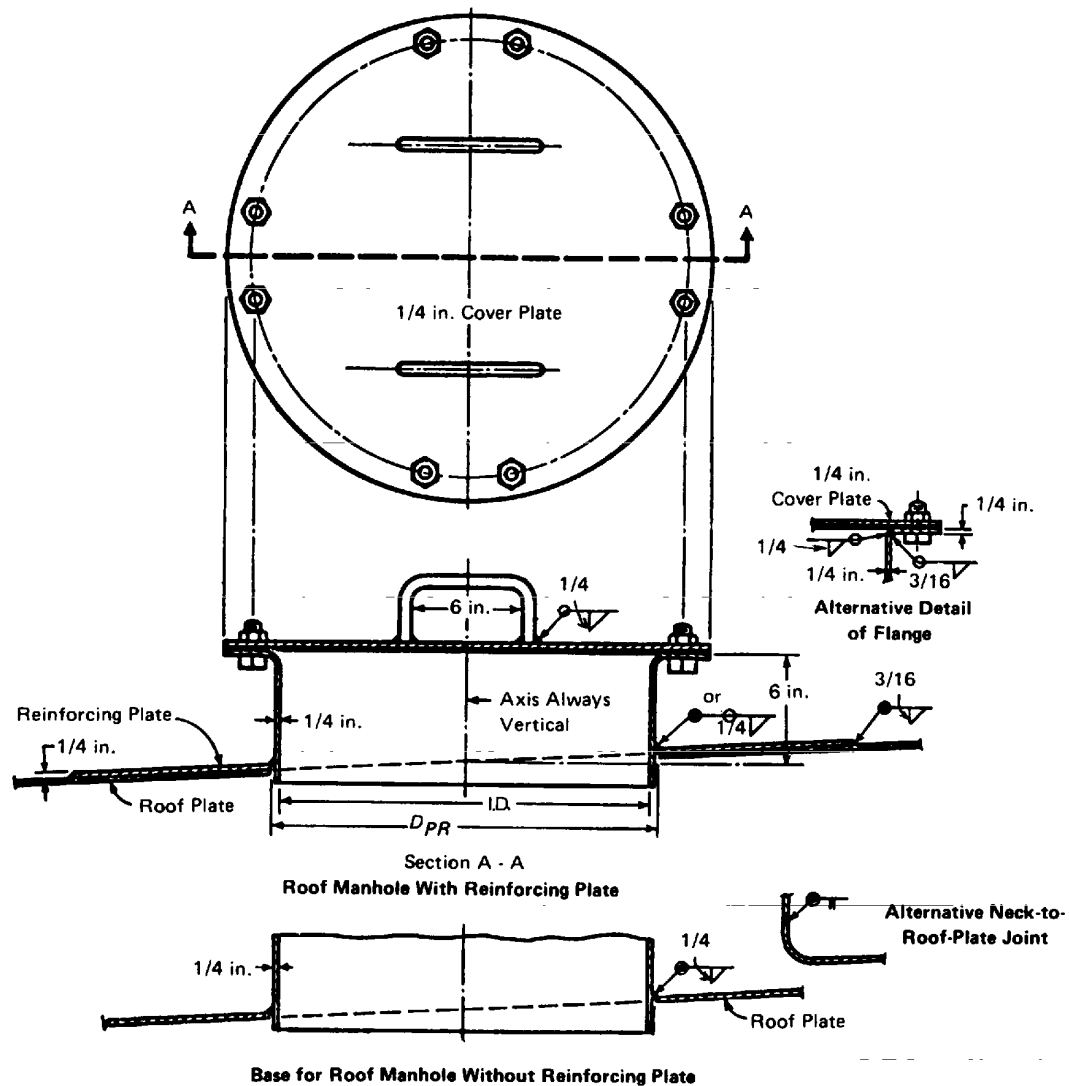


FIG. NC-4246.5-1 ROOF MANHOLES

FIG. NC-4246.5-1 ROOF MANHOLES

NC-4250 WELDING END TRANSITIONS - MAXIMUM ENVELOPE

The welding ends of items or fittings shall provide a gradual change in thickness from the item or fitting to the adjoining item. Any welding end transition which lies entirely within the envelope shown in Fig. NC-4250-1 is acceptable, provided that:

- (a) the wall thickness in the transition region is not less than the min. wall thickness of the adjoining pipe; and
- (b) sharp reentrant angles and abrupt changes in slope in the transition region are avoided. When the included angle between any two adjoining surfaces of a taper transition is less than 150 deg., the intersection or corner (except for the weld

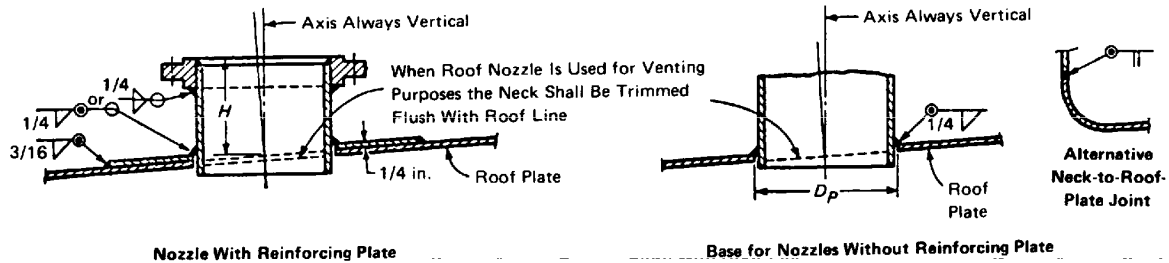
reinforcement) shall be provided with a radius of at least $0.05r_{min}$.

NC-4260 SPECIAL REQUIREMENTS FOR WELD JOINTS IN VESSELS DESIGNED TO NC-3200

NC-4261 General

Except for NC-4240, all other requirements of NC-4000 apply. The requirements of NC-4260 are to be used instead of those in NC-4240.

Page 251



NOTES:

- (1) Slip-on welding and welding-neck flanges shall conform to the requirements for 150-lb forged carbon steel raised-face flanges as given in ANSI B16.5.
- (2) Plate-ring flanges shall conform to all dimensional requirements for slip-on welding flanges, except that the extended hub on the back of the flange may be omitted.

FIG. NC-4246.5-2 FLANGED ROOF NOZZLES

FIG. NC-4246.5-2 FLANGED ROOF NOZZLES

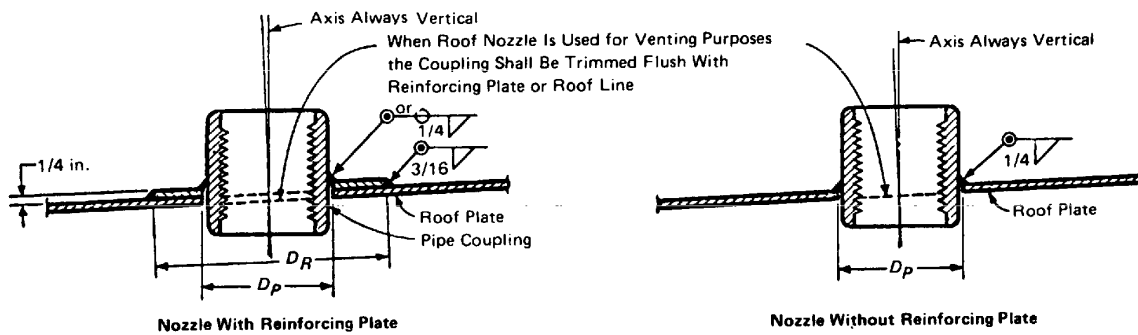


FIG. NC-4246.5-3 SCREWED OR SOCKET WELD ROOF NOZZLES

FIG. NC-4246.5-3 SCREWED OR SOCKET WELD ROOF NOZZLES

NC-4262 Description and Limitations of Joint Types

The description of the joint types are as follows.

(a) *Type No. 1 Butt Joints.* Type No. 1 butt joints are those produced by double welding or by other means which produce the same quality of deposited weld metal on both inside and outside weld surfaces. Welds using backing strips which remain in place do not qualify as Type No. 1 butt joints. Type No. 1 butt joints shall have complete joint penetration and full fusion and shall meet the requirements of NC-4424 and NC-4426.

(b) *Type No. 2 Butt Joints.* Type No. 2 butt joints are single welded butt joints having backing strips which remain in place. NC-3252.2 gives stress concentration factors to be applied to Type No. 2 joints when a fatigue analysis is required. When Type No. 2 butt joints are used, care shall be taken on aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joints for their full length. However, weld reinforcement need be supplied only on the side opposite the backing strip. The requirements of NC-4424 and NC-4426 shall be met.

(c) *Full Penetration Corner Joints.* Corner joints are those connecting two members approximately at right angles to each other in the form of an *L* or *T* and shall be made with full penetration welds.

(d) *Fillet Welded Joints.* Fillet welded joints, permitted by the rules of this subarticle, are those of approximately triangular cross section, joining two surfaces at approximately right angles to each other and having a

Page 252

throat dimension at least 70% of the smaller thickness of the parts being joined but not less than $\frac{1}{4}$ in. (6 mm).

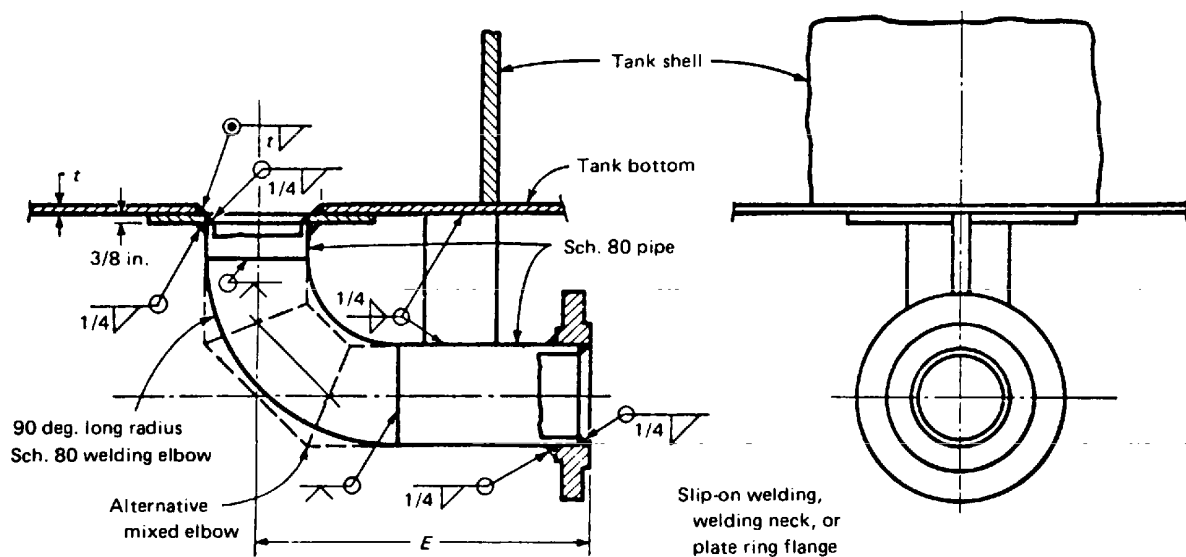


FIG. NC-4246.5-4 WELDED BOTTOM OUTLET ELBOW

FIG. NC-4246.5-4 WELDED BOTTOM OUTLET ELBOW

**TABLE NC-4247.6(d)-1
MINIMUM SIZE FOR FILLET WELDS**

Thickness of the Thicker of the Two Parts Joined, in.	Minimum Size of Fillet Weld, in.
Not over $\frac{1}{4}$	$\frac{3}{16}$
Over $\frac{1}{4}$ through $\frac{3}{4}$	$\frac{1}{4}$
Over $\frac{3}{4}$ through $1\frac{1}{4}$	$\frac{5}{16}$
Over $1\frac{1}{4}$	$\frac{3}{8}$

TABLE NC-4247.6(d)-1 MINIMUM SIZE FOR FILLET WELDS

NC-4263 Category A Weld Joints

Category A weld joints shall be Type No. 1 butt joints.

NC-4264 Category B Weld Joints

Category B weld joints shall be Type No. 1 or Type No. 2 butt joints. Backing strips shall be removed from Type No. 2 joints unless access conditions prevent their removal. Backing strips shall be continuous, and any splices shall be butt welded. Circumferential single welded butt joints with one plate offset to form a backing strip are prohibited.

NC-4265 Category C Weld Joints

Category C weld joints shall be Type No. 1 butt joints or full penetration corner joints. Welds in full penetration corner joints shall be groove welds extending completely through at least one of the parts being joined and shall be fully fused to each part. Typical details are shown in Figs. NC-4265-1 and NC-4265-2.

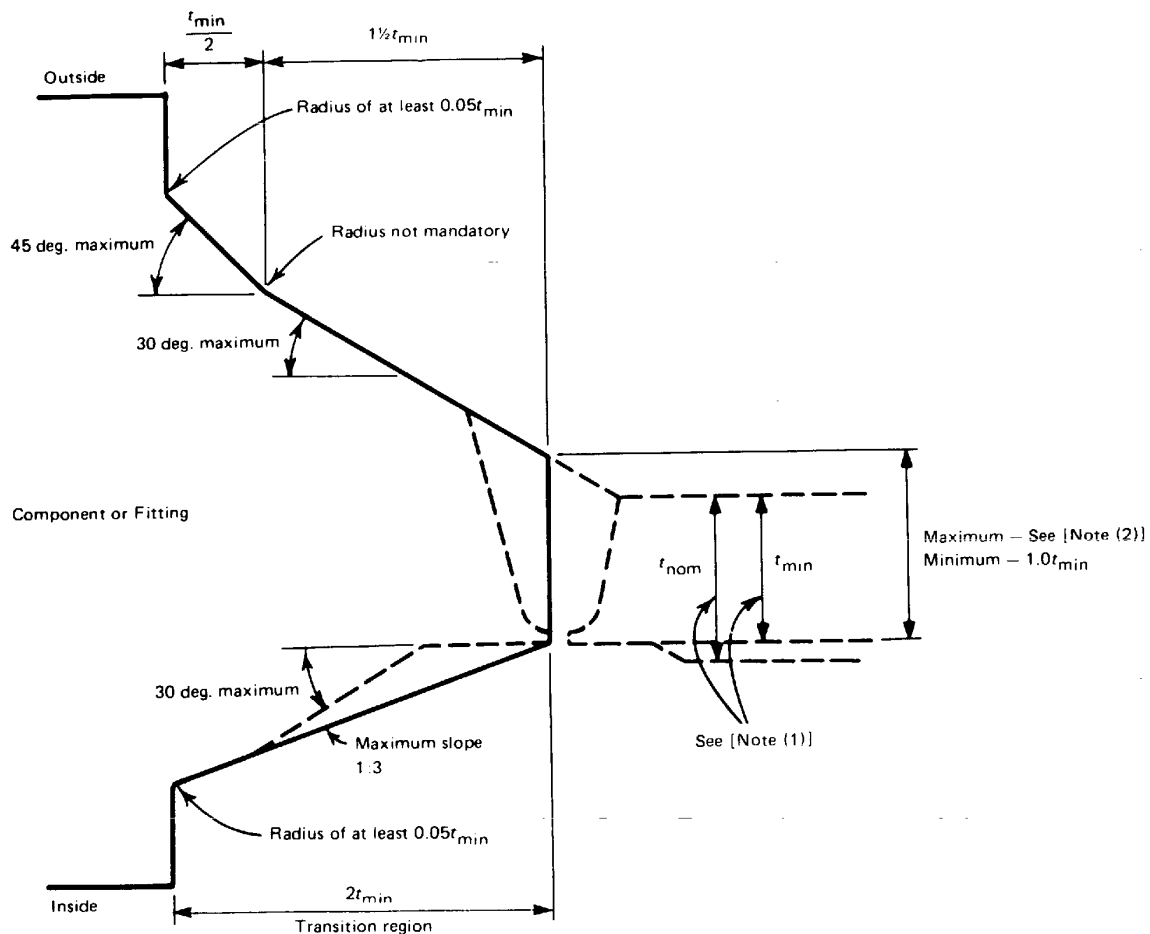
⁴ One test specimen may represent a group of forgings, provided they are of the same nominal dimensions, from the same heat material and the same heat treatment lot, and forged in the same manner.

NC-4265.1 Flat Heads and Tubesheets With Hubs

(a) Hubs for butt welding to the adjacent shell, head, or other pressure parts, as shown in Fig. NC-4243.1-1 for flat heads, shall not be machined from flat plate. The hubs shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material in the direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension test specimen (subsize, if necessary) taken in this direction and as close to the hub as is practical.⁴ The minimum height of the hub shall be the lesser of $1\frac{1}{2}$ times the thickness of the

Page 253

pressure part to which it is welded or $\frac{3}{4}$ in. (19 mm), but need not be greater than 2 in. (51 mm).



GENERAL NOTES:

- Weld bevel is shown for illustration only.
- The weld reinforcement permitted by NC-4426 may lie outside the maximum envelope.

NOTES:

- The value of t_{min} is whichever of the following is applicable:
 - the minimum ordered wall thickness of the pipe;
 - 0.875 times the nominal wall thickness of pipe ordered to a pipe schedule wall thickness which has an under tolerance of 12.5%;
 - the minimum ordered wall thickness of the cylindrical welding end of a component or fitting (or the thinner of the two) when the joint is between two components.
- The maximum thickness at the end of the component is:
 - the greater of $t_{min} + 0.15$ in. or $1.15t_{min}$ when ordered on a minimum wall basis;
 - the greater of $t_{min} + 0.15$ in. or $1.0t_{nom}$ when ordered on a nominal wall basis.

FIG. NC-4250-1 WELDING END TRANSITIONS MAXIMUM ENVELOPE

FIG. NC-4250-1 WELDING END TRANSITIONS MAXIMUM ENVELOPE

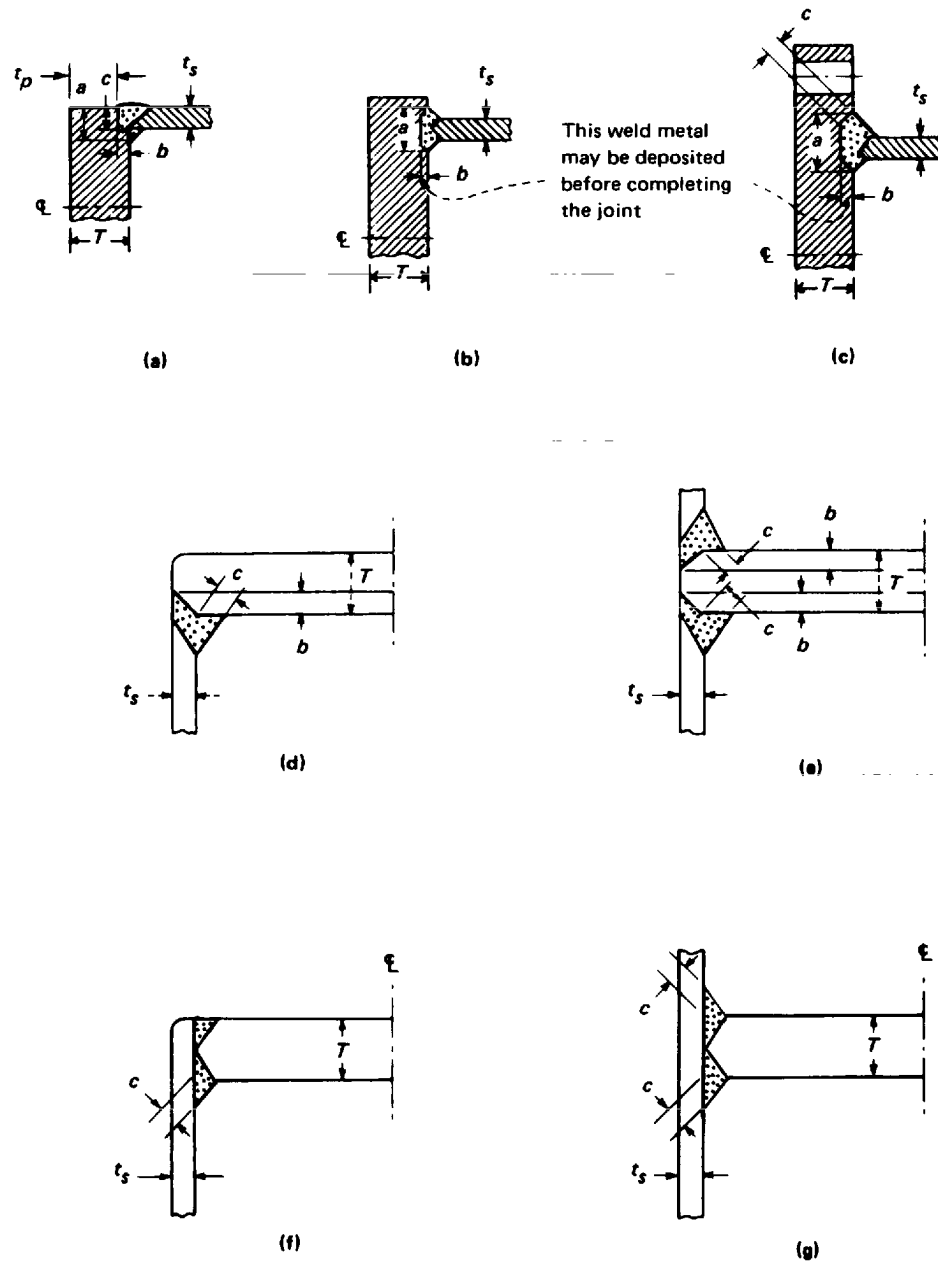


FIG. NC-4265-1 ACCEPTABLE FULL PENETRATION DETAILS TO FORM A CORNER JOINT
 For Definitions of Nomenclature of (a), (b), and (c), See NC-3358.3(e)(2)
 For Definitions of Nomenclature of (d), (e), (f), and (g), See NC-3358.3(e)(1)

FIG. NC-4265-1 ACCEPTABLE FULL PENETRATION DETAILS TO FORM A CORNER JOINT

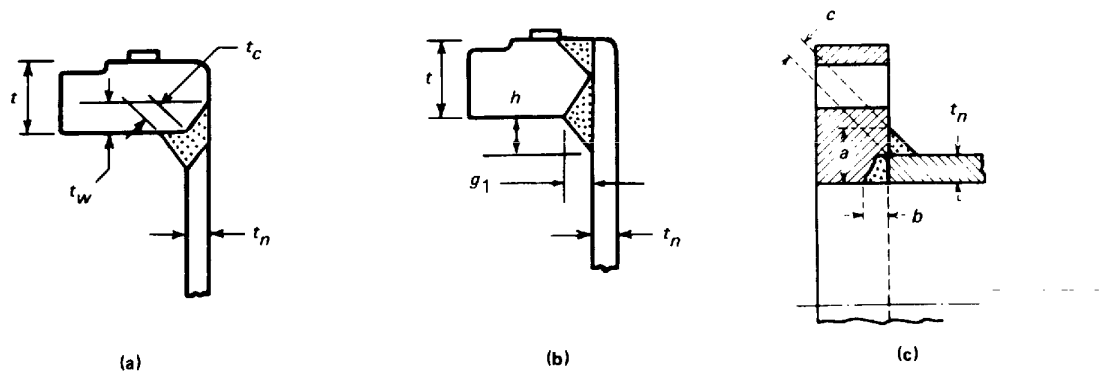


FIG. NC-4265-2 ACCEPTABLE FULL PENETRATION WELD DETAILS FOR CATEGORY C JOINTS

FIG. NC-4265-2 ACCEPTABLE FULL PENETRATION WELD DETAILS FOR CATEGORY C JOINTS

(b) Hubbed flanges, as shown in Fig. XI-3120-1 sketches (6), (6a), and (6b), shall not be machined from flat plate.

NC-4266 Category D Weld Joints

Category D and similar weld joints shall be welded using one of the details of (a) through (d) below.

(a) *Butt Welded Attachments.* Nozzles shall be attached by Type No. 1 butt welds through either the vessel or the nozzle wall as shown in Fig. NC-4266(a)-1.

(b) *Full Penetration Corner Welded Attachment.* Nozzles shall be attached by full penetration welds through the wall of the vessel or nozzle as shown in Fig. NC-4266(b)-1. The welds shall be groove welds extending completely through at least one of the parts being joined and shall be fully fused to each part. Backing strips shall be used with welds deposited from only one side or when complete joint penetration cannot be verified by visual inspection. Backing strips, when used, shall be removed after welding.

(c) *Pad and Screwed Fitting Types of Welded Nozzles*

(1) *Inserted Nozzle Necks With Added Reinforcement.* Inserted type necks having added reinforcement in the form of one or more separate reinforcing plates shall be attached by welds at the outer edge of the reinforcement plate and at the nozzle neck periphery. The weld at the outer edge of the reinforcement shall be a fillet weld with a minimum throat dimension of the smaller of $0.7t_e$ or $0.7t$. The welds attaching the neck to the vessel wall and to the reinforcement shall be full penetration groove welds. Permissible types of weld attachments are shown in Fig. NC-4266(c)-1 sketches (a), (b), and (c).

(2) *Studded Connections*

(a) Studded connections, which may have externally imposed loads, shall have tapped holes complying with the requirements of NC-3262.4. The vessel or integral weld buildup shall have a flat surface machined on the shell to receive the connection. Drilled holes to be tapped shall not penetrate within one-fourth of the wall thickness from the inside surface of the vessel after deducting corrosion allowance unless at least the minimum thickness required as above is maintained by adding metal to the inside surface of the vessel.

(b) Studded pad-type connections may be used for connections on which there are essentially no external mechanical loads, such as manways and handholes used only as inspection openings or thermowell connections, provided the requirements of NC-3239.8 are met. The pad shall be attached by a fillet weld along the outer edge and a single bevel weld along the inner edge. Permissible type of weld attachment is shown in Fig. NC-4266(c)-1 sketch (d). The tapped

holes for stud threads shall comply with NC-3262.4.

(3) *Fittings With Internal Threads.* Internally threaded fittings shall be limited to 2 in. nominal pipe size (DN 50). They shall be attached by means of full penetration groove welds as illustrated in Fig. NC-4266(c)-1 sketches (e), (f), and (g), except pad type fittings, such as shown in sketch (h), which may be used if attached by means of fillet welds having a minimum throat dimension of the smaller of $0.7t_e$ or $0.7t$, as shown in sketch (h).

(d) *Attachment of Nozzles Using Partial Penetration Welds.* Partial penetration welds are limited by the restrictions of NC-3252.4(d). The weld size shall be

Page 256

such that the depth of penetration t_w will be at least $1/4 t_n$. Typical details are shown in Fig. NC-4266(d)-1.

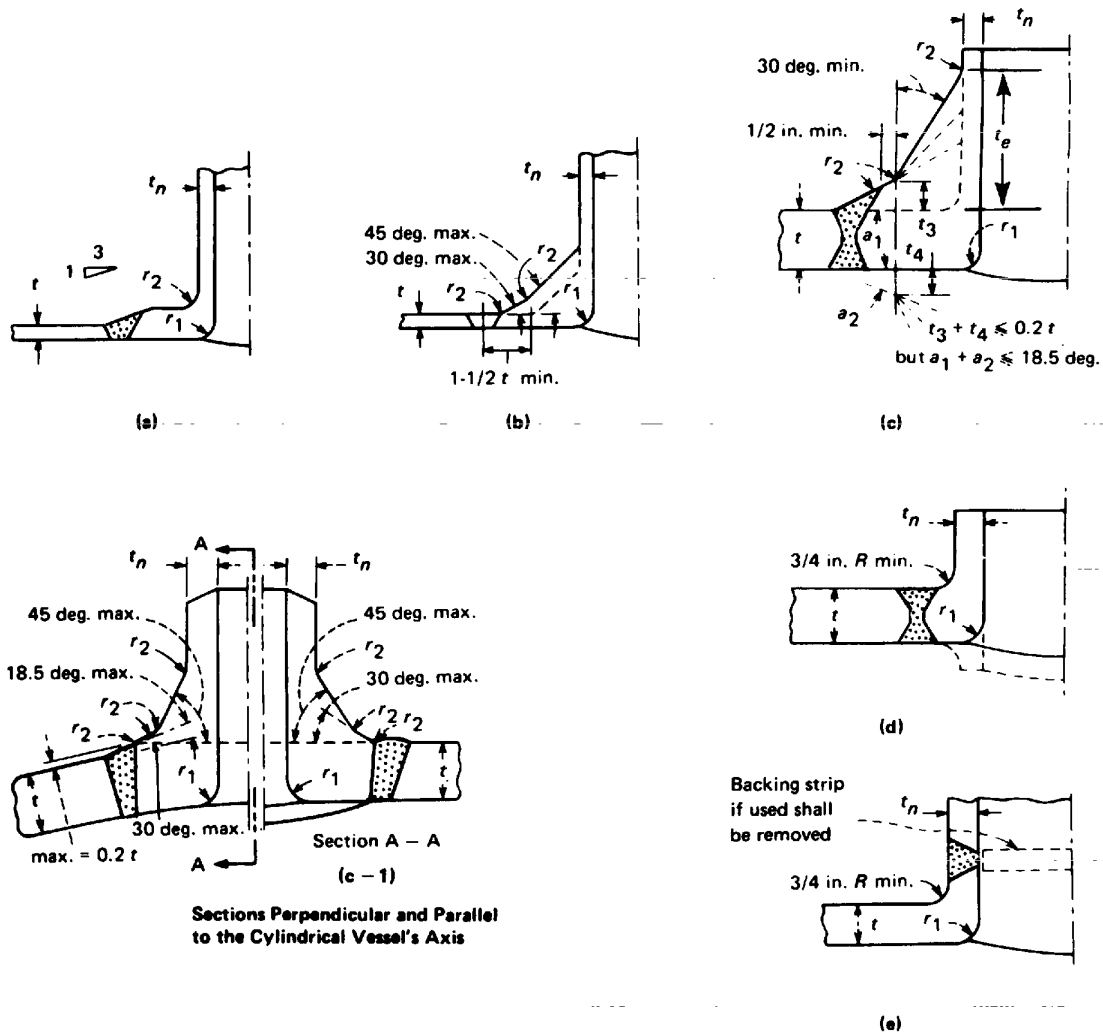


FIG. NC-4266(a)-1 NOZZLES ATTACHED BY FULL PENETRATION BUTT WELDS

FIG. NC-4266(a)-1 NOZZLES ATTACHED BY FULL PENETRATION BUTT WELDS

NC-4267 Types of Attachment Welds

Lugs, brackets, stiffeners, and other attachments shall be attached to the pressure retaining parts by continuous welds. Fillet or partial penetration welds shall be continuous on all sides.

NC-4300 WELDING QUALIFICATIONS

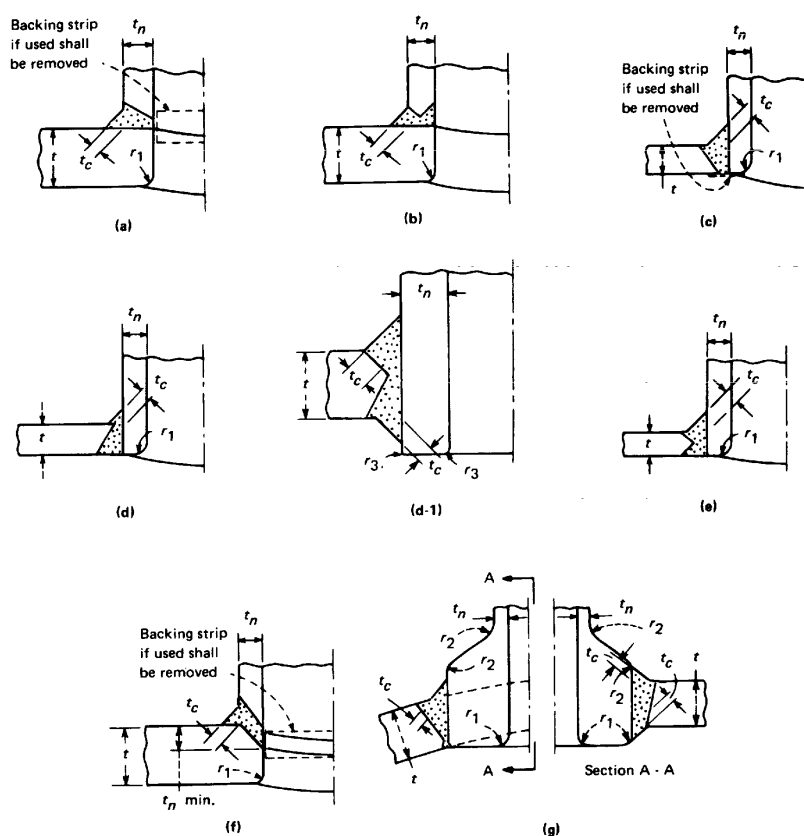
NC-4310 GENERAL REQUIREMENTS

NC-4311 Types of Processes Permitted

Only those welding processes which are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Subsection may be used for welding pressure retaining material or attachments thereto. Any process used shall be such that the records required by NC-4320 can be prepared, except that records for stud welds shall be

Page 257

traceable to the welders and welding operators and not necessarily to each specific weld.



Sections Perpendicular and Parallel to the Cylindrical Vessel Axis

FIG. NC-4266(b)-1 FULL PENETRATION CORNER WELDED ATTACHMENTS

FIG. NC-4266(b)-1 FULL PENETRATION CORNER WELDED ATTACHMENTS

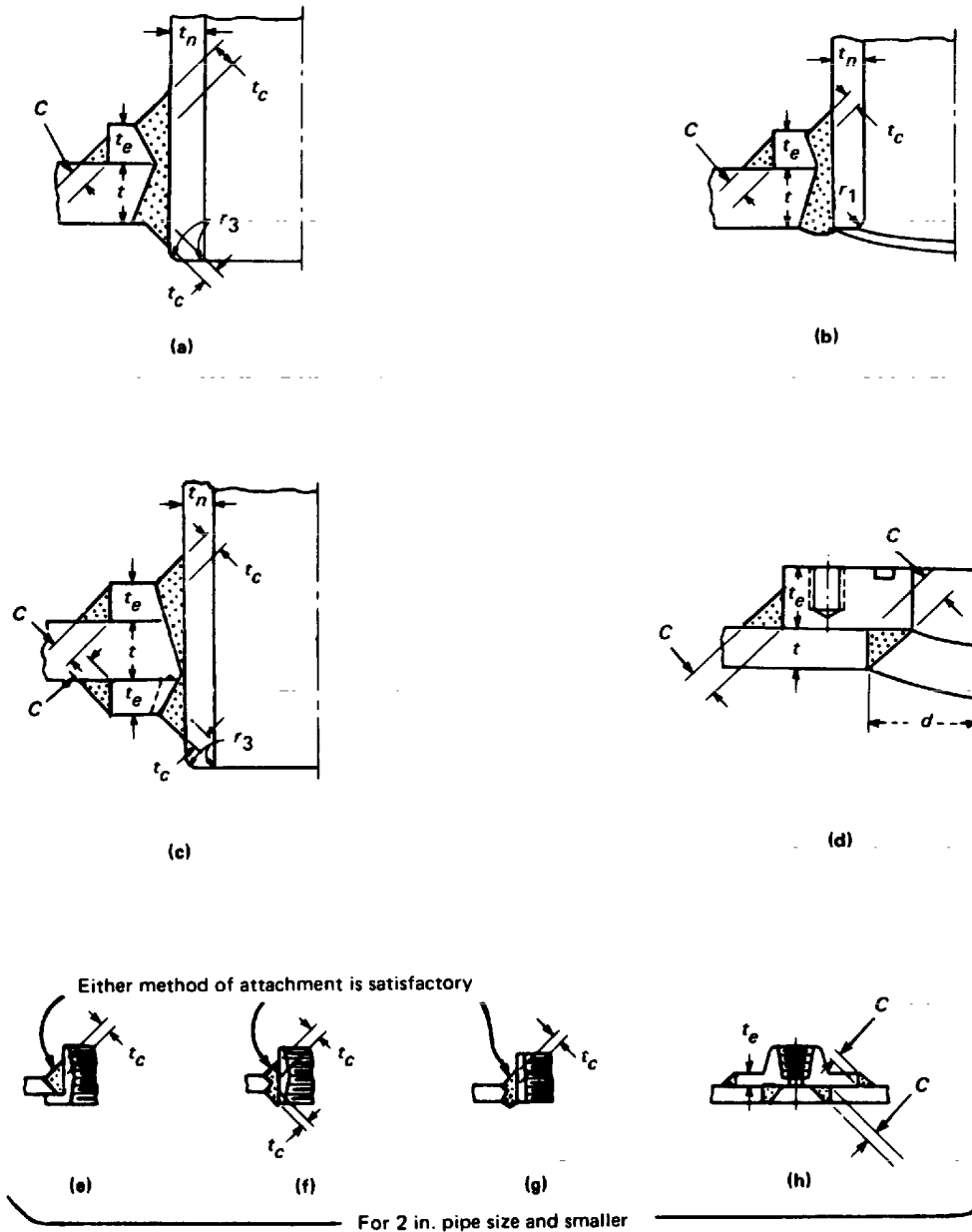


FIG. NC-4266(c)-1 PAD AND SCREWED FITTING TYPES OF WELDED NOZZLES AND OTHER CONNECTIONS TO SHELLS, DRUMS, AND HEADERS

FIG. NC-4266(c)-1 PAD AND SCREWED FITTING TYPES OF WELDED NOZZLES AND OTHER CONNECTIONS

TO SHELLS, DRUMS, AND HEADERS

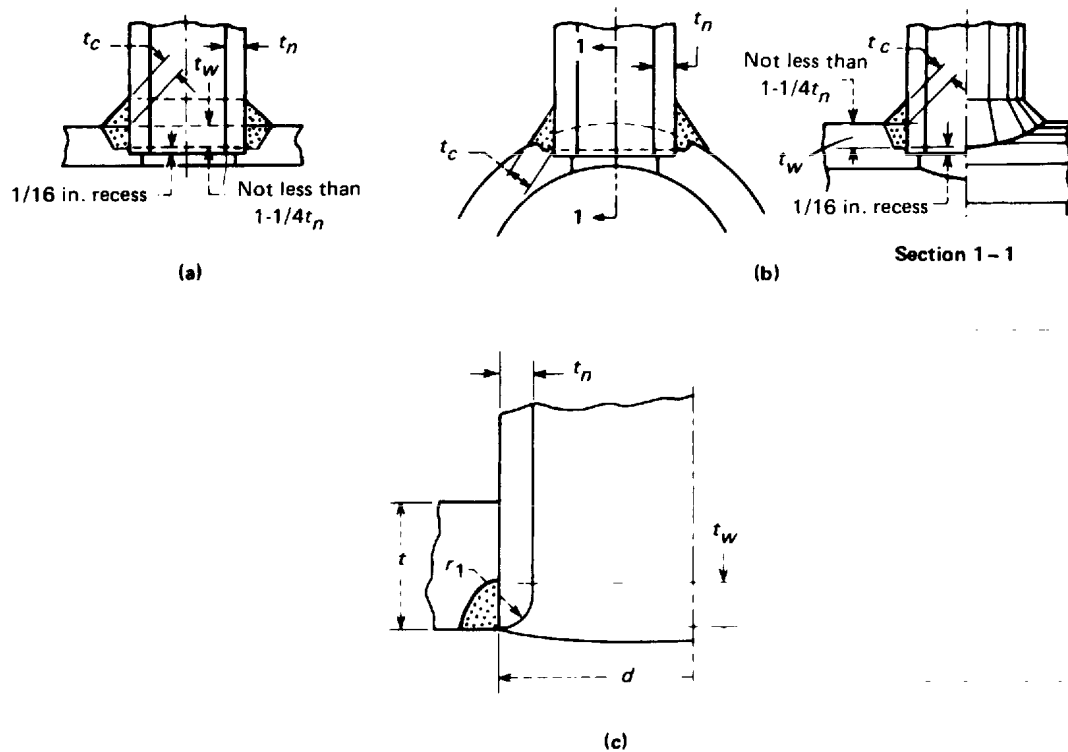


FIG. NC-4266(d)-1 PARTIAL PENETRATION WELD CONNECTIONS

FIG. NC-4266(d)-1 PARTIAL PENETRATION WELD CONNECTIONS

NC-4311.1 Stud Welding Restrictions.

Stud welding is acceptable only for nonstructural and temporary attachments (NC-4435). Studs shall be limited to 1 in. (25 mm) maximum diameter for round studs and an equivalent cross-sectional area for studs of other shapes when welding in the flat position and $3/4$ in. (19 mm) diameter for all other welding positions. Postweld heat treatment shall comply with NC-4600, except that time at temperature need not exceed $1/2$ hr regardless of base material thickness. Welding procedure and performance qualification shall comply with the requirements of Section IX.

NC-4311.2 Capacitor Discharge Welding.

Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments provided:

- (a) temporary attachments are removed in accordance with the provisions of NC-4435(b);
- (b) the energy output for permanent nonstructural attachments such as strain gages and thermocouples is limited to 125 W-sec and the minimum thickness of the material to which the attachment is made is greater than 0.09 in. (2.3 mm); and
- (c) a Welding Procedure Specification is prepared describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required.

NC-4311.4 Inertia and Continuous Drive Friction Welding

- (a) Inertia and continuous drive friction welding shall not be used for the fabrication of piping.
- (b) The weld between the two members shall be a full penetration weld.

NC-4320 WELDING QUALIFICATIONS, RECORDS, AND IDENTIFYING STAMPS

NC-4321 Required Qualifications

- (a) Each Certificate Holder is responsible for the welding done by his organization, and he shall establish the procedure and conduct the tests required by this

Page 260

Article and by Section IX in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures.

- (b) Procedures, welders, and welding operators used to join permanent or temporary attachments to pressure parts and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Article.

- (c) When making procedure test plates for butt welds, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. This applies particularly to material and weld metal of 80.0 ksi (552 MPa) tensile strength or higher and heavy sections of both low and high tensile strength material. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

NC-4322 Maintenance and Certification of Records

The Certificate Holder shall maintain a record of his qualified welding procedures and of the welders and welding operators qualified by him, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and signed by any authorized individual assigned by the Certificate Holder, and they shall be accessible to the Owner and to the Inspector.

NC-4322.1 Identification of Joints by Welder or Welding Operator

- (a) Each welder or welding operator shall apply the identification mark assigned to him by the Certificate Holder on or adjacent to all permanent welded joints or series of joints on which he welds. The marking shall be at intervals of 3 ft (0.9 m) or less and shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps. As an alternative, the Certificate Holder shall keep a record of permanent welded joints in each item and of the welders and welding operators used in making each of the joints.

- (b) When a multiple number of permanent structural attachment welds, nonstructural welds, fillet welds, socket welds, welds of specially designed seals, weld

Page 262

metal cladding, hard surfacing and tube-to-tubesheet welds are made on an item, the Certificate Holder need not
identify the welder or welding operator who welded each individual joint, provided: Pages 261-261

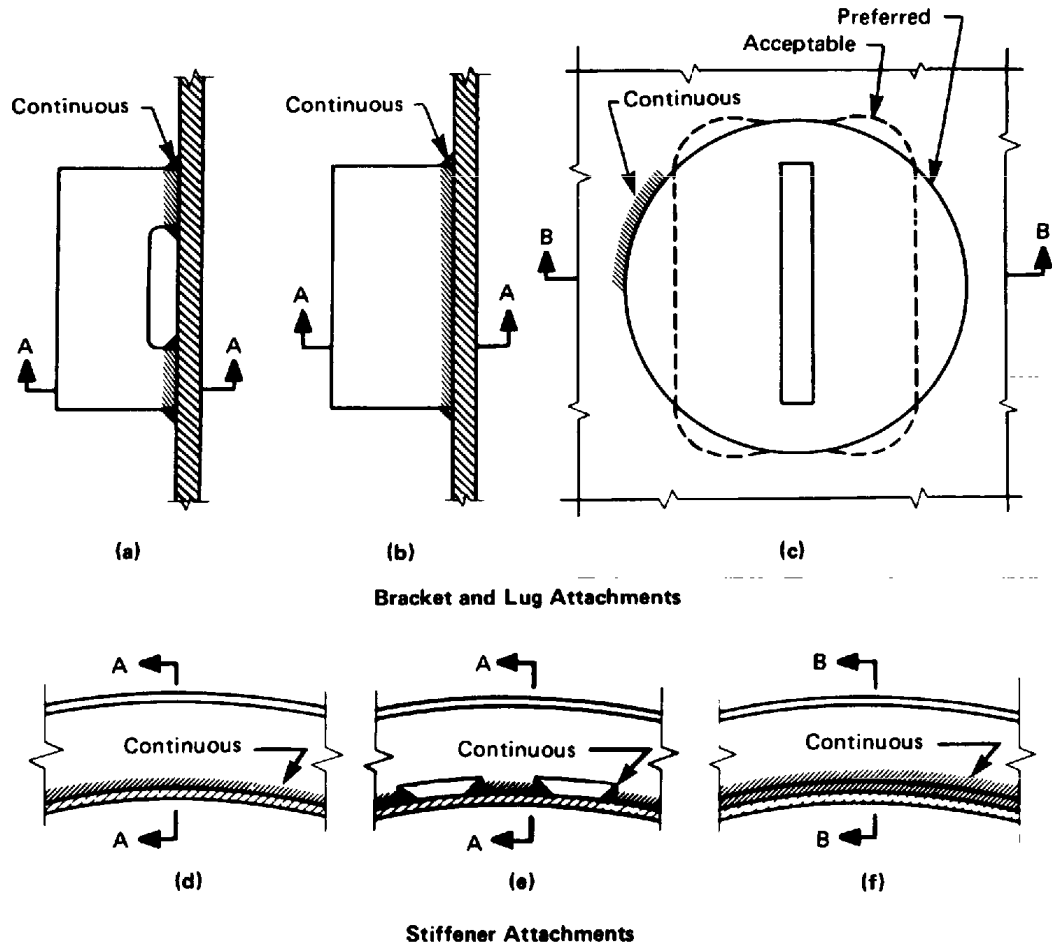
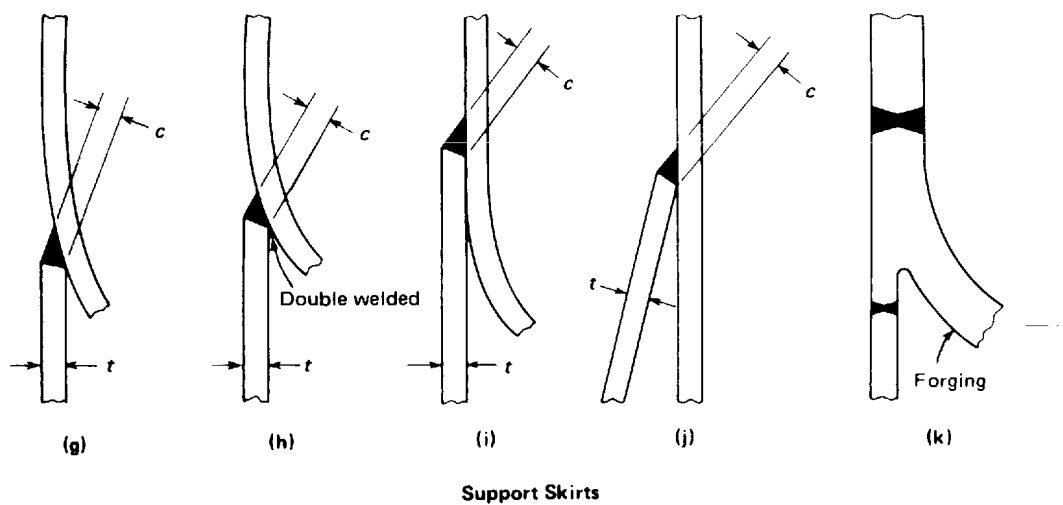
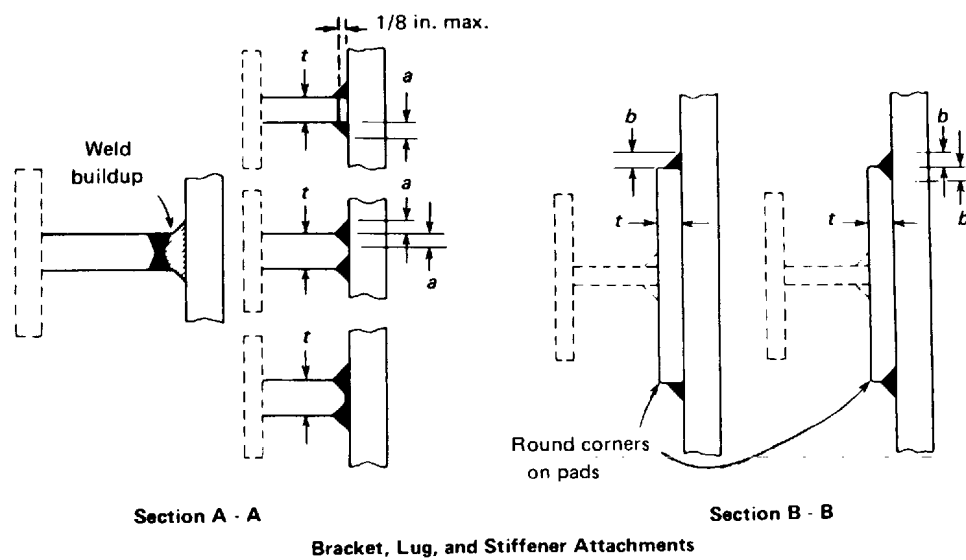


FIG. NC-4267-1 ATTACHMENTS

FIG. NC-4267-1 ATTACHMENTS



$a \geq t/4; b \geq t/2; c \geq t$
 t = thickness of attached member
 c = minimum thickness of weld metal from the root to the face of the weld

GENERAL NOTE: All welds continuous.

FIG. NC-4267-1 ATTACHMENTS (CONT'D)

FIG. NC-4267-1 ATTACHMENTS (CONT'D)

- (1) the Certificate Holder maintains a system that will identify the welders or welding operators who made such welds on each item so that the Inspector can verify that the welders or welding operators were all properly qualified;
- (2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification.
- (c) The identification of welder or welding operator is not required for tack welds.

NC-4323 Welding Prior to Qualifications

No welding shall be undertaken until after the welding procedures which are to be used have been qualified. Only welders and welding operators who are qualified in accordance with NC-4320 and Section IX shall be used.

NC-4324 Transferring Qualifications

The welding procedure qualifications and performance qualification tests for welders and welding operators conducted by one Certificate Holder shall not qualify welding procedures, and shall not qualify welders or welding operators to weld for any other Certificate Holder, except as provided in Section IX, QW-201 and QW-300.20.

NC-4330 GENERAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION TESTS

NC-4331 Conformance to Section IX Requirements

All welding procedure qualification tests shall be in accordance with the requirements of Section IX as supplemented or modified by the requirements of this Article.

NC-4333 Heat Treatment of Qualification Welds for Ferritic Materials

Postweld heat treatment of procedure qualification welds shall conform to the applicable requirements of NC-4600 and Section IX. The postweld heat treatment time at temperature is to be at least 80% of the maximum time to be applied to the component weld material. The postweld heat treatment total time may be applied in one heating cycle.

NC-4334 Preparation of Test Coupons and Specimens

(a) Removal of test coupons from the test weld and the dimensions of specimens made from them shall conform to the requirements of Section IX, except that the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with (b) below.

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test specimens. When each process cannot be included in the full size impact test specimen at the $\frac{1}{4}t$ location required by this Section, additional full size specimens shall be obtained from locations in the test weld that will ensure that at least a portion of each process has been included in full size test specimens. As an alternative, additional test welds can be made with each process so that full size specimens can be tested for each process.

NC-4334.1 Coupons Representing the Weld Deposits.

Impact test specimens and testing methods shall conform to NC-2321. The impact specimen shall be located so that the longitudinal axis of the specimen is at least $\frac{1}{4}t$ and, where the thickness of the test assembly permits, not less than $\frac{3}{8}$ in. (10 mm) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified in NC-4620, and the test assembly is cooled at an accelerated rate, the longitudinal axis of the specimen shall be a minimum of t from the edge of the test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the weld. The length of the notch of the Charpy V-notch specimen shall be normal to the surface of the weld. Where drop weight specimens are required, the tension surface of the specimen shall be oriented parallel to the surface of the test assembly.

NC-4334.2 Coupons Representing the Heat Affected Zone.

Where impact tests of the heat affected zone are required by NC-4335.2, specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through (c) below.

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented either parallel to or perpendicular to the principal direction of rolling or forging.

Page 263

(b) The heat affected zone impact test specimens and testing methods shall conform to the requirements of NC-2321.2. The specimens shall be removed from a location as near as practical to a depth midway between the surface and center thickness. The coupons for heat affected zone impact specimens shall be taken transverse to the axis of the weld and etched to define the heat affected zone. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much heat affected zone as possible in the resulting fracture. Where the material thickness permits, the axis of a specimen may be inclined to allow the root of the notch to align parallel to the fusion line. When a grain refining heat treatment is not performed on welds made by the electroslag or electrogas welding process, the notch for the impact specimens shall be located in the grain coarsened region.

(c) For the comparison of heat affected zone values with base material values [NC-4335.2(b)], Charpy V-notch specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the heat affected zone specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the heat affected zone specimens, and the axis of the notch shall be normal to the surface of the base material. When required by NC-4335.2(b)(4), drop weight specimens shall be removed from a depth as near as practical to midway between the surface and center thickness of the unaffected base material and shall be tested in accordance with the requirements of NC-2321.1.

NC-4335 Impact Test Requirements

When materials are required to be impact tested per NC-2300, impact tests of the weld metal and heat affected zone shall be performed in accordance with the following subparagraphs. Exemption from impact testing under NC-2311(a)(8) does not apply to weld metal unless the specific weld metal used is included in Table NC-2311(a)-1. Exemption from impact testing of the heat affected zone of those base materials exempted by NC-2311(a)(8) is not permitted. The weld procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of NC-2330 and NC-4334. Retests in accordance with the provisions of NC-2350 are permitted.

NC-4335.1 Impact Tests of Weld Metal

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding $\frac{5}{8}$ in. in thickness when the weld will be made on the surface or will penetrate the base material that requires impact testing in accordance with NC-2310. In addition, such testing of the weld metal is required for the welding procedure qualification tests for any weld repair to base material that requires impact testing in accordance with NC-2310, regardless of the depth of the repair. Exemption from impact testing under NC-2311(a)(8) does not apply to weld metal of welding procedure qualification tests for either production weld joints or base material repairs unless the specific weld metal used is included in Table NC-2311(a)-1.

(b) The impact test requirements and acceptance standards for welding procedure qualification weld metal shall be the same as specified in NC-2330 for the base material to be welded or repaired. Where two materials are to be joined by welding and have different fracture toughness requirements, the test requirements and acceptance standards of either material may be used for the weld metal, except where otherwise specified by NCA-1280 or other parts of this Section.

(c) A Welding Procedure Specification qualified to the impact testing requirements of Subsection NB or NE may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection.

NC-4335.2 Impact Tests of Heat Affected Zone

(a) Charpy V-notch tests of the heat affected zone of the welding procedure qualification test assembly are required whenever the thickness of the weld exceeds $\frac{5}{8}$ in. (16 mm) and either of the base materials require impact testing in

accordance with the rules of NC-2310. Exemption of base materials by NC-2311(a)(8) does not apply to the welding procedure qualification heat affected zone or unaffected base material for such materials. The only exceptions to the requirements are the following:

(1) the qualification for welds in P-Nos. 1 and 3 and SA-336 F12 materials that are postweld heat treated and are made by any process other than electroslog, electrogas, or thermit;

(2) the qualification for weld deposit cladding or hear-facing on any base material.

(b) Impact testing of the procedure qualification test heat affected zone, where required by NC-4335, shall be conducted in accordance with (b)(1) through (3) below, or (b)(4) through (6) below, and (c) below, as applicable.

(1) For tests of welding procedure qualifications for materials that require testing in accordance with NC-2332.1, the three Charpy V-notch heat affected zone specimens and three Charpy V-notch unaffected base material specimens shall be tested at a temperature in accordance with NC-2331(a)(1). The Charpy V-notch impact test of the unaffected

Page 264

base material shall meet the requirements of Table NC-2332.1-1 or Table NC-2332.1-2. If the average lateral expansion value of the three heat affected zone specimens is equal to or greater than the average value of the unaffected base material Charpy V-notch specimens, the qualification test shall be considered acceptable, and the values and testing temperature shall be recorded on the Welding Procedure Qualification Record.

(2) If the heat affected zone Charpy V-notch average toughness value of (b)(1) above is less than the unaffected base material value, and the qualification test meets the other criteria of acceptance, the Charpy V-notch test results may be recorded on the Welding Procedure Qualification Record. Data shall then be obtained, as specified in (b)(3) below, to provide an additive temperature for the adjustment of the lowest service temperature (LST) of the base material that is to be welded in production with the welding procedure that is being qualified. Alternatively, the welding procedure qualification may be rewelded and retested.

(3) The data for use in (b)(2) above shall be developed by performing additional Charpy V-notch tests on either the welding procedure qualification test heat affected zone or the unaffected base material, or both, at temperatures which provide toughness values that meet or exceed those required for the thickness or thickness-strength combination of the material to be welded in production. The average toughness data for the heat affected zone and unaffected base material shall be plotted on a property-temperature chart. The temperature at which these two sets of data exhibit a common acceptable value of toughness for the production thickness or thickness-strength combination involved shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the heat affected zone. This difference, if a positive number, shall be used in (b)(2) above as the adjustment temperature. The welding procedure adjustment temperature shall be added to the highest LST established by the tests of NC-2332.1 for all of the base material to be welded by this procedure in production. If the temperature difference is zero or a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by the tests for NC-2332.1 will still apply as stated in (b)(1) above. Where the actual LST is not required for the production material to be welded, for example, where a testing temperature is established by the Design Specification to determine that the material has adequate toughness to meet the requirements at the specified test temperature, the adjustment temperature determined by the curves shall be used to establish a reduction in the specified testing temperature for the production material. The adjustment temperature shall be used to lower the specified testing temperature for any production material on which the procedure will be used.

(4) For tests of welding procedure qualifications for materials that require tests in accordance with NC-2332.2, three Charpy V-notch heat affected zone specimens and three Charpy V-notch unaffected base material specimens shall be tested at a temperature lower than or equal to the LST. The Charpy V-notch impact tests of the unaffected base material shall each meet or exceed the applicable Over $2\frac{1}{2}$ in. (64 mm) thickness requirements of Table NC-2332.1-1 or Table NC-2332.1-2. If the average toughness value of the three heat affected zone specimens is equal to or greater than the average value for the unaffected base material Charpy V-notch specimens, the qualification test shall be considered acceptable. The values and testing temperature shall be recorded on the Welding Procedure Qualification Record.

(5) If the average Charpy V-notch toughness value for the heat affected zone of (b)(4) above is less than that for the unaffected base material, and the qualification test meets the other criteria of acceptance, the Charpy V-notch test

results may be recorded on the Welding Procedure Qualification Record. Data of (b)(6) below, which will provide an adjustment temperature for any base material for which the welding procedure is being qualified, shall be included. Alternatively, the welding procedure qualification may be rewelded and retested.

(6) The data for use in (b)(5) above shall be developed by performing additional Charpy V-notch tests on either the welding procedure qualification heat affected zone or the unaffected base material, or both, at temperatures which provide toughness values equal to or greater than the applicable Over $2\frac{1}{2}$ in. (64 mm) thickness requirements of Table NC-2332.1-1 or Table NC-2332.1-2. The average toughness data for the heat affected zone and the unaffected base material shall be plotted on a property-temperature chart. The temperatures at which these two sets of data exhibit a common toughness value equal to or greater than the applicable Over $2\frac{1}{2}$ in. thickness requirements of Table NC-2332.1-1 or Table NC-2332.1-2 shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the heat affected zone. This difference, if a positive number, shall be used in (b)(5) above as the adjustment temperature. The adjustment

Page 265

temperature shall be added to the highest T_{NDT} established by the tests of NC-2332.2 for all of the base material to be welded by this procedure in production. If the temperature difference is zero or is a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by the tests for NC-2332.2 will still apply as stated in (b)(4) above. Where the actual T_{NDT} is not required for the product material to be welded, for example, where a testing temperature is established by the Design Specification to determine that the T_{NDT} is at or below the specified temperature, the adjustment temperature determined by the curves shall be used to establish a reduction in the specified testing temperature for the production material. The adjustment temperature shall be used to lower the specified testing temperature for any production material on which the procedure will be used.

(c) Should the unaffected base material Charpy V-notch impact test results fail to meet the applicable requirements referenced in (b)(1) or (b)(4) above, additional unaffected base material Charpy V-notch impact tests shall be tested at higher temperatures until the applicable requirements are met. Charpy V-notch impact tests of the heat affected zone shall be tested at the same temperature at which acceptable unaffected base material properties were achieved. The rules governing the average toughness of the heat affected zone relative to the average toughness of the unaffected base material shall be followed as in (b)(1) through (3) above or (b)(4) through (6) above, as applicable, to determine the data which are to be recorded on the Welding Procedure Qualification Record.

(d) A Welding Procedure Specification qualified to the impact testing requirements of Subsection NB or NE may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection.

NC-4336 Qualification Requirements for Built- Up Weld Deposits

Built-up weld deposits for base metal reinforcement shall be qualified in accordance with the requirements of NC-4331 to NC-4335, inclusive.

NC-4350 SPECIAL QUALIFICATION REQUIREMENTS FOR TUBE-TO-TUBESHEET WELDS

NC-4351 General Requirements

The welding procedure for tube-to-tubesheet welds shall be qualified as a new procedure specification and shall be completely requalified when any of the changes listed below are made in the procedure. Changes other than those given may be made in a procedure without the necessity for requalification, provided the procedure specification is amended to show these changes.

NC-4352 Essential Variables for All Welding Processes

Essential variables for all welding processes shall be as listed in (a) through (k) below:

(a) a Change from one welding process to any other welding process or combination of welding processes;

(b) a change in the P-Number classification of tube material in Section IX, QW-422. A separate qualification is required for each tube material which is not included under any P-Number;

(c) a change in the P-Number of the tube sheet base material. The base material may be a homogeneous material or a cladding material of wrought type or weld-overlay type. If welding is performed between the tube and cladding, the cladding shall be considered the base material. A separate qualification is required for welding tubes to base material or cladding material which is not included under any P-Number;

(d) a change in the weld metal analysis of the deposited weld metal as given in (1) and (2) below:

(1) a change from any A-Number in QW-442 of Section IX to any other A-Number or to any F-Number in QW-432 or to any analysis not listed in the tables, except that each AISI type similar to A-No. 7 or A-No. 8 of QW-442, shall require separate qualifications;

(2) a change from any F-Number in QW-432 to any other F-Number or to any A-Number in QW-442 or to any analysis not listed in the tables;

(e) for tubes of specified wall thicknesses of 0.100 in. or less, an increase or decrease of 10% of specified wall thickness or specified diameter;

(f) for specified wall thicknesses greater than 0.100 in., only one qualification test is required;

(g) a decrease of 10% or more in the specified width of the ligament between tube holes when the specified width of the ligament is less than the greater of $\frac{3}{8}$ in. (10 mm) or three times the specified tube wall thickness;

(h) the addition of other welding positions than those already qualified (Section IX, QW-461.1).

(i) a change in the specified preheating temperature range;

(j) a change in the specified postweld heat treating temperature;

(k) a change from multiple pass to single pass or vice versa.

Page 266

NC-4353 Essential Variables for Shielded Metal-Arc Welding

An additional essential variable for shielded metal-arc welding is an increase in electrode diameter.

NC-4354 Essential Variables for Gas Tungsten- Arc and Gas Metal-Arc Welding

Additional essential variables for gas tungsten-arc and gas metal-arc welding are as given in (a) through (f) below:

(a) a change in the configuration of the tubesheet at the tube hole edges, including the addition or omission of preplaced metal inserts;

(b) a change in the size or shape of preplaced metal inserts;

(c) a change from one shielding gas to another shielding gas or to a mixture of shielding gases;

(d) when using mixed shielding gas, a change of plus or minus 25% or 5 cu ft/hr (0.14 m³/hr), whichever is the larger, in the rate of flow of the minor gas constituent;

(e) for gas tungsten-arc welding process, the addition or omission of filler metal;

(f) a change in the nominal diameter of the filler metal.

NC-4355 Essential Variables for Explosive Welding

Additional essential variables for explosive welding are as given in (a) through (e) below:

(a) an increase or decrease in the specified tube wall thickness or diameter of 10% for all diameters and wall thicknesses instead of the provision of NC-4352(e);

(b) a change in the method of pressure application;

(c) a change in the type of explosive or a change in energy content of plus or minus 10%;

- (d) a change of plus or minus 10% in the placement of the charge from the tube sheet face;
- (e) a change in the specified clearance between the tube and the tube sheet of plus or minus 10%.

NC-4356 Test Assembly

The procedure qualification shall be made on a test assembly which simulates the conditions to be used in production with respect to the tube hole pattern and the essential variables listed in NC-4352 through NC-4354. In addition, the thickness of the tubesheet in the test assembly shall be as thick as the production tubesheet, except it need not exceed 2 in. (51 mm). The minimum required number of weld joints shall be ten.

NC-4357 Examination of Test Assembly

The assembly shall be examined by a liquid penetrant method in accordance with the requirements of NC-5110 and shall meet the acceptance standards of NC-5350. Following this, the assembly shall be sectioned longitudinally through each tube. The thickness of the assembly may be reduced to $\frac{1}{2}$ in. (13 mm) prior to this sectioning. The four faces of each tube exposed by sectioning shall be polished and etched with a suitable etchant and shall be visually examined for cracks. The weld throat, minimum leakage path, shall be not less than two-thirds of the specified tube wall thickness, and the weld shall be free from cracks on visual examination with $\times 10$ magnification.

NC-4358 Performance Qualification

NC-4358.1 Welders.

The requirements for the performance qualification test for welders shall be the same as those for the procedure qualification, except that the minimum required number of tubes in the test assembly shall be six.

NC-4358.2 Welding Operators.

The requirements for the performance qualification test for welding operators (automatic weld process) shall be the same as those for the procedure qualification, except that:

- (a) the essential variables for performance qualification are those detailed in NC-4352(a), (b), (c), (d), and (h), and
- (b) the minimum required number of tubes in the test assembly shall be six.

NC-4360 QUALIFICATION REQUIREMENTS FOR WELDING SPECIALLY DESIGNED WELDED SEALS

NC-4361 General Requirements

(a) Specially designed welded seals are defined as the walls or membranes, such as an omega shaped seal membrane, which confine the fluid and where strength is provided by a separate device.

(b) The welding procedure shall be qualified as a new procedure specification and shall be completely requalified when any of the essential variables specified or listed in the following paragraphs are made in the procedure. Changes other than those given may be made in the procedure without the necessity for requalification,

Page 267

provided the procedure is amended to show these changes. In addition, the essential variables specified in Section IX shall apply for both procedure and performance qualification.

NC-4362 Essential Variables for Automatic, Machine, and Semiautomatic Welding

The welding procedure shall be qualified as a new procedure specification and shall be completely requalified when any of the changes listed in this paragraph or the applicable portions of Section IX are made:

- (a) when preplaced filler metal is melted to form all or part of a weld, a change from one alloy type or classification to

any other alloy type or classification of base material or filler metal, even though previously qualified base materials and filler metals are of the same P-Number or A-Number;

(b) a change of any dimension of the weld joint for automatic welding or a change of any dimension of the weld joint by more than 10% for semiautomatic or machine welding beyond that qualified;

(c) a change in the nominal size or shape of any filler metal added to the arc;

(d) for automatic welding, an increase or decrease in the length of the seal weld by more than 30%;

(e) for automatic welding, a change in the welding current greater than 50% of the difference between the maximum and minimum amperages used during qualification; only two test assemblies need to be welded for requalification;

(f) any change in the angular relationship or distance between the welding electrode and the work and the filler metal beyond the range qualified;

(g) the addition or deletion of the use of tack welds or locating fixtures to facilitate alignment or to maintain the root opening of the weld joint;

(h) the addition or deletion of consumable inserts.

NC-4363 Essential Variables for Manual Welding

The welding procedure shall be qualified as a new procedure specification and shall be completely requalified when any of the changes listed in (a) or (b) below are made in the procedure:

(a) a change of more than $\pm 10\%$ of any dimension, excluding angularity of the groove, of the weld joint cross section, except that base material thickness may vary from the minus 10% to 2.5 times the thickness qualified when welding parts of the same material thickness or the thin member may vary from minus 10% to two times the thickness qualified when welding a thin seal membrane to a thick member;

(b) when preplaced filler metal is melted to form all or a part of a weld, a change from one type or classification to any other type or classification of base material or filler metal, even though previously qualified base materials and filler metals are of the same P-Number or A-Number.

NC-4366 Test Assembly

The test assembly shall consist of a duplicate of the production weld, except that tolerances as stated in NC-4362(b) or NC-4363(a) are permitted. Except for automatic welding, the Certificate Holder may use a 12 in. length to qualify, if the length of the production weld is considered to be greater than necessary to qualify.

NC-4366.1 Automatic Welding.

For automatic welding, at least six consecutive test assemblies representing the range of dimensions to be qualified shall be required to establish the reproducibility of the welding procedure. In addition, the Certificate Holder making the production welds shall verify this capability of making two consecutive test assemblies prior to production welding using the previously qualified procedure.

NC-4366.2 Manual, Machine, and Semiautomatic Welding.

For manual, machine, and semiautomatic welding, two test assemblies shall be required.

NC-4367 Examination of Test Assembly

(a) Where 100% weld penetration is required, the test assembly shall be sectioned, if necessary, to permit examination of the entire underside weld surface.

(b) A minimum of four cross sections shall be taken from each test assembly and examined. One cross section shall be made in a weld start-and-stop area and the others shall be taken at random. When doubt exists as to the acceptability of the weld after examination of four cross sections, the Inspector may require that additional metallographic cross sections be prepared for examination of the weld and adjacent base material. All cross sections shall be examined in accordance with

NC-5370.

NC-4368 Performance Qualification Test

The performance qualification test assembly shall meet the same requirements specified for the procedure qualification test assembly in NC-4366 and shall be examined in accordance with NC-4367. Furthermore,

Page 268

welding operators shall qualify using the welding machine which will be used to make production welds and shall be required to set up the machine with regard to adjustments and settings which affect the welding characteristics. One test assembly is required.

NC-4400 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS

NC-4410 PRECAUTIONS TO BE TAKEN BEFORE WELDING

NC-4411 Identification, Storage, and Handling of Welding Materials

Each Certificate Holder is responsible for control of the welding electrodes and other materials which are used in the fabrication and installation of components (NC-4120). Suitable identification, storage, and handling of electrodes, flux, and other welding materials shall be maintained. Precautions shall be taken to minimize absorption of moisture by electrodes and flux.

NC-4412 Cleanliness and Protection of Welding Surfaces

The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

NC-4420 RULES FOR MAKING WELDED JOINTS

NC-4421 Backing Rings

Backing rings which remain in place may be used for piping in accordance with the requirements of NC-3661.2. The materials for backing rings shall be compatible with the base metal, but spacer pins shall not be incorporated into the weld.

NC-4422 Backup Plates, Backing Rings, and Compression Rings or Stiffeners for Storage Tanks

Backup plates and backing rings which remain in place and compression rings or stiffeners of storage tanks, such as angles, bars, and ring girders, may be used. The materials used for such backup plates, backing rings, and compression rings or stiffeners shall be compatible with the base metal, but spacer pins shall not be incorporated into the weld.

NC-4423 Double Welded Joints, Single Welded Joints, and Peening

NC-4423.1 Double Welded Joints.

Before applying weld metal on the second side to be welded, the root of full penetration double welded joints shall be prepared by suitable methods such as chipping, grinding, or thermal gouging, except for those processes of welding by which proper fusion and penetrations are otherwise obtained and demonstrated to be satisfactory by welding procedure qualifications.

NC-4423.2 Single Welded Joints.

Where single welded joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joint for its full length.

NC-4423.3 Peening.

Controlled peening may be performed to minimize distortion. Peening shall not be used on the internal layer (root) of the weld metal nor on the final layers unless the weld is postweld heat treated.

NC-4424 Surfaces of Welds

As-welded surfaces are permitted except for inertia and continuous drive friction welding where the flash shall be removed to sound metal. For piping, the appropriate stress indices given in Table NB-3683.2-1 shall be applied. However, the surface of welds shall be sufficiently free from coarse ripples, grooves, overlaps, abrupt ridges, and valleys to meet the requirements of (a) through (e) below.

(a) The surface condition of the finished weld shall be suitable for the proper interpretation of radiographic and other required nondestructive examination of the weld. In those cases where there is a question regarding the surface condition on the interpretation of a radiographic film, the film shall be compared to the actual weld surface for interpretation and determination of acceptability.

(b) Reinforcements are permitted in accordance with NC-4426.1 for vessels, pumps, and valves, and NC-4426.2 for piping.

(c) Undercuts shall not exceed $\frac{1}{32}$ in. (0.8 mm) and shall not encroach on the required section thickness.

(d) Concavity on the root side of a single welded circumferential butt weld is permitted when the resulting

Page 269

thickness of the weld meets the requirements of NC-3000.

(e) If the surface of the weld requires grinding to meet the above criteria, care shall be taken to avoid reducing the weld or base material below the required thickness.

(f) For inertia and continuous drive friction welding, the weld upset shall meet the specified amount within $\pm 10\%$.

NC-4425 Welding Components of Different Diameters

When components of different diameters are welded together, there shall be a gradual transition between the two surfaces. The slope of the transition shall be such that the length-offset ratio shall not be less than 3:1 (Figs. NC-3361-1 and NC-4233-1), unless greater slopes are shown to be acceptable by analysis for vessels designed to NC-3200. The length of the transition may include the weld.

NC-4426 Reinforcement of Welds

NC-4426.1 Thickness of Weld Reinforcement for Vessels, Pumps, and Valves.

The surface of the reinforcement of all butt welded joints in vessels, pumps, and valves may be flush with the base material or may have uniform crowns. The height of reinforcement on each face of the weld shall not exceed the thicknesses in the following tabulation:

Nominal Thickness, in.	Maximum Reinforcement, in.
Up to 1, incl.	$\frac{3}{32}$
Over 1 to 2, incl.	$\frac{1}{8}$
Over 2 to 3, incl.	$\frac{5}{32}$
Over 3 to 4, incl.	$\frac{7}{32}$
Over 4 to 5, incl.	$\frac{1}{4}$
Over 5	$\frac{5}{16}$

NC-4426.2 Thickness of Weld Reinforcement for Piping.

For double welded butt joints, the limitation on the reinforcement given in Column 1 of the following tabulation shall apply separately to both inside and outside surfaces of the joint. For single welded butt joints, the reinforcement given in Column 2 shall apply to the inside surface and the reinforcement given in Column 1 shall apply to the outside surface. The reinforcements shall be determined from the higher of the abutting surfaces involved.

Material Nominal Thickness, in.	Maximum Reinforcement Thickness, in.	
	Column 1	Column 2
Up to $\frac{1}{8}$ incl.	$\frac{3}{32}$	$\frac{3}{32}$
Over $\frac{1}{8}$ to $\frac{3}{16}$ incl.	$\frac{1}{8}$	$\frac{3}{32}$
Over $\frac{3}{16}$ to $\frac{1}{2}$ incl.	$\frac{5}{32}$	$\frac{1}{8}$
Over $\frac{1}{2}$ to 1, incl.	$\frac{3}{16}$	$\frac{5}{32}$
Over 1 to 2, incl.	$\frac{1}{4}$	$\frac{5}{32}$
Over 2	The greater of $\frac{1}{4}$ in. or $\frac{1}{8}$ times width the weld inches.	$\frac{5}{32}$

NC-4427 Shape and Size of Fillet Welds

(a) Fillet welds may vary from convex to concave. Except as permitted in (b) below, the shape and size of the weld shall be in accordance with the requirements of Fig. NC-4427-1. A fillet weld in any single continuous weld may be less than the specified fillet weld dimension by not more than $\frac{1}{16}$ in. (1.6 mm), provided that the total undersize portion of the weld does not exceed 10% of the length of the weld. Individual undersize weld portions shall not exceed 2 in. (51 mm) in length. In making socket welds, a gap as shown in Fig. NC-4427-1 shall be provided prior to welding. The gap need not be present nor be verified after welding. For sleeve type joints without internal shoulder, the gap shall be between the butting ends of the pipe or tube.

(b) Socket welds smaller than those specified in Fig. NC-4427-1 may be used provided the requirements of NC-3000 are met.

NC-4428 Seal Welds of Threaded Joints

Where seal welding of threaded pipe joints is performed, the exposed threads shall be either removed entirely or covered with weld metal.

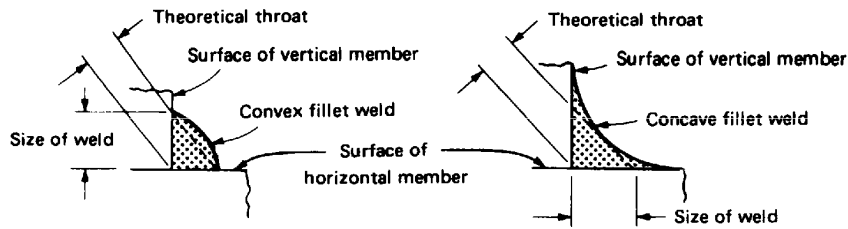
NC-4430 WELDING OF ATTACHMENTS

NC-4431 Materials for Attachments

Nonpressure-retaining attachments (NC-1132.1) welded to pressure retaining components shall be of materials which meet the requirements of NC-2190. Materials for pressure retaining attachments shall meet the requirements of NC-2120.

Page 270

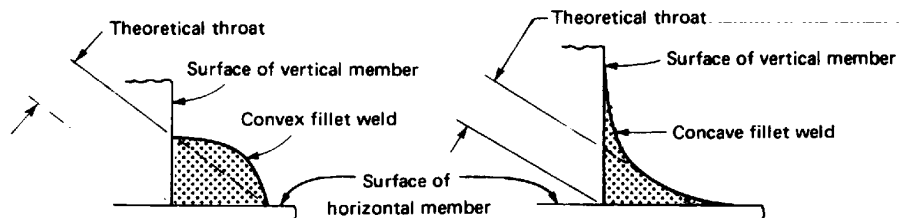
Page 271



GENERAL NOTE:

The size of an equal leg fillet weld is the leg length of the largest inscribed right isosceles triangle.
Theoretical throat = $0.7 \times$ size of weld.

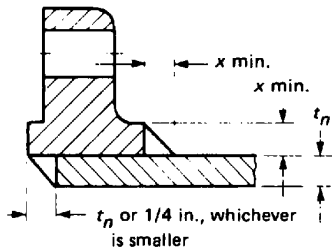
(a) Equal Leg Fillet Weld



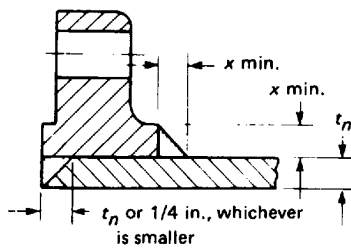
GENERAL NOTE:

The size of an unequal leg fillet weld is the shorter leg length of the largest right triangle which can be inscribed within the fillet weld cross section.

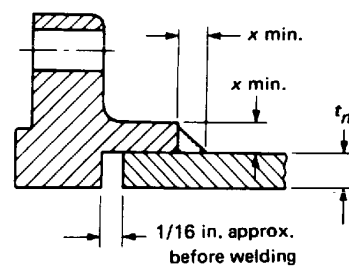
(b) Unequal Leg Fillet Weld



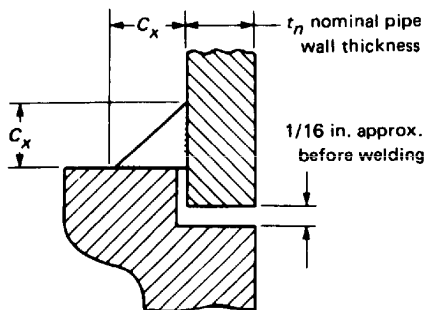
Front and Back Weld



Face and Back Weld



(c-2) Socket Welding Flange



(c-3) Socket Welding Fittings

GENERAL NOTES:

$x \text{ min.} = 1.4t_n$ or thickness of the hub, whichever is smaller, but not less than $1/8 \text{ in.}$

$C_x \text{ min.} = 1.09t_n$ where $t_n =$ nominal pipe wall thickness

(c) Minimum Welding Dimensions for Slip-on and Socket Welding Flanges and Socket Welding Fittings

FIG. NC-4427-1 FILLET AND SOCKET WELD DETAILS AND DIMENSIONS

FIG. NC-4427-1 FILLET AND SOCKET WELD DETAILS AND DIMENSIONS

NC-4432 Welding of Structural Attachments

The rules of NC-4321 governing welding qualifications shall apply to the welding of structural attachments to pressure retaining material.

NC-4433 Structural Attachments

Structural attachments shall conform reasonably to the curvature of the surface to which they are to be attached and shall be attached by full penetration, fillet, or partial penetration continuous or intermittent welds. Figure NC-4433-1 illustrates some of the typical details for attaching structural attachments to a component using full penetration welds. Valve seats may be attached to the pressure boundary part by fillet or partial penetration welds, provided the valve seat is shouldered against the pressure boundary part.

NC-4434 Welding of Internal Structural Supports to Clad Components

Internal structural supports on clad components shall be welded to the base metal and not to the cladding except for weld overlay cladding.

NC-4435 Welding of Nonstructural and Temporary Attachments and Their Removal

(a) Nonstructural attachments (NC-1132.1) welded to the pressure retaining portion of the component need not comply with NC-2000 and may be welded with continuous or intermittent fillet or partial penetration welds, provided the requirements of (1) through (4) below are met.

- (1) The welding procedure and the welders have been qualified in accordance with NC-4321.
- (2) The material is identified and is compatible with the material to which it is attached.
- (3) The welding material is identified and is compatible with the materials joined.
- (4) The welds are postweld heat treated when required by NC-4620.

(b) Except for tanks or tank parts, removal of nonstructural attachments, when temporary, shall be accomplished as follows.

- (1) The immediate area around the temporary attachment is marked in a suitable manner so that after removal the area can be identified until after it has been examined in accordance with (3) below.
 - (2) The temporary attachment is completely removed in accordance with the procedures of NC-4211.
 - (3) After the temporary attachment has been removed, the marked area is examined by the liquid penetrant or magnetic particle method in accordance with the requirements of NC-5110 and meets the acceptance standards of NC-5340 or NC-5350, whichever is applicable.
 - (4) As an alternative to (a)(4) above, postweld heat treatment may be deferred until after removal of the attachment.
- (c) For tanks and tank parts, removal of temporary attachments shall be in accordance with (b)(2) and (b)(4) above.

NC-4436 Installation of Attachments to Piping Systems After Testing

Attachments may be welded to the piping system after performance of the pressure test provided that:

- (a) the welds do not require PWHT under NC-4622.7;
- (b) welds shall be restricted to fillet welds not exceeding $\frac{3}{8}$ in. (10 mm) throat thickness and to full penetration welds attaching materials not exceeding $\frac{1}{2}$ in. (13 mm) in thickness;
- (c) welds shall not exceed a total length of 24 in. (610 mm) for fillet welds or 12 in. (305 mm) for full penetration welds; and

(d) welds shall be examined as required by NC-5000.

NC-4437 Attachment of Stiffener Rings

NC-4437.1 General Requirements.

All permanent and temporary attachments of stiffener rings to shells, including tack welds, shall be made by qualified welders using qualified welding procedures.

NC-4437.2 Attachment of Stiffening Rings to Shell

(a) Stiffening rings, when used, may be placed on the inside or outside of a vessel and shall be attached to the shell by welding or bolting. The ring shall be in contact with the shell.

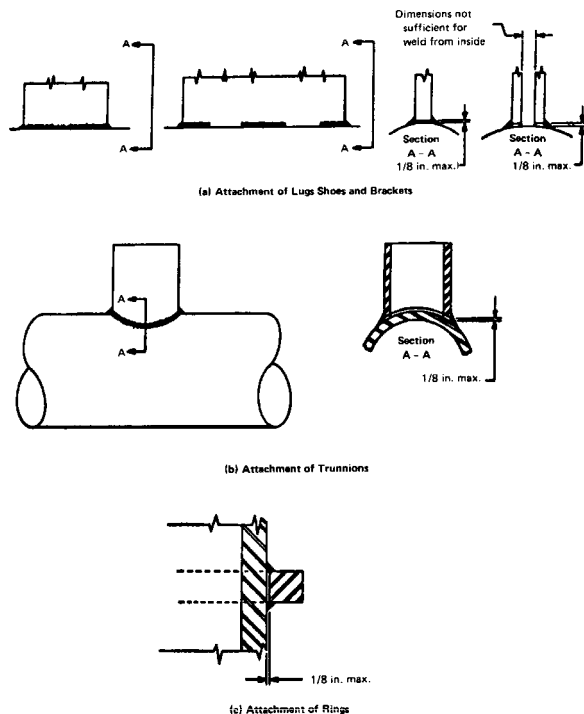
(b) Stiffening rings may be attached to the shell by either continuous or intermittent welding. The total length of the intermittent welding on each side of the stiffening ring shall be:

- (1) not less than one-half the outside circumference of the component for rings on the outside; and
- (2) not less than one-third the circumference of the vessel for rings on the inside.

Acceptable arrangements and spacings of intermittent welds are shown in Fig. NC-4437.2(b)-1. Welds on opposite sides of the stiffener may be either staggered or in-line as indicated.

Page 272

Page 273



GENERAL NOTE: The welds may be partial penetration or fillet welds.

FIG. NC-4433-1 TYPES OF ATTACHMENT WELDS

FIG. NC-4433-1 TYPES OF ATTACHMENT WELDS

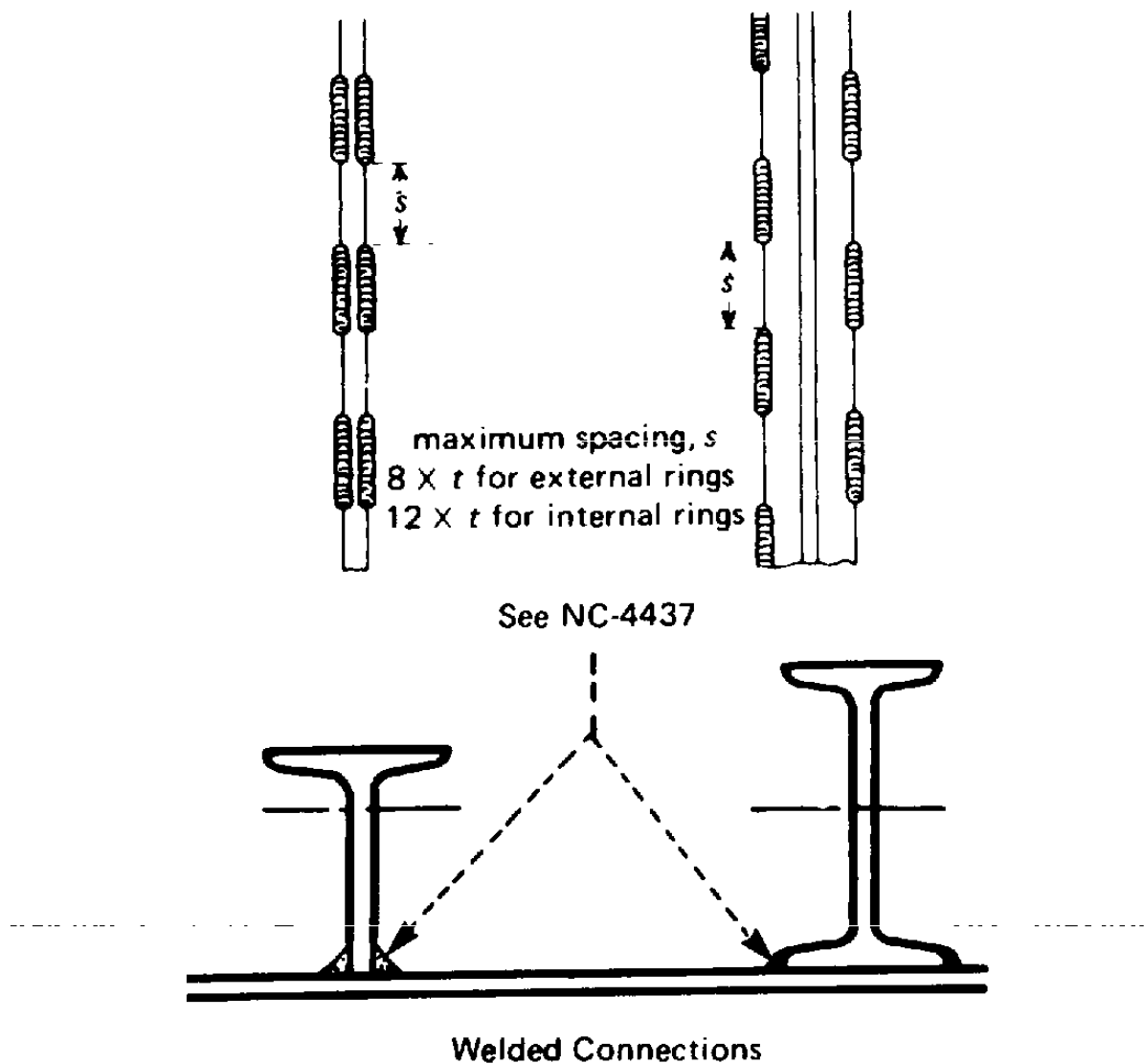


FIG. NC-4437.2(b)-1 SOME ACCEPTABLE METHODS OF ATTACHING STIFFENING RINGS TO SHELLS OF CYLINDRICAL VESSELS SUBJECTED TO EXTERNAL PRESSURE

FIG. NC-4437.2(b)-1 SOME ACCEPTABLE METHODS OF ATTACHING STIFFENING RINGS TO SHELLS OF CYLINDRICAL VESSELS SUBJECTED TO EXTERNAL PRESSURE

(c) All welding of stiffening rings shall comply with the requirements of this Subsection. In areas where a corrosion allowance is specified in the Design Specification, stiffening rings shall be attached to the shell with a continuous fillet weld, seal weld, or full penetration weld.

NC-4450 REPAIR OF WELD METAL DEFECTS

NC-4451 General Requirements

Defects in weld metal detected by the examinations required by NC-5000 or by the tests of NC-6000 shall be eliminated and repaired when necessary or the indication reduced to an acceptable limit.

NC-4452 Elimination of Surface Defects

Weld metal surface defects may be removed by grinding or machining and need not be repaired by welding, provided the requirements of (a), (b), and (c) below are met.

(a) The remaining thickness of the section is not reduced below that required by NC-3000.

(b) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(c) The area is examined by a magnetic particle or liquid penetrant method in accordance with NC-5110 after blending and meets the acceptance standards of NC-5300 to ensure that the defect has been removed or the indication reduced to an acceptable limit. Defects detected by visual or volumetric method and located on an interior surface need only be reexamined by the method which initially detected the defect when the interior surface is inaccessible for surface examination.

NC-4453 Requirements for Making Repairs of Welds

Excavations in weld metal, when repaired by welding, shall meet the requirements of the following subparagraphs.

NC-4453.1 Defect Removal.

Defects may be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined by a liquid penetrant or magnetic particle method in accordance with NC-5110 and meet the acceptance standards of NC-5340 or NC-5350. This examination is not required where defect elimination removes the full thickness of the weld and where the backside of the weld joint is not accessible for removal of examination materials.

NC-4453.2 Requirements for Welding Materials, Procedures, and Welders.

The weld repair shall be made using welding materials, welders, and welding procedures qualified in accordance with NC-4125 and NC-4300.

NC-4453.3 Blending of Repaired Areas.

After repair the surface shall be blended uniformly into the surrounding surface.

NC-4453.4 Examination of Repair Welds

(a) The examination of a weld repair shall be repeated as required for the original weld, except that it need only be reexamined by the liquid penetrant or magnetic particle method when the unacceptable indication was originally detected by the liquid penetrant or magnetic particle method and when the repair cavity does not exceed the following:

(1) $\frac{1}{3}t$ for $t \leq \frac{3}{4}$ in.

(2) $\frac{1}{4}$ in. for $\frac{3}{4}$ in. $\leq t \leq 2\frac{1}{2}$ in.

(3) the lesser of $\frac{1}{8}$ in. or $10\%t$ for $t > 2 \frac{1}{2}$ in.

where t equals the thickness of the weld.

Page 274

(b) When repairs to welds joining P-No. 1 and P-No. 3 materials require examination by radiography as required in (a) above, but construction assembly prevents meaningful radiographic examination, ultrasonic examination may be substituted, provided that:

(1) the weld has been previously radiographed and met the applicable acceptance standards;

(2) the ultrasonic examination is performed using a procedure in accordance with Section V, Article V to the acceptance standards of NC-5330;

(3) the substitution is limited to Category A and B welds in vessels and similar type welds in other items.

The absence of suitable radiographic equipment is not justification for the substitution.

NC-4453.5 Heat Treatment of Repaired Areas.

The area shall be heat treated in accordance with NC-4620.

NC-4500 BRAZING

NC-4510 RULES FOR BRAZING

NC-4511 Where Brazing May Be Used

(a) Brazing is permitted for the attachment of tubes to tubesheets and as permitted for pipe joints in NC-3671.6. Appurtenances and piping with outside diameter equal to that of NPS 1 (DN 25) and less for all other materials may be fabricated using brazed joints in accordance with Fig. NC-4511-1.

(b) Valves with inlet piping connections of NPS 4 (DN 100) and less may have seats brazed to the valve body or bonnet, provided the seat is shouldered against the pressure boundary part.

(c) Headers, NPS 4 (DN 100) and less, fabricated from copper, copper alloys, or copper-nickel alloys, which are an integral part of finned tubular heat exchangers, may utilize brazed joints fabricated in accordance with Fig. NC-4511-1.

NC-4512 Brazing Material

Where brazing is permitted, the brazing filler material and fluxes shall conform to the rules covering identification in NC-2150 and to the requirements of (a), (b), and (c) below.

(a) The filler material used in brazing shall be a nonferrous metal or alloy with a solidus temperature above 800°F (427°C) and at least 500°F (278°C) above the highest temperature of the joint in service.

(b) The filler material shall melt and flow freely by capillary action within the desired temperature range, and in conjunction with a suitable flux or controlled atmosphere the filler material shall wet and adhere to the surfaces to be joined.

(c) Fluxes that are fluid and chemically active at the brazing temperature shall be used, when necessary, to prevent oxidation of the filler metal and the surfaces to be joined, and to promote free flowing of the filler material.

NC-4520 BRAZING QUALIFICATION REQUIREMENTS

NC-4521 Brazing Procedure and Performance Qualifications

Qualification of the brazing procedure to be used and of the performance of brazers and brazing operators is required and shall comply with the requirements of Section IX, except that validation of the procedure qualification per QB-451.5 Note (1) is not required for the furnace brazing of seat rings to bodies or bonnets of valves having inlet piping connections of 4 in. nominal size (DN 100) and less. When the Design Temperature is greater than 200°F (93°C), tension testing shall be

in. nominal size (DN 100) and less. When the Design Temperature is greater than 200°F (93°C), tension testing shall be performed at the Design Temperature.

NC-4522 Brazing Requalification Requirements

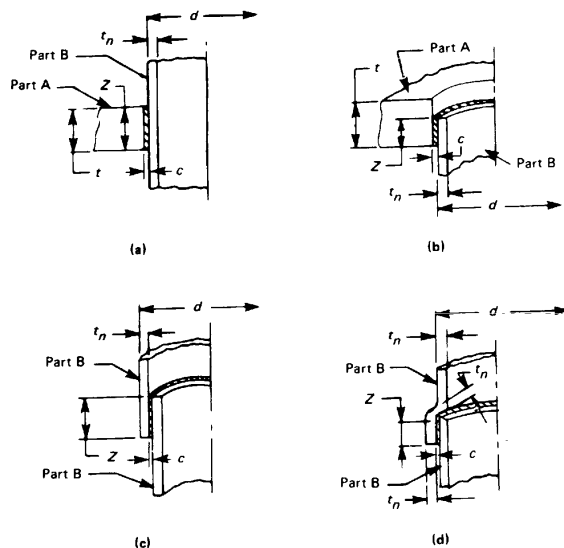
In addition to the requirements of Section IX, the brazing procedure shall be set up as a new procedure specification and shall be completely requalified when the construction of the brazed components includes reheating of any portion of the completed brazed joint to a temperature that is within 300°F (167°C) of the solidus temperature of the filler metal.

NC-4530 FITTING AND ALIGNING OF PARTS TO BE BRAZED

Parts to be joined by brazing shall be fitted, and retained in position during the brazing operation within the tolerances specified in the brazing procedure specification. Brazed joints shall be assembled in a sequence which will permit the maximum number of joints to be visually examined on both sides of the joint after brazing.

Page 275

Page 276



- t = thickness of part penetrated
 t_n = nominal thickness of connecting part
 d = outside diameter of part B
 c = clearance or interference between mating parts and shall be in accordance with the brazing procedure specification
 z = depth of engagement and shall be the lesser of $3t_n$ or d , but in no case less than 1/4 in.

GENERAL NOTES:

- (1) Part A shall be attached to a component in accordance with the requirements for the component proper.
- (2) Part B shall be attached either to part A or to another part B by the joints shown above, or in accordance with the requirements of the component proper.
- (3) Grooves for preplaced filler metal are permitted, provided the reduction in cross section due to the grooves is considered in the design.

FIG. NC-4511-1 BRAZED CONNECTIONS FOR APPURTENANCES AND PIPING

NC-4540 EXAMINATION OF BRAZED JOINTS

The completed brazed joints shall be visually examined on all accessible surfaces in accordance with NC-5275.

NC-4600 HEAT TREATMENT

NC-4610 WELDING PREHEAT REQUIREMENTS

NC-4611 When Preheat Is Necessary

The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, elevated temperature, physical properties, and material thicknesses. Some practices used for preheating are given in Appendix D as a general guide for the materials listed by P-Number of Section IX. It is cautioned that the preheating suggested in Appendix D does not necessarily ensure satisfactory completion of the welded joint and that the preheating requirements for individual materials within the P-Number listing may be more or less restrictive. The welding procedure specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.

NC-4612 Preheating Methods

Preheat for welding or thermal cutting, when employed, may be applied by any method which does not harm the base material or any weld metal already applied or which does not introduce deleterious material into the welding area which is harmful to the weld.

NC-4613 Interpass Temperature

Consideration must be given to the limitations of interpass temperatures for quenched and tempered materials to avoid detrimental effects on the mechanical properties.

NC-4620 POSTWELD HEAT TREATMENT

NC-4621 Heating and Cooling Methods

Postweld heat treatment (PWHT) may be accomplished by any suitable methods of heating and cooling, provided the required heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control are maintained.

NC-4622 PWHT Time and Temperature Requirements

NC-4622.1 General Requirements.⁵

Except as otherwise permitted in NC-4622.7, all welds, including repair welds, shall be postweld heat treated. During postweld heat treatment, the metal temperature shall be maintained within the temperature ranges for the minimum holding time specified in Table NC-4622.1-1 except as otherwise permitted in NC-4622.4(c). P-Number groups in Table NC-4622.1-1 are in accordance with Section IX, QW-420. Except as provided in NC-4624.3, PWHT shall be performed in temperature-surveyed and -calibrated furnaces, or PWHT shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. In addition, the requirements of the following subparagraphs shall apply

NC-4622.2 Time-Temperature Recordings.

Time-temperature recordings of all postweld heat treatments shall be made available for review by the Authorized Inspector. Identification on the time-temperature recording shall be to the weld, part, or component. A summary of the time-temperature recording may be provided for permanent records in accordance with NCA-4134.17.

NC-4622.3 Definition of Nominal Thickness Governing PWHT.

Nominal thickness in Table NC-4622.7(b)-1 is the thickness of the weld, the pressure retaining material for structural attachment welds or the thinner of the pressure retaining materials being joined, whichever is least. It is not intended that nominal thickness include material provided for forming allowance, thinning, or mill overrun when the excess material does not exceed $\frac{1}{8}$ in. For fillet welds the nominal thickness is the throat thickness, and for partial penetration and material repair welds the nominal thickness is the depth of the weld groove or preparation.

NC-4622.4 Holding Times at Temperature

(a) The holding time at temperature as specified in Table NC-4622.1-1 shall be based on the nominal thickness of the weld. The holding time need not be continuous. It may be an accumulation of the times of multiple postweld heat-treat cycles.

5 Any postweld heat treatment time which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

Page 277

Page 278

TABLE NC-4622.1-1
MANDATORY REQUIREMENTS FOR POSTWELD HEAT
TREATMENT OF WELDS¹

P-No. (Sect. IX, QW-420)	Holding Temperature Range [Note (2)]	Minimum Holding Time at Temperature for Weld Thickness (Nominal)			
		$\frac{1}{2}$ in. or less	Over $\frac{1}{2}$ in. to 2 in.	Over 2 in. to 5 in.	Over 5 in.
1, 3	1100–1250°F	30 min	1 hr/in.	2 hr plus 15 min each additional inch over 2 in.	2 hr plus 15 min each additional inch over 2 in.
4	1100–1250°F	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
5A, 5B, 5C, 6 (except P-No. 6 Gr. 4)	1250–1400°F	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
6 Gr. 4	1050–1150°F				
7	1300–1400°F	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
9A Gr. 1	1100–1250°F	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
9B Gr. 1	1100–1175°F				
10C Gr. 1, 10F Gr. 1	1100–1250°F	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
10I Gr. 1	1300–1400°F				
11A Gr. 4	1000–1050°F	30 min	1 hr/in.	1 hr/in.	1 hr/in.
P-Nos. 8, 10H Gr. 1, 34, 42, 43, 45 and hard sur- facing on P-No. 1 base metal whose reported carbon content is not more than 0.30%	PWHT neither required nor prohibited				

NOTES:

- (1) Exemptions to the mandatory requirements of this Table are defined in NC-4622.7.
(2) All temperatures are metal temperatures.

**TABLE NC-4622.4(c)-1
ALTERNATIVE HOLDING TEMPERATURES
AND TIMES¹**

Material P-Numbers	Alternative Minimum Holding Temperatures, °F	Alternative Minimum Holding Times
1, 3, 9A Gr.1 9B Gr.1	1050	2 hr/in. thick
1, 3, 9A Gr.1, 9B Gr.1	1000	4 hr/in. thick

NOTE:

(1) All other requirements of NC-4622 shall apply.

TABLE NC-4622.4(c)-1 ALTERNATIVE HOLDING TEMPERATURES AND TIMES¹

(b) Holding time at temperature in excess of the minimum requirements of Table NC-4622.1-1 may be used, provided that specimens so heat treated are tested in accordance with NC-2200, NC-2400, and NC-4300.

(c) Alternatively, when it is impractical to postweld heat treat at the temperature range specified in Table NC-4622.1-1, it is permissible to perform the postweld heat treatment of certain materials at lower temperatures for longer periods of time in accordance with Table NC-4622.4(c)-1 and (1), (2), and (3) below.

(1) Except for P-No. 1 materials, when welds in the materials listed in Table NC-4622.4(c)-1 are to be postweld heat treated at the lower minimum temperatures, the impact test specimens for the welding procedure qualification required by NC-4300 shall be made using the same minimum temperatures and increased minimum holding time. Welding procedures, qualified at the temperature range and minimum holding time specified in Table NC-4622.1-1 and at the lower temperature and increased minimum holding time permitted by Table NC-4622.4(c)-1, are also qualified for any temperature in between. When such an in-between temperature is used, the minimum holding time shall be interpolated from Table NC-4622.1-1 and the alternative requirements from Table NC-4622.4(c)-1.

(2) Except for P-No. 1 materials, when welds in the materials listed in Table NC-4622.4(c)-1 are to be postweld heat treated at these lower minimum temperatures, the welding material certification required by NC-2400 shall be made using the same minimum temperature and increased minimum holding time. Welding material certified at the temperature range and minimum holding time specified in Table NC-4622.1-1 and at the lower minimum temperatures and increased minimum holding time permitted by Table NC-4622.4(c)-1 are also certified for any temperature in between.

(3) Base materials certified in accordance with NC-2200 may be postweld heat treated at these lower minimum temperatures and increased minimum holding times without recertification. Postweld heat treatment at these lower minimum temperatures and increased minimum holding times may also be the tempering operation, provided a higher tempering temperature is not required by the material specification.

NC-4622.5 PWHT Requirements When Different P-Number Materials Are Joined.

When pressure retaining materials of two different P-Number groups are joined by welding, the applicable postweld heat treatment shall be that specified in Table NC-4622.1-1 for the material requiring the higher PWHT temperature range.

NC-4622.6 PWHT Requirements for Nonpressure- Retaining Parts.

When nonpressure-retaining materials are welded to pressure retaining materials, the postweld heat treatment temperature range of the pressure retaining materials shall control.

NC-4622.7 Exemptions to Mandatory Requirements.

Postweld heat treatment in accordance with this Subarticle is not required for (a) through (e) below:

(a) nonferrous materials;

(b) welds exempted in Table NC-4622.7(b)-1;

(c) welds subjected to temperatures above the PWHT temperature range specified in Table NC-4622.1-1, provided the Welding Procedure Specification is qualified in accordance with Section IX and the base material and the deposited weld material have been heat treated at the higher temperature;

(d) welds connecting nozzles to components or branch to run piping, provided the requirements in NC-4622.8 are met;

(e) weld repairs to P-No. 3 materials in vessels, provided the requirements of NC-4622.9 are met.

NC-4622.8 Requirements for Exempting PWHT of Nozzles to Component Welds and Branch-to-Run Piping Welds.

Welds connecting nozzles or branch piping of P-No. 1 materials to components or run piping of P-No. 1 or P-No. 3 materials that are not exempted from PWHT in Table NC-4622.7(b)-1 need not be given a postweld heat treatment if the requirements of (a) are met for partial penetration and (b) are met for full penetration welds.

Page 279

Page 281

Pages 280-280

**TABLE NC-4622.7(b)-1
EXEMPTIONS TO MANDATORY PWHT¹**

P-No. (Sect. IX, QW-420)	Type of Weld [Note (2)]	Nominal Thickness (NC-4622.3)	Max. Reported Carbon, % [Note (3)]	Min. Preheat Req'd., °F
1	All welds, where the materials being joined are 1½ in. and less	1¼ in. and less	0.30 and less	...
		Over 1¼ in. to 1½ in.	0.30 and less	200
		¾ in. or less	Over 0.30	...
		Over ¾ in. to 1½ in.	Over 0.30	200
	All welds in material over 1½ in.	¾ in. or less	...	200
1 Gr. 1 or Gr. 2	Cladding or repair of cladding [Note (4)] with A-No. 8 or F-No. 43 filler metal in base material of: 1½ in. or less	...	0.30	100
	Over 1½ in. to 3 in.	...	0.30	200 [Note (5)]
	Over 3 in.	...	0.30	250 [Note (6)]
3	For vessel repair without required PWHT, see NC-4622.9	...	...	350
3 except Gr. 3	All welds, except repair welds in vessels, provided weld procedure qualification is made using equal or greater thickness base material than production weld	5⁄8 in. or less	0.25 or less	200
	Attachment welds joining nonpressure- retaining material to pressure retaining material	½ in. or less	0.25 or less	200
	Circumferential butt welds in pipe and tubes	½ in. or less	0.25 or less	200
	Socket welds in pipe and tubes with nominal O.D. 2¾ in. or less	½ in. or less	0.25 or less	200
4	Circumferential butt welds in pipe and tubes with nominal O.D. 4 in. or less and attachment welds	½ in. or less	0.15 or less	250
	Socket welds in pipe and tubes with nominal O.D. 2¾ in. or less	½ in. or less	0.15 or less	250
5A, 5B, 5C	Circumferential butt welds in pipe and tubes with maximum reported chromium 3.00% or less and nominal O.D. 4 in. or less and attachment welds	½ in. or less	0.15 or less	300
	Socket welds in pipe and tubes with maximum reported chromium 3.00% or less and nominal O.D. 2¾ in. or less	½ in. or less	0.15 or less	300

TABLE NC-4622.7(b)-1 EXEMPTIONS TO MANDATORY PWHT¹

**TABLE NC-4622.7(b)-1 (CONT'D)
EXEMPTIONS TO MANDATORY PWHT¹**

P-No. (Sect. IX, QW-420)	Type of Weld [Note (2)]	Nominal Thickness (NC-4622.3)	Max. Reported Carbon, % [Note (3)]	Min. Preheat Req'd., °F
6 (for Type 410S) or 7 Gr. 1 (for Type 405)	Type 405 and 410S welded with A-No. 8, A-No. 9, or F-No. 43 filler metal	$\frac{3}{8}$ in. or less	0.08 or less	...
9A Gr. 1	All welds provided the procedure qualification is made using equal or greater thickness base material than the production weld	$\frac{3}{8}$ in. or less	...	200
	Attachment welds joining nonpressure-retaining material to pressure retaining material over $\frac{5}{8}$ in.	$\frac{1}{2}$ in. or less	...	200
	Circumferential butt welds in pipe and tubes with nominal O.D. 4 in. or less and attachment welds	$\frac{1}{2}$ in. or less	0.15 or less	250
	Socket welds in pipe and tubes with nominal O.D. $2\frac{3}{8}$ in. or less	$\frac{1}{2}$ in. or less	0.15 or less	250
9B Gr. 1	All welds provided the procedure qualification is made using equal or greater thickness base material than the production weld	$\frac{5}{8}$ in. or less	...	200
	Attachment welds joining nonpressure-retaining material to pressure retaining material over $\frac{5}{8}$ in.	$\frac{1}{2}$ in. or less	...	200
	Circumferential butt welds in pipe and tubes with nominal O.D. 4 in. or less and attachment welds	$\frac{1}{2}$ in. or less	0.15 or less	250
	Socket welds in pipe and tubes with nominal O.D. $2\frac{3}{8}$ in. or less	$\frac{1}{2}$ in. or less	0.15 or less	250
10C Gr. 1	All welds, including repair welds, in material $1\frac{1}{2}$ in. and less	$1\frac{1}{4}$ in. and less	0.30 and less	...
		Over $1\frac{1}{4}$ in. to $1\frac{1}{2}$ in.	0.30 and less	200
		$\frac{3}{4}$ in. or less	Over 0.30	...
		Over $\frac{3}{4}$ in. to $1\frac{1}{2}$ in.	Over 0.30	200
	Fillet, partial penetration, and repair welds in material over $1\frac{1}{2}$ in.	$\frac{3}{4}$ in. or less	...	200
10I Gr. 1	All welds in material $\frac{1}{2}$ in. and less	$\frac{1}{2}$ in. or less	...	...
11A Gr. 4	All welds in material $\frac{1}{2}$ in. and less	$\frac{1}{2}$ in. or less	...	250

NOTES:

- (1) The exemptions noted in this Table do not apply to the following:
 - (a) electron beam welds in ferritic materials over $\frac{1}{8}$ in. in thickness;
 - (b) inertia and friction welds in material of any thickness of P-Nos. 3, 4, 5, 7 (except for Types 405 and 410 S), 10, and 11 materials.
- (2) Where the thickness of material is identified in the column Type of Weld, it is the thickness of the base material at the welded joint.
- (3) Carbon level of the pressure retaining materials being joined.
- (4) Maximum process heat input = 150,000 J/in. The maximum resulting hardness in the procedure qualification test plate shall not exceed 35 Rc.
- (5) Intermediate postweld soak at not less than 200°F for 2 hr minimum.
- (6) Intermediate postweld soak at not less than 300°F for 2 hr minimum.

TABLE NC-4622.7(b)-1 (CONT'D) EXEMPTIONS TO MANDATORY PWHT¹

(a) The partial penetration welds are made with A-No. 8 or non-air-hardening nickel-chromium-iron weld metal after:

(1) the ferritic materials to be joined are buttered or built up with A-No. 8 or non-air-hardening nickel-chromium-iron weld metal having a minimum thickness of $\frac{1}{4}$ in. (6 mm); and

(2) the heat affected zones of the buttered or built-up ferritic materials are postweld heat treated in accordance with NC-4620, without the PWHT exemptions being applied, prior to making the final welds.

(b) The full penetration welds are made with A-No. 1 or A-No. 2 weld metal, provided that:

(1) the component or run pipe is built up or buttered in the area of the attachment with A-No. 1 or A-No. 2 metal having a minimum thickness of $\frac{1}{4}$ in. (6 mm);

(2) the A-No. 1 or A-No. 2 weld metal buildup or buttering is postweld heat treated in accordance with NC-4620 for P-No. 1 or P-No. 3 materials without the PWHT exemptions being applied;

(3) the welds do not penetrate through the component or run pipe thickness;

(4) weld metal with A-No. 1 or A-No. 2 analysis is used to join the nozzle or branch pipe of P-No. 1 material to the weld buildup or buttering;

(5) the nominal thickness of the weld joining the nozzle or branch pipe to the component or run pipe does not exceed $1\frac{1}{2}$ in. (38 mm), and the maximum reported carbon content of the nozzle or branch piping connection does not exceed 0.30%;

(6) a 200°F (93°C) minimum preheat is maintained during welding whenever the nominal thickness of the weld exceeds:

(a) $1\frac{1}{4}$ in. (32 mm) and the maximum reported carbon content of the material of the nozzle or branch pipe is 0.30% or less; or

(b) $\frac{3}{4}$ in. (19 mm) and the maximum reported carbon content of material of the nozzle or branch pipe connection exceeds 0.30%.

NC-4622.9 Weld Repair to Vessels.

Limited weld repairs to vessels of P-No. 3 materials and A-No. 1, A-No. 2, A-No. 10, or A-No. 11 weld filler metal (Section IX, QW-442) may be made without PWHT or after the final PWHT, provided the requirements of the following subparagraphs are met:

(a) *Examination of Area to Be Repaired.* Before a repair is made, the area shall be examined by magnetic particle or liquid penetrant method in accordance with NC-5110 and shall meet the acceptance standards of NC-5340 or NC-5350, as appropriate.

(b) *Maximum Extent of Repairs.* A repair shall not exceed 10 sq in. in surface area and shall not be greater in depth than 50% of the base metal or weld thickness or $\frac{1}{2}$ in. (13 mm), whichever is less.

(c) *Repair Welding Procedure*

(1) The repairs shall be made using one or more procedures and welders qualified in accordance with Section IX and the requirements of this Subsection using the shielded metal-arc process and low hydrogen covered electrodes.

(2) The largest electrode diameter shall be $\frac{5}{32}$ in. (4 mm), and the bead width shall not exceed four times the electrode diameter.

(3) The repair weld shall be made with a minimum of two layers of weld metal. The last layer shall be limited or ground off so that the weld surface does not extend above the base metal a greater distance than that allowed for reinforcement of butt welds.

(4) A preheat and interpass temperature of 300°F (149°C) minimum shall be used.

(d) *Examination of Repair Welds.* Following the repair and when the area has reached ambient temperature, the area shall again be examined by magnetic particle methods and accepted in accordance with NC-4622.9(a) above.

NC-4623 PWHT Heating and Cooling Rate Requirements

Above 800°F (427°C), the rate of heating and cooling in any hourly interval shall not exceed 400°F divided by the maximum thickness in inches of the material being heat treated, but shall not exceed 400°F (222°C) and need not be less than 100°F (56°C) in any hourly interval. During the heating and cooling period there shall not be a greater variation in temperature than 250°F (139°C) within any 15 ft (4.6 mm) interval of weld length. The exceptions of (a) and (b) below are permitted.

(a) P-No. 6 materials may be cooled in air from the postweld heat treatment holding temperature specified in Table NC-4622.1-1.

(b) For P-No. 7 materials the cooling rate at temperatures above 1200°F (649°C) shall not exceed 100°F/hr (56°C), after which the rate of cooling shall be sufficiently rapid to prevent embrittlement.

NC-4624 Methods of Postweld Heat Treatment

The postweld heat treatment shall be performed in accordance with the requirements of one of the following subparagraphs.

Page 282

NC-4624.1 Furnace Heating - One Heat.

Heating the component or item in a closed furnace in one heat is the preferred procedure and should be used whenever practical. The furnace atmosphere shall be controlled so as to avoid excessive oxidation, and direct impingement of flame on the component or item is prohibited.

NC-4624.2 Furnace Heating - More Than One Heat.

The component or item may be heated in more than one heat in a furnace, provided the furnace atmosphere control requirements of NC-4624.1 apply and that overlap of the heated sections of the component or item is at least 5 ft (1.5 m). When this procedure is used, the portion of the component or item outside the furnace shall be shielded so that the temperature gradient is not harmful. The cross section where the component or item projects from the furnace shall not intersect a nozzle or other structural discontinuity.

NC-4624.3 Local Heating.

Welds may be locally postweld heat treated when it is not practical to heat treat the entire component or item. Local postweld heat treatment shall consist of heating a circumferential band around the component or item at temperatures within the ranges specified in this Subarticle. The minimum width of the controlled band at each side of the weld, on the face of the greatest weld width, shall be the thickness of the weld or 2 in. (51 mm), whichever is less. The temperature of the component or item from the edge of the controlled band outward shall be gradually diminished so as to avoid harmful thermal gradients. This procedure may also be used for postweld heat treatment after repairs.

NC-4624.4 Heating Components Internally.

The component or item may be heated internally by any appropriate means and with adequate indicating and recording temperature devices to aid in the control and maintenance of a uniform distribution of temperature in the component or item. Previous to this operation, the component or item should be fully enclosed with insulating material.

NC-4630 HEAT TREATMENT OF WELDS OTHER THAN THE FINAL POSTWELD HEAT TREATMENT

The holding temperature, the time at temperature, the heating rate, and the cooling rate need not conform to the requirements of this Article for heat treatments other than the final postweld heat treatment.

NC-4650 HEAT TREATMENT AFTER BENDING OR FORMING FOR PIPE, PUMPS, AND VALVES

NC-4651 Conditions Requiring Heat Treatment After Bending or Forming

(a) Ferritic alloy steel pipe or formed portions of pumps or valves that have been heated for bending or other forming operations shall receive a heat treatment in accordance with NC-4620, a full anneal, a normalizing and tempering treatment, or a quenching and tempering treatment.

(b) Carbon steel pipe or formed portions of pumps or valves with a wall thickness greater than $\frac{3}{4}$ in. (19 mm) included in group P-No. 1 in Section IX that have been cold bent or formed shall receive heat treatment in accordance with NC-4620.

(c) Ferritic alloy pipe or formed portions of pumps or valves with an outside diameter greater than 4 in. (102 mm) and a wall thickness greater than $\frac{1}{2}$ in. (13 mm) included in groups P-No. 3 through P-No. 5 in Section IX that have been cold bent or formed shall require a heat treatment in accordance with NC-4620.

NC-4652 Exemptions From Heat Treatment After Bending or Forming

If the conditions described in (a) through (d) are met, heat treatment after bending or forming is not required.

(a) Carbon steel pipe or portions of pumps and valves that have been bent or formed at a temperature of 1650°F or higher shall require no subsequent heat treatment, providing the requirements of NC-4213 have been met.

(b) Austenitic stainless steel pipe, or portions of pumps or valves that have been heated for bending or other forming operations, may be used in the as-bent condition, unless the Design Specifications require a heat treatment following bending or forming.

(c) Austenitic stainless steel pipe or portions of pumps or valves that have been cold bent or formed may be used in the as-bent condition, unless the Design Specifications require a heat treatment following bending or forming.

(d) Carbon steel and ferritic alloy-steel pipe or portions of pumps or valves with size and wall thicknesses less than specified in subparagraphs NC-4651(b) and (c) may be cold bent or formed without a heat treatment following bending.

Page 283

NC-4660 HEAT TREATMENT OF ELECTROSLAG WELDS

Electroslag welds in ferritic material over $1\frac{1}{2}$ in. (38 mm) in thickness at the joints shall be given a grain refining heat treatment.

NC-4700 MECHANICAL JOINTS

NC-4710 BOLTING AND THREADING

NC-4711 Thread Engagement

The threads of all bolts or studs shall be engaged in accordance with the design.

NC-4712 Thread Lubricants

Any lubricant or compound used in threaded joints shall be suitable for the service conditions and shall not react unfavorably with either the service fluid or any component material in the system.

NC-4713 Removal of Thread Lubricants

All threading lubricants or compounds shall be removed from surfaces which are to be seal-welded.

NC-4720 BOLTING FLANGED JOINTS

In bolting gasketed flanged joints, the contact faces of the flanges shall bear uniformly on the gasket and the gasket shall be properly compressed in accordance with the design principles applicable to the type of gasket used. All flanged joints shall be made up with relatively uniform bolt stress.

NC-4730 ELECTRICAL AND MECHANICAL PENETRATION ASSEMBLIES

(a) Electrical and mechanical penetration assemblies, except those portions performing an electrical conducting or insulating function, shall be constructed in accordance with the rules for components.

(b) Tubes or pipes of 2 in. nominal pipe size (DN 50) and less may be joined to a penetration assembly in accordance with the rules of NC-4350.

(c) The closing seam for the penetration assembly may be made with a multipass single lap fillet weld as shown in Fig. NC-4730-1, provided the requirements of (1) through (5) below are met.

(1) One of the heads on the penetration assembly shall meet the requirements of NC-3352.3.

(2) The penetration assembly shall not exceed 18 in. (457 mm) outside diameter.

(3) The Design Pressure of the penetration assembly shall not exceed 100 psi (690 kPa) and the Design Temperature shall not exceed 400°F (204°C).

(4) Examination of the fillet weld shall be by the liquid penetrant method in accordance with NC-5350.

(5) The fillet weld and closure head shall meet the requirements of NC-3720(b).

NC-4800 EXPANSION JOINTS

NC-4810 FABRICATION AND INSTALLATION RULES FOR BELLOWS EXPANSION JOINTS

For bellows type expansion joints, the requirements of (a) through (f) below shall be met.

(a) All welded joints shall comply with the requirements of NC-4000.

(b) The longitudinal seam welds in the bellows shall be a butt type full penetration weld.

(c) The bellows of the expansion joint shall be attached to the welding ends or flange by circumferential welds of a butt type having a full penetration through the thickness of the bellows portion, as shown in Fig. NC-4810(c)-1.

(d) Other than the attachment welds, no circumferential welds are permitted in the bellows elements.

(e) Prior to installation of the expansion joint in the system, weld repairs shall not be permitted on parent material of the bellows.

(f) See NC-3649.2 for general requirements applicable to fabrication and installation.

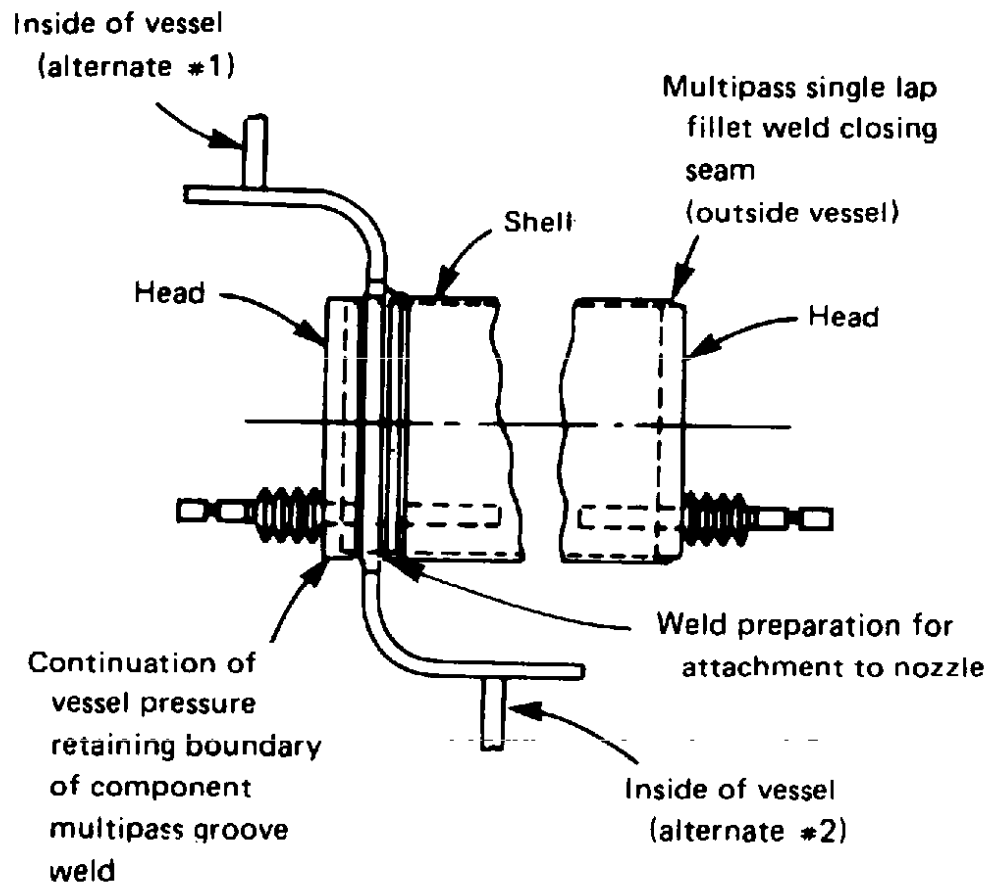


FIG. NC-4730-1 PENETRATION ASSEMBLY

FIG. NC-4730-1 PENETRATION ASSEMBLY

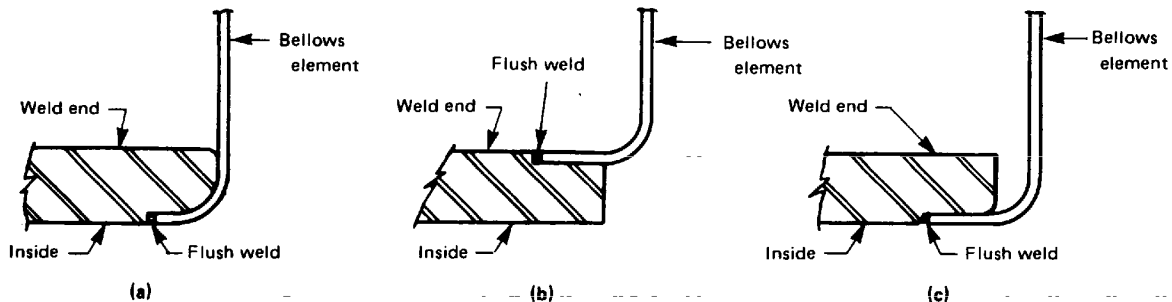


FIG. NC-4810(c)-1 PERMISSIBLE ATTACHMENT WELDS FOR BELLOWS

FIG. NC-4810(c)-1 PERMISSIBLE ATTACHMENT WELDS FOR BELLOWS

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NC-5000

ARTICLE NC-5000 EXAMINATION

Page 285

NC-5100 GENERAL REQUIREMENTS FOR EXAMINATION

NC-5110 PROCEDURE, QUALIFICATION, AND EVALUATION

NC-5111 General Requirements

(a) Nondestructive examinations shall be conducted in accordance with the examination methods of Section V, except as they may be modified by the requirements of this Article. Radiographic examination shall be by film radiography or real time radiography in accordance with Section V, Article 2, except that fluorescent screens are not permitted for film radiography, the geometric unsharpness shall not exceed the limits of T-285, and the penetrameters of Table NC-5111-1 shall be used in lieu of those shown in Table T-276. The requirements for the retention of radioscopic images are the same as for film radiography. Ultrasonic examination shall be in accordance with Section V, Article 5; magnetic particle examination shall be in accordance with Section V, Article 7; liquid penetrant examination shall be in accordance with Section V, Article 6; and leak testing shall be in accordance with Section V, Article 10.

(b) Class 2 pressure vessels designed to the requirements of NC-3200 shall meet the requirements of NC-5250 in lieu of NC-5210 through NC-5240.

(c) Nondestructive examination requirements for tanks are given in NC-5280.

(d) The examinations required by this Article, or by reference to this Article, shall be performed by personnel who have been qualified as required by this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards of this Article.

NC-5112 Nondestructive Examination Procedures

All nondestructive examinations required by this Article shall be performed in accordance with detailed written procedures which have been proven by actual demonstration to the satisfaction of the Inspector. The procedure shall comply with the appropriate Article of Section V for the particular examination method. The digitization of radiographic film and radiosopic images shall meet the requirements of Section V, Article 2, Mandatory Appendix III, "Digital Image Acquisition, Display and Storage for Radiography and Radioscopy". Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Inspector on request. At least one copy of the procedure shall be readily available to all applicable nondestructive examination personnel for reference and use.

NC-5113 Post-Examination Cleaning

Following any nondestructive examination in which examination materials are applied to the piece, the piece shall be thoroughly cleaned in accordance with applicable materials or procedure specifications.

NC-5120 TIME OF EXAMINATION OF WELDS AND WELD METAL CLADDING

Acceptance examinations of welds and weld metal cladding required by NC-5200 shall be performed at the times stipulated in (a) through (d) below during fabrication and installation.

(a) Radiographic examination of welds shall be performed after an intermediate¹ or final postweld heat treatment, when required, except as provided in (1) and (2) below.

¹ An intermediate postweld heat treatment for this purpose is defined as a postweld heat treatment performed on a weld within a temperature range not lower than the minimum holding temperature range to which the weld will be subjected during the final postweld heat treatment.

Page 290

TABLE NC-5111-1
THICKNESS, PENETRATOR DESIGNATIONS, AND ESSENTIAL HOLES, AND WIRE DIAMETERS

Single Wall Material Thickness Range, in.	Penetrator(s) — Hole or Wire Type (1)							
	Source Side				Film Side			
	Designation	Hole Size	Essential Hole	Required Wire Diameter — IQI	Designation	Hole Size	Essential Hole	Required Wire Diameter — IQI
Up to 0.25 incl.	5	0.040	4T	0.006	5	0.040	4T	0.006
Over 1/4–3/8	7	0.040	4T	0.006	7	0.040	4T	0.006
Over 3/8–1/2	10	0.040	4T	0.010	10	0.040	4T	0.010
Over 1/2–5/8	12	0.050	4T	0.013	12	0.050	4T	0.013
Over 5/8–3/4	15	0.060	4T	0.016	12	0.050	4T	0.013
Over 3/4–1	20	0.040	2T	0.016	17	0.035	2T	0.013
Over 1–1 1/4	25	0.050	2T	0.020	17	0.035	2T	0.013
Over 1 1/4–1 1/2	30	0.060	2T	0.025	20	0.040	2T	0.016
Over 1 1/2–2	35	0.070	2T	0.032	25	0.050	2T	0.020
Over 2–2 1/2	40	0.080	2T	0.040	30	0.060	2T	0.025
Over 2 1/2–3	45	0.090	2T	0.040	35	0.070	2T	0.032
Over 3–4	50	0.100	2T	0.050	40	0.080	2T	0.040
Over 4–6	60	0.120	2T	0.063	45	0.090	2T	0.040
Over 6–8	80	0.160	2T	0.100	50	0.100	2T	0.050
Over 8–10	100	0.200	2T	0.126	60	0.120	2T	0.063
Over 10–12	120	0.240	2T	0.160	80	0.160	2T	0.100
Over 12–16	160	0.320	2T	0.250	100	0.200	2T	0.126
Over 16–20	200	0.400	2T	0.320	120	0.240	2T	0.160

NOTE:

(1) Hole (plaque) type penetrators may be used on flat plates and on objects with geometries such that the penetrator hole image is not distorted.

TABLE NC-5111-1 THICKNESS, PENETRATOR DESIGNATIONS, AND ESSENTIAL HOLES, AND WIRE DIAMETERS

(1) Radiographic examination of welds in items fabricated of P-No. 1 materials may be performed prior to any required postweld heat treatment.

(2) Radiographic examination of welds in P-No. 3 materials may be performed prior to an intermediate or final postweld heat treatment provided the welds are ultrasonically examined after an intermediate or the final postweld heat treatment. The ultrasonic examination and acceptance standards shall be in accordance with this Article.

(b) Magnetic particle or liquid penetrant examinations of welds shall be performed after any required postweld heat treatment, except that welds in P-No. 1 materials may be examined either before or after postweld heat treatment.

(c) All dissimilar metal weld joints such as in austenitic or high nickel to ferritic material or using austenitic or high nickel alloy filler metal to join ferritic materials which penetrate the wall shall be examined after final postweld heat treatment.

(d) The magnetic particle or liquid penetrant examination of weld surfaces that are to be covered with weld metal cladding shall be performed before the weld metal cladding is deposited. The magnetic particle or liquid penetrant examination of weld surfaces that are not accessible after a postweld heat treatment shall be performed prior to the operation which caused this inaccessibility. These examinations may be performed before PWHT.

(e) Ultrasonic examination of electroslag welds in ferritic materials shall be performed after a grain refining heat treatment, when performed, or after final postweld heat treatment.

NC-5130 EXAMINATION OF WELD EDGE PREPARATION SURFACES

All full penetration weld edge preparation surfaces for joint Categories A, B, C, D, and similar joints in material 2 in. or more in thickness shall be examined by the magnetic particle or liquid penetrant method. Indications shall be evaluated in accordance with the acceptance standards of (a), (b), and (c) below.

(a) Only indications with major dimensions greater than $\frac{1}{16}$ in. shall be considered relevant imperfections.

(b) Laminar-type imperfections are acceptable without repair if they do not exceed 1 in. (25 mm) in

Page 291

length. The extent of all laminar-type imperfections exceeding 1 in. (25 mm) in length shall be determined by ultrasonic examination. Imperfections exceeding 1 in. (25 mm) in length shall be repaired by welding to a depth of $\frac{3}{8}$ in. (10 mm) or the depth of the imperfection, whichever is less, unless the ultrasonic examination reveals that additional depth of repair is required to meet the ultrasonic examination requirement for the product form.

(c) Indications of nonlaminar imperfections of (1) through (3) below are unacceptable:

(1) any linear indications greater than $\frac{3}{16}$ in. (4.8 mm) long;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);

(3) four or more indications, in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less, edge to edge.

(d) Weld repairs made to weld edge preparations for Category A, B, C, D, and similar type welds shall be examined by the magnetic particle or liquid penetrant method before the surfaces become inaccessible. The examination may be performed before or after postweld heat treatment.

NC-5140 EXAMINATION OF OPENINGS CUT IN VESSELS DESIGNED TO NC-3200

For nozzle connections with necks abutting the vessel wall [Fig. NC-4266(b)-1 sketches (a) and (b)], the radially disposed surfaces of the openings cut in the vessel walls shall be examined by either magnetic particle method or a liquid penetrant method in accordance with the requirements of this Article. Defects thus discovered shall be removed and repaired as required by the applicable Article.

NC-5200 EXAMINATION OF WELDS²

NC-5210 CATEGORY A VESSEL WELDED JOINTS AND LONGITUDINAL WELDED JOINTS IN PIPING, PUMPS, AND VALVES

NC-5211 Vessel Welded Joints

(a) Category A welded joints shall be fully radiographed when either of the members being joined exceeds $\frac{3}{16}$ in. (4.8 mm) thickness.

2 See NC-5250 for vessels designed to NC-3200. See NC-5280 for requirements for storage tank welds.

(b) Category A welded joint surfaces may be examined by either the magnetic particle or liquid penetrant method as an alternative to the radiographic examination when the thickness of each member being joined is $\frac{3}{16}$ in. (4.8 mm) or less.

NC-5212 Pipe, Pump, and Valve Welded Joints

Longitudinal butt welded joints, as defined in NC-3351.1, shall be radiographed.

NC-5220 CATEGORY B VESSEL WELDED JOINTS AND CIRCUMFERENTIAL WELDED JOINTS IN PIPING, PUMPS, AND VALVES

NC-5221 Vessel Welded Joints

(a) Category B welded joints shall be fully radiographed when either of the members being joined exceeds $\frac{3}{16}$ in. (4.8 mm) thickness.

(b) Category B welded joint surfaces may be examined by either the magnetic particle or liquid penetrant method as an alternative to the radiographic examination when the thickness of each member being joined is $\frac{3}{16}$ in. (4.8 mm) or less.

NC-5222 Piping, Pump, and Valve Welded Joints

(a) Butt welded joints shall be radiographed.

(b) Fillet and partial penetration welded joints shall be examined by either the magnetic particle or liquid penetrant method.

NC-5230 CATEGORY C VESSEL WELDED JOINTS AND SIMILAR WELDED JOINTS IN OTHER COMPONENTS

(a) Category C full penetration butt welded joints and similar welded joints in other components shall be fully radiographed when either of the members being joined exceeds $\frac{3}{16}$ in. (4.8 mm) of thickness.

(b) Category C full penetration corner welded joints and similar welded joints in other components shall be ultrasonically or radiographically examined when either of the members being joined exceeds $\frac{3}{16}$ in. (4.8 mm) of thickness.

(c) Category C welded joint surfaces and similar welded joints in other components may be examined by either the magnetic particle or liquid penetrant method as an alternative to the radiographic or ultrasonic

Page 292

examination when the thickness of each member being joined is $\frac{3}{16}$ in. (4.8 mm) or less.

(d) Category C partial penetration and fillet welded joints and similar welded joints in other components shall be examined by the magnetic particle or liquid penetrant method on all accessible surfaces.

NC-5240 CATEGORY D VESSEL WELDED JOINTS AND SIMILAR WELDED JOINTS IN OTHER COMPONENTS

NC-5241 Vessel Welded Joints

(a) Category D full penetration butt welded joints and similar welded joints in other components shall be fully radiographed when either of the members being joined exceeds $\frac{3}{16}$ in. (4.8 mm) of thickness.

(b) Category D full penetration corner welded joints and similar welded joints in other components shall be ultrasonically or radiographically examined when either of the members being joined exceeds $\frac{3}{16}$ in. (4.8 mm) of thickness.

(c) Category D welded joint surfaces and similar welded joints in other components may be examined by either the magnetic particle or liquid penetrant method as an alternative to the radiographic or ultrasonic examination when the thickness of each member being joined is $\frac{3}{16}$ in. (4.8 mm) or less.

(d) Category D partial penetration and fillet welded joints and similar welded joints in other components shall be examined by the magnetic particle or liquid penetrant method on all accessible surfaces.

NC-5242 Welded Branch Connections³ and Nozzles in Piping, Pumps, and Valves

(a) Branch connections³ and nozzles with nominal pipe size exceeding 4 in. shall be examined by radiography.

(b) Branch connections³ and nozzles with nominal pipe size 4 in. and smaller shall have the external weld surface and the accessible internal weld surface examined by either the magnetic particle or liquid penetrant method.

³ Welds in branch piping runs shall be examined as required by NC-5212 and NC-5222.

NC-5250 EXAMINATION OF WELDS FOR VESSELS DESIGNED TO NC-3200

NC-5251 Category A Welded Joints

Category A welded joints shall be fully radiographed.

NC-5252 Category B Welded Joints

Category B welded joints shall be fully radiographed.

NC-5253 Category C Welded Joints

(a) Category C full penetration butt welded joints shall be fully radiographed.

(b) Category C full penetration corner welded joints shall be ultrasonically or radiographically examined.

(c) Category C partial penetration or fillet welded joints shall be examined by either the liquid penetrant or magnetic particle method on all accessible surfaces.

(d) For corner joint constructions as illustrated in Fig. NC-4265-1 sketches (b) and (c), except when dimension b is equal to or greater than t_s , the unstayed flat head, prior to welding, shall be 100% examined by the ultrasonic method in accordance with the requirements of SA-435, except that no lamination in the head is acceptable.

NC-5254 Category D Welded Joints

(a) Category D full penetration butt welded joints shall be fully radiographed.

(b) Category D full penetration corner welded joints shall be ultrasonically or radiographically examined.

(c) Category D partial penetration or fillet welded joints shall be examined by either the liquid penetrant or magnetic particle method on all accessible surfaces.

NC-5257 Other Welded Joints for Vessels Designed to NC-3200

The requirements of NC-5260, NC-5270, and NC-5410 also apply to vessels designed to NC-3200.

NC-5260 FILLET, PARTIAL PENETRATION, SOCKET, AND ATTACHMENT WELDS

NC-5261 Fillet, Partial Penetration, and Socket Welded Joints

shall be examined by the magnetic particle or liquid penetrant method.

NC-5262 Structural Attachment Welded Joints

Structural attachment welded joints made to pressure retaining material shall be examined by either the magnetic particle or liquid penetrant method.

NC-5270 SPECIAL WELDS

NC-5271 Welds of Specially Designed Seals

Welds of this type shall be examined by either the magnetic particle or liquid penetrant method.

NC-5272 Weld Metal Cladding

Weld metal cladding shall be examined by the liquid penetrant method.

NC-5273 Hard Surfacing

Hard surfacing shall be examined by the liquid penetrant method in accordance with NC-2546, and the acceptance standards applicable to materials less than $\frac{5}{8}$ in. (16 mm) thick shall apply. Penetrant examination is not required for hard surfacing on valves with inlet connections 4 in. nominal pipe size (DN 100) or less.

NC-5274 Tube-to-Tubesheet Welds

Tube-to-tubesheet welds shall be examined by the liquid penetrant method.

NC-5275 Brazed Joints

Flux and flux residue shall be removed from all surfaces prior to examination. Joints shall be visually examined on all accessible surfaces to determine whether there has been adequate flow of brazing metal through the joint. Optical aids may be employed for indirect visual examination of joints which cannot be directly examined.

NC-5276 Inertia and Continuous Drive Friction Welds

(a) When radiographic examination is required by this Article, inertia and continuous drive friction welds shall also be examined by the ultrasonic method to verify bonding over the entire area.

(b) The materials used shall be those assigned a P-Number by Section IX, but shall not include rimmed or semikilled steel.

(c) One of the two parts to be joined must be held in a fixed position and the other part rotated. The two faces to be joined must be symmetrical with respect to the axis of rotation.

(d) The weld between the two members shall be a full penetration weld.

NC-5278 Electroslag Welds

In addition to the requirements for the type of weld being examined, all complete penetration welds made by the electroslag welding process in ferritic materials shall be ultrasonically examined.

NC-5279 Special Exceptions

When the joint detail does not permit radiographic examination of joints attaching penetration assemblies, which are fabricated as appurtenances, or the closing seam within an electrical penetration assembly, which is not fabricated as an appurtenance, ultrasonic examination plus liquid penetrant or magnetic particle examination of the completed weld may be substituted for the radiographic examination. The absence of suitable radiographic equipment shall not be justification

be substituted for the radiographic examination. The absence of suitable radiographic equipment shall not be justification for such substitution. The substitution of ultrasonic examination can be made, provided the examination is performed using a detailed written procedure which has been proven by actual demonstration to the satisfaction of the Inspector as capable of detecting and locating defects described in this Subsection. The nondestructive examination shall be in accordance with Section V and meet the acceptance standards of NC-5300.

NC-5280 WELD JOINTS IN STORAGE TANKS

NC-5281 Examination Procedures

Nondestructive examinations of welds in storage tanks shall be in accordance with the examination procedures of Section V.

NC-5282 Atmospheric Storage Tanks

NC-5282.1 Sidewall Joints.

Sidewall joints shall be fully radiographed.

Page 294

NC-5282.2 Roof Joints and Roof-to-Sidewall Joints.

Roof joints and roof-to-sidewall joints shall be examined visually.

NC-5282.3 Bottom Joints.

Bottom joints shall be examined from the inside of the tank by applying soapsuds to the joints and pulling a partial vacuum of at least 3 psi by means of a vacuum box with transparent top.

NC-5282.4 Bottom-to-Sidewall Joints.

Bottom-to-sidewall joints shall be examined by the vacuum box method as detailed in NC-5282.3 and by a magnetic particle or liquid penetrant surface examination.

NC-5282.5 Nozzle-to-Tank Joints.

Nozzle-to-sidewall or bottom joints shall be examined by either the magnetic particle or liquid penetrant method. Nozzle-to-roof joints shall be visually examined.

NC-5282.6 Joints in Nozzles.

All joints in roof nozzles shall be visually examined. Butt joints in other nozzles shall be examined by the radiographic method; other types of nozzle joints shall be examined by the liquid penetrant or magnetic particle method.

NC-5282.7 Other Joints.

Joints not specifically covered by NC-5282 shall be examined in the same manner as similar weld joints in vessels as required by this Subarticle.

NC-5283 Weld Joints in 0-15 psi (0-103 kPa) Storage Tanks

NC-5283.1 Sidewall Joints.

Sidewall joints shall be fully radiographed.

NC-5283.2 Roof Joints.

Roof joints shall be fully radiographed.

NC-5283.3 Roof-to-Sidewall Joints.

Roof-to-sidewall joints shall be fully radiographed if the design permits. If not radiographed, these joints shall be examined by the magnetic particle or liquid penetrant method.

NC-5283.4 Bottom Joints.

Joints in bottoms supported directly on grade shall be examined by the vacuum box method as detailed in NC-5282.3. Joints not supported directly on grade shall be fully radiographed.

NC-5283.5 Bottom-to-Sidewall Joints.

Bottom-to-sidewall joints shall be examined by the vacuum box method as detailed in NC-5282.3 and by either the magnetic particle method or the liquid penetrant method.

NC-5283.6 Nozzle-to-Tank Joints.

Nozzle-to-tank joints shall be examined by either the magnetic particle or liquid penetrant method.

NC-5283.7 Joints in Nozzles.

Butt joints in nozzles shall be fully radiographed. Other joints shall be examined by magnetic particle or liquid penetrant methods.

NC-5283.8 Other Joints.

Joints not specifically covered by NC-5283 shall be examined in the same manner as similar weld joints in vessels as required by this Subarticle.

NC-5300 ACCEPTANCE STANDARDS

NC-5320 RADIOGRAPHIC ACCEPTANCE STANDARDS

Indications shown on the radiographs of welds and characterized as imperfections are unacceptable under the following conditions:

- (a) any indication characterized as a crack or zone of incomplete fusion or penetration;
- (b) any other elongated indication which has a length greater than:
 - (1) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive
 - (2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. to $2\frac{1}{4}$ in. (19 mm to 57 mm), inclusive
 - (3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm)

where t is the thickness of the thinner portion of the weld.

(c) Internal root weld conditions are acceptable when the density change as indicated in the radiograph is not abrupt; elongated indications on the radiograph at either edge of such conditions shall be unacceptable as provided in (b) above;

(d) any group of aligned indications having an aggregate length greater than t in a length of $12t$ unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication;

(e) rounded indications in excess of those shown as acceptable in Appendix VI.

NC-5330 ULTRASONIC ACCEPTANCE STANDARDS

All imperfections which produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and evaluate them in terms of the

(a) Imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths exceeding:

- (1) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive
- (2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. to $2\frac{1}{4}$ in. (19 mm to 57 mm), inclusive
- (3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm)

where t is the thickness of the weld being examined; if a weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses.

(b) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

NC-5340 MAGNETIC PARTICLE ACCEPTANCE STANDARDS

NC-5341 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication which is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. After an indication has been verified to be nonrelevant, it is not necessary to reinvestigate repetitive nonrelevant indications of the same type. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are those which result from imperfections. Linear indications are those indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NC-5342 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

- (1) any cracks or linear indications;
- (2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);
- (3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;
- (4) ten or more rounded indications in any 6 sq in. (645 mm²) of surface, with the major dimension of this area not to exceed 6 in. (152 mm), with the area taken in the most unfavorable location relative to the indications being evaluated.

NC-5350 LIQUID PENETRANT ACCEPTANCE STANDARDS

NC-5351 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities such as may occur from machining marks, surface conditions, or an incomplete bond between base metal and cladding may produce similar indications which are nonrelevant.

(b) Any indication which is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are those which result from imperfections. Linear indications are those indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NC-5352 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks or linear indications;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);

(3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 sq in. (645 mm²) of surface, with the major dimension of this area not to exceed 6 in. (152 mm), with the area taken in the most unfavorable location relative to the indications being evaluated.

Page 296

NC-5360 VISUAL ACCEPTANCE STANDARDS FOR BRAZED JOINTS

Braze metal shall give evidence of having flowed uniformly through a joint by the appearance of an uninterrupted, narrow visible line of brazing alloy at the ends of the joint.

NC-5370 ACCEPTANCE STANDARDS FOR METALLOGRAPHIC EXAMINATION OF SPECIALLY DESIGNED WELDED SEALS

(a) Each cross section of the qualification test assembly (NC-4367) for specially designed welded seals shall be examined at $\times 10$ to $\times 15$, in accordance with the ASTM Standard E 2.

(b) All surfaces shall be free of cracks, incomplete penetration, incomplete melting of insert on consumable type welds, and rounded indications or inclusions in excess of one rounded void with the maximum dimension not greater than 10% of the thickness of the weld.

NC-5380 GAS AND BUBBLE FORMATION TESTING

For gas and bubble formation testing, the test procedure shall be in accordance with T-1030 of Section V, Article 10. When vacuum box testing is used, the soak time shall be a minimum of 10 sec. Any indication of leaking, by the formation of bubbles or the breaking of the continuous soap film by leaks, shall be evidence of an unacceptable condition.

NC-5400 FINAL EXAMINATION OF COMPONENTS

NC-5410 EXAMINATION AFTER PRESSURE TESTING

After the required pressure test of a component constructed of ferritic materials with properties enhanced by quenching and tempering, all pressure retaining welded joints shall be examined by the magnetic particle or liquid penetrant method on all accessible surfaces.

NC-5500 QUALIFICATIONS AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

NC-5510 GENERAL REQUIREMENTS

Organizations performing Code required nondestructive examinations shall use personnel competent and knowledgeable to the degree specified by NC-5520. When these services are subcontracted by the Certificate Holder or Quality System Certificate Holder, he shall verify the qualification of personnel to the requirements of NC-5520. All nondestructive examinations required by this Subsection shall be performed by and the results evaluated by qualified nondestructive

examination personnel.

NC-5520 PERSONNEL QUALIFICATION, CERTIFICATION, AND VERIFICATION

NC-5521 Qualification Procedure

(a) Personnel performing nondestructive examinations shall be qualified in accordance with the recommended guidelines of SNT-TC-1A.⁴⁵ The Employer's⁶ written practice required by paragraph 5 of SNT-TC-1A shall identify his requirements relative to the recommended guidelines. The recommended guidelines of SNT-TC-1A shall be considered minimum requirements, except as modified in (1) through (5) below.

(1) Qualification of Level III nondestructive examination personnel shall be by examination.

(a) The basic and method examinations, paragraphs 8.8(1) and 8.8(2) of SNT-TC-1A, may be prepared and administered by the Employer, ASNT, or an outside agency.

4 SNT-TC-1A is a Recommended Practice for Nondestructive Testing Personnel Qualification and Certification published by the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, Ohio 43228-0518. SNT-TC-1A-1992 is the applicable edition.

5 Personnel qualified by examination and certified to previous editions of SNT-TC-1A are considered to be qualified to the 1992 edition when the recertification is based on continuing satisfactory performance. All reexaminations and new examinations shall be in accordance with the 1992 edition.

6 Employer as used in this Article shall include: N Certificate Holders; Quality System Certificate Holders; Material Manufacturers and Material Suppliers who are qualified in accordance with NCA-3862(a)(1); and organizations who provide subcontracted nondestructive examination services to organizations described above.

(b) The specific examination, paragraph 8.8(3) of SNT-TC-1A, shall be prepared and administered by

Page 297

the Employer or an outside agency. The Employer or outside agency administering the specific examination shall identify the minimum grade requirement in the written program when the basic and method examinations have been administered by ASNT, which issues grades on a pass/fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(2) The written practice identified in paragraph 5 of SNT-TC-1A and the procedures used for examination of personnel shall be referenced in the Employer's Quality Program.

(3) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform nondestructive examination of limited scope, may be less than that recommended in Table 6.3.1 of SNT-TC-1A. The training and experience times shall be described in the written practice, and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate.

(a) The minimum classroom training times identified in Table 6.3.1 of SNT-TC-1A may be reduced from 8 and 16 hours to 4 and 8 hours, respectively for visual examination personnel.

(4) or visual examination, the Jaeger Number 1 letters shall be used in lieu of the Jaeger Number 2 letters specified in paragraph 8.2(1) of SNT-TC-1A. The use of equivalent type and size letters is permitted.

(5) A Level I individual shall be qualified to perform specific setups, calibrations, and tests and to record and evaluate data by comparison with specific acceptance criteria defined in written instructions. The Level I individual shall implement these written NDE instructions under the guidance of a Level II or III individual. A Level I individual may independently accept the results of nondestructive examinations when the specific acceptance criteria are defined in the written instructions.

(b) For nondestructive examination methods not covered by SNT-TC-1A documents, personnel shall be qualified to comparable levels of competency by subsection to comparable examinations on the particular method involved.

(c) The emphasis shall be on the individual's ability to perform the nondestructive examination in accordance with the applicable procedure for the intended application.

(d) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use

personnel qualified to perform one or more operations. As an example, one person may be used who is qualified to conduct radiographic examination and another may be used who is qualified to interpret and evaluate the radiographic film.

NC-5522 Certification of Personnel

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of Levels I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations [NC-5521(a)(2)], the Employer may use a letter from ASNT as evidence on which to base the certification.

(c) When an outside agency is the examining agent for Level III qualification of the Employer's personnel, the examination results shall be included with the Employer's record.

NC-5523 Verification of Nondestructive Examination Personnel Certification

The Certificate Holder has the responsibility to verify the qualification and certification of nondestructive examination personnel employed by Material Manufacturers and Material Suppliers qualified by them in accordance with NCA-3820 and subcontractors who provide nondestructive examination services to them.

NC-5530 RECORDS

Personnel qualification records identified in paragraph 9.4 of SNT-TC-1A shall be retained by the Employer.

NC-5700 EXAMINATION REQUIREMENTS FOR EXPANSION JOINTS

NC-5720 BELLOWS EXPANSION JOINTS

The examinations stipulated in (a) through (f) below are required to verify the integrity of bellows expansion joints for installation in components.

(a) The formed bellows shall be determined to be free of defects such as notches, crevices, material buildup or upsetting, weld spatter, etc., by visual examination. Suspect surface areas shall be further examined by liquid penetrant examination in accordance with NC-5110.

(b) The longitudinal seam welds in the bellows shall be examined by the liquid penetrant method in accordance with NC-5110. When the individual ply thickness

Page 298

exceeds $\frac{1}{8}$ in. (3.2 mm), the weld shall also be radiographed in accordance with NC-5110. These examinations may be performed either before or after the bellows is formed.

(c) The circumferential attachment welds between the bellows and pipe or flange shall be liquid penetrant examined in accordance with NC-5110 when the total bellows thickness is $\frac{1}{4}$ in. (6 mm) or less. When the total thickness exceeds this limit, the weld shall be radiographed in accordance with NC-5110 except where radiography is not meaningful, such as when the weld thickness constitutes less than 20% of the total thickness being radiographed, liquid penetrant examination may be substituted.

(d) In the case of liquid penetrant examination of bellows welds, imperfections producing the following indications are unacceptable:

(1) cracks or linear indications;

(2) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(3) five or more randomly distributed rounded indications in a weld length of 6 in. (152 mm);

(4) any rounded indication exceeding the lesser of one-half the bellows thickness or $\frac{1}{16}$ in. (1.6 mm) in diameter.

(e) The examination of all other welds in the expansion joint shall comply with NC-5000.

(f) The variation of the cylindrical end thickness of the formed bellows from the nominal or specified thickness shall not exceed the values given in Table 2 of SA-480. Thinning of the bellows material during forming shall be considered in the design and selection of material thickness, but need not be limited to the values specified in Table 2 of SA-480.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NC-6000

ARTICLE NC-6000 TESTING

Page 299

NC-6100 GENERAL REQUIREMENTS

NC-6110 PRESSURE TESTING OF COMPONENTS, APPURTENANCES, AND SYSTEMS

NC-6111 Scope of Pressure Testing

All pressure retaining components, appurtenances, and completed systems shall be pressure tested, except as specified in (a) through (d) below. Portions of piping systems which are exempt shall be identified in the Design Specification and the N-5 Data Report Form. The Design Specification shall be available to the Authorized Nuclear Inspector when the balance of the system is hydrostatically tested.

(a) Bolts, studs, nuts, washers, and gaskets are exempt.

(b) The following portions of piping systems whose only function is to transport fluids to and from spray ponds, lakes, reservoirs, or tanks which are open to the atmosphere are exempt:

(1) piping downstream of the last isolation valve preceding the pipe discharge to the spray pond, lake, reservoir, or tank; and

(2) piping upstream of the intake pump inlet isolation valve.

(c) Where systems discharge into Class 2 vessels, or the gaseous regions of MC containment vessels through spargers or spray nozzles, only that portion of the system external to the vessel is required to be pressure tested.

(d) The portion of a Class 2 safety and safety relief valve discharge piping that is submerged below the minimum Design Level in a containment pressure suppression pool of an MC or CC containment vessel is exempt. The minimum Design Level shall be specifically designated in the Design Specification.

NC-6112 Pneumatic Testing

A pneumatic test in accordance with NC-6300 may be substituted for the hydrostatic test when permitted by NC-6112.1 (a).

NC-6112.1 Pneumatic Test Limitations

(a) A pneumatic test may be used in lieu of a hydrostatic test only when any of the following conditions exist:

(1) when components, appurtenances, or systems are so designed or supported that they cannot be safely filled with liquid¹

(2) when components, appurtenances, or systems which are not readily dried are to be used in services where traces of the testing medium cannot be tolerated.

(b) A pneumatic test at a pressure not to exceed 25% of the Design Pressure may be applied, prior to either a hydrostatic or a pneumatic test, as a means of locating leaks.

NC-6112.2 Precautions to Be Employed in Pneumatic Testing.

Compressed gaseous fluid is hazardous when used as a testing medium. Therefore, it is recommended that special precautions for protection of personnel be taken when a gaseous fluid under pressure is used as a test medium.

NC-6113 Witnessing of Pressure Tests

Pressure testing required by this Article shall be performed in the presence of the Inspector, except that testing of each line valve and each pump having piping connections of NPS 4 (DN 100) and less need not be witnessed by the Inspector. For line valves and pumps NPS 4 and less, the Inspector's review and acceptance of the Certificate Holder's test records will be authorization to sign the Data Report Form, and takes precedence over NCA-5280.

NC-6114 Time of Pressure Testing

NC-6114.1 System Pressure Test.

The installed system shall be pressure tested prior to initial operation.

1 These tests may be made with the item being tested partially filled with liquid, if desired.

Page 304

The pressure test may be performed progressively on erected portions of the system.

NC-6114.2 Component and Appurtenance Pressure Test

(a) Components and appurtenances shall be pressure tested prior to installation in a system, except as permitted in (b) below.

(b) The system pressure test may be substituted for a component or appurtenance pressure test, provided:

(1) the component can be repaired by welding in accordance with the rules of NC-4130 and NC-4450, if required, as a result of the system pressure test;

(2) the component repair weld can be postweld heat treated in accordance with NC-4620, if required, and nondestructively examined in accordance with the rules of NC-4130 and NC-4450, as applicable; and

(3) the component is resubjected to the required system pressure test following the completion of repair and examination if the repair is required to be radiographed by NC-4453.4.

(c) Valves require pressure testing prior to installation in a system in accordance with NC-3500.

(d) Items which, when assembled, form a completed pump or valve may be tested in the form of subassemblies, provided:

(1) the test pressure is in accordance with the requirements of NC-6221;

(2) the pressure test is performed in a manner which, in the subassembly under test, will simulate the loadings present when the completed pump or valve is assembled and pressurized;

(3) the component Certificate Holder approves any pressure test of component subassemblies;

(4) the component Certificate Holder specifies the pressure test requirements and test pressure to be used;

(5) each subassembly pressure test is performed by a Certificate Holder and is performed in the presence of the Authorized Nuclear Inspector;

(6) each subassembly pressure tested by other than the component Certificate Holder is stamped with the NPT symbol, except as provided in NCA-8330; the test pressure shall be identified on the Partial Data Report Form;

(7) each subassembly pressure tested by other than the component Certificate Holder is listed on the Code Data Report Form;

- (8) the pressure tested subassemblies of pumps or valves are subsequently assembled by mechanical methods only;
- (9) welds examined during the subassembly pressure test need not be reexamined during the system pressure test.

NC-6114.3 Material Pressure Test.

The component or appurtenance pressure test may be used in lieu of any such test required by the material specification for a part or material used in the component or appurtenance, provided:

- (a) nondestructive examinations, if required by the material specification, can be performed subsequent to the component or appurtenance pressure test;
- (b) the material can be repaired by welding in accordance with the rules of NC-4130 if required as a result of the pressure test; and
- (c) postweld heat treatment, when required after repairs, can be performed in accordance with NC-4620.

NC-6115 Machining After Pressure Test

An additional amount of material, not to exceed 10% of the wall thickness or $\frac{3}{8}$ in. (10 mm), whichever is less, is permitted on the completed component during pressure testing where machining to critical dimensions and tolerances is required.

NC-6120 PREPARATION FOR TESTING

NC-6121 Exposure of Joints

All joints, including welded joints, shall be left uninsulated and exposed for examination during the test.

NC-6122 Addition of Temporary Supports

Components designed to contain vapor or gas may be provided with additional temporary supports, if necessary, to support the weight of the test liquid.

NC-6123 Restraint or Isolation of Expansion Joints

Expansion joints shall be provided with temporary restraints, if required, for the additional pressure load under test.

NC-6124 Isolation of Equipment Not Subjected to Pressure Test

Equipment that is not to be subjected to the pressure test shall be either disconnected from the component or system or isolated during the test by a blind flange or similar means. Valves may be used if the valves with their closures are suitable for the proposed test pressure.

Page 305

NC-6125 Treatment of Flanged Joints Containing Blanks

Flanged joints at which blanks are inserted to isolate other equipment during the test need not be retested.

NC-6126 Precautions Against Test Medium Expansion

If a pressure test is to be maintained for a period of time and the test medium in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure.

NC-6127 Check of Test Equipment Before Applying Pressure

The test equipment shall be examined before pressure is applied to ensure that it is tight and that all low pressure filling lines and other items that should not be subjected to the test have been disconnected or isolated.

NC-6200 HYDROSTATIC TESTS

The requirements of this paragraph apply to all components except tanks, for which NC-6500 applies.

NC-6210 HYDROSTATIC TEST PROCEDURE

NC-6211 Venting During Fill Operation

The component or system in which the test is to be conducted shall be vented during the filling operation to minimize air pocketing.

NC-6212 Test Medium and Test Temperature

(a) Water or an alternative liquid, as permitted by the Design Specification, shall be used for the hydrostatic test.

(b) It is recommended that the test be made at a temperature that will minimize the possibility of brittle fracture. The test pressure shall not be applied until the component, appurtenance, or system and the pressurizing fluid are at approximately the same temperature.

NC-6220 HYDROSTATIC TEST PRESSURE REQUIREMENTS

NC-6221 Minimum Hydrostatic Test Pressure

(a) The installed system shall be hydrostatically tested at not less than 1.25 times the lowest Design Pressure of any component within the boundary protected by the overpressure protection devices which satisfy the requirements of NC-7000.

(b) Vessels designed in accordance with NC-3200 shall be hydrostatically tested at not less than 1.25 times the Design Pressure.

(c) Valves shall be hydrostatically tested in accordance with the rules of NC-3500.

(d) Other components, excluding piping systems, shall be hydrostatically tested at not less than 1.50 times their Design Pressure.

(e) As an alternative to NC-6221(a) above, piping between the discharge side of a centrifugal pump and the first shutoff valve may be hydrostatically tested at the shutoff head of the pump. The pressure shall be maintained for a sufficient time to permit examination of all joints, connections, and regions of high stress.

NC-6222 Maximum Permissible Pressure

(a) If the minimum test pressure of NC-6221(a) or (d) is to be exceeded by 6% at any location, the upper limit shall be established by analysis using all loadings that may exist during the test.

(b) For vessels designed to NC-3200, the stress limits of NC-3218 shall be used in determining the maximum permissible pressure.

(c) When testing a system, the test pressure shall not exceed the maximum permissible test pressure of any component in the system.

NC-6223 Hydrostatic Test Pressure Holding Time

The hydrostatic test pressure shall be maintained a minimum of 10 min prior to initiation of the examination for leakage required by NC-6224.

NC-6224 Examination for Leakage After Application of Pressure

Following the application of the hydrostatic test pressure for the required time (NC-6223), all joints, connections, and regions of high stress such as regions around openings and thickness transition sections shall be examined for leakage. Except in the case of pumps and valves, which shall be examined while at test

pressure, this examination shall be made at a pressure equal to the greater of the Design Pressure or three-fourths of the test pressure, and it shall be witnessed by the Inspector. Leakage of temporary gaskets and seals, installed for the purpose of conducting the hydrostatic test, and which will be replaced later, may be permitted unless the leakage exceeds the capacity to maintain system test pressure for the required amount of time. Other leaks, such as from permanent seals, seats, and gasketed joints in components, may be permitted when specifically allowed by the Design Specifications. Leakage from temporary seals or leakage permitted by the Design Specification shall be directed away from the surface of the component to avoid masking leaks from other joints.

NC-6230 BELLOWS EXPANSION JOINTS

The hydrostatic test requirements for bellows expansion joints shall be as required in (a) through (c) below.

(a) The completed expansion joint shall be subjected to a hydrostatic test in accordance with the applicable provisions of this Article as supplemented by the Design Specifications.

(b) This test may be performed with the bellows fixed in the straight position, at its neutral length, when the design has been shown to comply with NC-3649.4(e)(1) or (e)(2). If the design is to comply with NC-3649.4(e)(3), this test shall be performed with the bellows fixed at the maximum design rotation angle or offset movement.

(c) In addition to inspecting the expansion joint for leaks and general structural integrity during the test, the Inspector shall also visually inspect the bellows for evidence of meridional yielding as defined in NC-3649.4(b) and for evidence of squirm as defined in NC-3649.4(c). If the design is to comply with NC-3649.4(e)(3), actual measurements shall be made before, during, and after the pressure test in accordance with NC-3649.4(b) and (c).

NC-6240 PROVISION FOR EMBEDDED OR INACCESSIBLE WELDED JOINTS IN PIPING

When welded joints in piping subassemblies or piping systems will be embedded or are otherwise inaccessible for inspection at the time of the system hydrostatic test, either of the following alternatives may be employed. Alternative (b) does not apply to brazed joints.

(a) The piping subassembly, or portion of the piping system which is to be embedded, or will be otherwise inaccessible, shall be hydrostatically tested at some point in the fabrication or installation prior to embedment or inaccessibility.

(b) Radiography shall be performed on all circumferential butt welds, and either magnetic particle or liquid penetrant examination shall be performed on all fillet or socket welds in accordance with the requirements of NC-5000. The longitudinal butt welds shall meet the requirements of NC-2000. The hydrostatic test may then be performed after embedment, using maintenance of pressure as the acceptance criterion for those welds only. The system shall be pressurized to the hydrostatic test pressure and then isolated from the pressurizing source for a period of 1 hr/in. of wall thickness but not less than 1 hr. During the test period, there shall be no drop in pressure.²

NC-6300 PNEUMATIC TESTS

NC-6310 PNEUMATIC TESTING PROCEDURES

NC-6311 General Requirements

When a pneumatic test is performed, it shall be conducted in accordance with the requirements of NC-6100 and this Subarticle.

NC-6312 Test Medium and Test Temperature

(a) The gas used as the test medium shall be nonflammable.

(b) Testing temperature shall be in accordance with NC-6212(b).

NC-6313 Procedure for Applying Pressure

The pressure in the system shall be gradually increased to not more than one-half of the test pressure, after which the

The pressure in the system shall be gradually increased to not more than one-half of the test pressure, after which the pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached.

2 Temperature fluctuations within the piping system may affect the pressure. Precautions must be taken to ensure that the test is not biased by temperature effects.

Page 307

NC-6320 PNEUMATIC TEST PRESSURE REQUIREMENTS

NC-6321 Minimum Required Pneumatic Test Pressure

(a) The installed system shall be pneumatically tested at not less than 1.25 times the lowest Design Pressure of any component within the boundary protected by the overpressure protection devices which satisfy the requirements of NC-7000.

(b) Valves shall be pneumatically tested in accordance with the rules of NC-3500.

(c) Components shall be pneumatically tested at not less than 1.25 times their Design Pressure.

NC-6322 Maximum Permissible Test Pressure

The maximum test pressure shall be limited as defined in NC-6222.

NC-6323 Test Pressure Holding Time

The test pressure of NC-6321 shall be maintained for a minimum total time of 10 min.

NC-6324 Examination for Leakage After Application of Pressure

Following the application of pressure for the time specified in NC-6323, the test pressure shall be reduced to a value equal to the greater of the Design Pressure or three-fourths of the test pressure, and held for a sufficient time to permit examination as defined in NC-6224.

NC-6330 BELLOWS EXPANSION JOINTS

When a pneumatic test is performed on a bellows expansion joint in lieu of a hydrostatic test, the requirements of NC-6230 shall be met.

NC-6400 PRESSURE TEST GAGES

NC-6410 REQUIREMENTS FOR PRESSURE TEST GAGES

NC-6411 Types of Gages to Be Used and Their Location

Pressure test gages used in pressure testing shall be indicating pressure gages and shall be connected directly to the component. If the indicating gage is not readily visible to the operator controlling the pressure applied, an additional indicating gage shall be provided where it will be visible to the operator throughout the duration of the test. For systems with a large volumetric content, it is recommended that a recording gage be used in addition to the indicating gage.

NC-6412 Range of Indicating Pressure Gages

(a) Analog-type indicating pressure gages used in testing shall be graduated over a range not less than $1\frac{1}{2}$ times nor more than 4 times the test pressure.

(b) Digital-type pressure gages may be used without range restriction provided the combined error due to calibration and readability does not exceed 1% of the test pressure.

NC-6413 Calibration of Pressure Test Gages

All test gages shall be calibrated against a standard dead-weight tester or a calibrated master gage. The test gages shall be calibrated before each test or series of tests. A series of tests is that group of tests, using the same pressure test gage or gages, which are conducted within a period not exceeding 2 weeks.

NC-6500 ATMOSPHERIC AND 0-15 psi STORAGE TANKS

NC-6510 TESTING OF ATMOSPHERIC STORAGE TANKS

NC-6511 Testing of Reinforcement Pads

Following the examination specified in NC-5282.5 and before filling the tank with test water, the reinforcement pads shall be tested by applying up to 15 psi pneumatic pressure between the tank shell and the reinforcement plate on each opening, using the telltale hole; and while each such space is subject to such pressure, soapsuds, linseed oil, or other suitable material for detection of leaks shall be applied to all attachment welding around reinforcement, both inside and outside the tank.

NC-6512 Preparation for Testing

Preparation for testing of storage tanks shall conform to the requirements of NC-6120, as applicable. Flat bottoms supported directly on grade need not comply with NC-6121.

Page 308

NC-6513 Hydrostatic Testing of Tank Shell

Upon completion of the tank, the shell shall be tested. For tanks with supported cone, self-supported cone, self-supported dome, and self-supported umbrella roofs, the tank shall be filled with water and inspected frequently during the filling operation. The filling height shall be 2 in. (51 mm) above the top leg of the angle. For tanks with flat roofs, the filling height shall be the liquid level for which the tank was designed or the bottom of any overflow which limits the filling height.

NC-6520 TESTING OF 0-15 psi STORAGE TANKS

NC-6521 Testing of Reinforcement Pads

Following the examination specified in NC-5282.5 and before performing the preliminary pneumatic testing, the reinforcement pads shall be tested by using the same procedure as given in NC-6511.

NC-6522 Preparation for Testing

Preparation for testing of storage tanks shall conform to the requirements of NC-6120, as applicable. Flat bottoms supported directly on grade need not comply with NC-6121.

NC-6523 Preliminary Pneumatic Testing

Prior to the application of the hydrostatic or combination hydrostatic pneumatic test, the tank shall be filled with air to a pressure of 2 psi (13.8 kPa) or one-half the pressure P_G for which the vapor space at the top of the tank is designed, whichever pressure is the smaller. Soapsuds shall be applied to all joints in the tank wall above the high liquid design level. If any leaks appear, the defective condition shall be corrected and the applicable preliminary tightness test shall be repeated. In the case of a tank whose bottom rests directly on the tank grade without having anchor bolts provided near the boundary of contact to hold it down, if the bottom at this boundary rises slightly off the foundation during the tightness test with air pressure in the tank, sand shall be tamped firmly under the bottom, while the tank is under pressure, to fill the gap so formed.

NC-6524 Combination Hydrostatic Pneumatic Tests

The following requirements apply to tanks which have not been designed to be filled with liquid to a test level higher than their specified capacity level.

NC-6524.1 Pressurizing.

After the preliminary tests specified in NC-6523 have been completed, the pressure relief valve or valves shall be blanked off. With the top of the tank vented to atmosphere to prevent accumulation of pressure, the tank shall be filled with water to its high liquid level. The vents at the top of the tank shall then be closed, and air shall be injected slowly into the top of the tank until the pressure in the vapor space is about one-half the pressure P_G for which this space is designed. Thereafter, the test pressure shall be increased in steps of approximately 2 psi (13.8 kPa) or one-fourth of the intended test pressure, whichever is the smaller, until the pressure in the vapor space is 1.25 times the pressure P_G for which this space is designed. Means shall be provided so that the required test pressure will not be exceeded.

NC-6524.2 Time at Pressure.

The pressure in the tank shall be held stationary for a reasonable time after the application of each increment of pressure as specified so as to provide an opportunity to examine the tank carefully for signs of distress. The maximum test pressure of 1.25 times the vapor space design pressure shall be held for at least 1 hr, after which the pressure shall be reduced slowly to the vapor space design pressure.

NC-6524.3 Soap Bubble Test.

The vapor space design pressure shall be held for a sufficient time to permit a close visual examination of all joints in the walls of the tank and of all welding around manways, nozzles, and other connections. In this examination, soapsuds shall be applied to all weld joints located above the high liquid design level for which the tank is designed, including the roof-to-sidewall joint. This examination is not required for welds subject to radiography.

NC-6524.4 Precautions to Be Employed in Pneumatic Testing.

An air test, as specified in NC-6523 and in NC-6524, introduces some hazard. In view of the large amount of air which will be present during such a test, it is recommended that no one be permitted to go near the tank while the pressure is being applied for the first time in this test. While the pressure in the tank exceeds the pressure for which the vapor space is designed, the inspections should be made from a

Page 309

reasonable distance from the tank using optical aids, if necessary, for observations of particular areas.

NC-6525 Hydrostatic Test

The following requirements apply to tanks which have been designed and constructed to be filled with liquid to the top of the roof.

NC-6525.1 Filling.

Following the preliminary tests specified in NC-6523, the pressure relief valve or valves shall be blanked off. With the top of the tank vented to atmosphere, the tank shall be filled with water to the top of the roof, while allowing all air to escape in order to prevent accumulation of pressure. The vents on the tank shall be closed, and the pressure in the tank shall be increased slowly until the hydrostatic pressure under the topmost point in the roof is 1.25 times the pressure P_G for which the vapor space is designed to withstand when in operation with the tank filled to its specified high liquid level.

NC-6525.2 Pressurizing.

Test pressure may be developed by (a) or (b) below:

(a) pumping water into the tank with all vents closed;

(b) superimposing a vertical pipe, not less than 6 in. nominal pipe size, above the top of the tank with an overflow located at such a height as to give the desired test pressure by static head alone and then filling the pipe to the level of said overflow.

NC-6525.3 Time at Pressure.

Test pressure shall be held for at least 1 hr. The hydrostatic pressure under the roof shall then be reduced to the Design Pressure and shall be held at this level for a sufficient time to permit close visual examination of all joints in the walls of the tank and of all welding around manways, nozzles, and other connections.

NC-6526 Partial Vacuum Testing Procedure

NC-6526.1 Development of Partial Vacuum for Which Tank Was Designed.

Following the tests specified in NC-6524 or in NC-6525, the pressure in the tank shall be released and a manometer shall be connected to the vapor space. The ability of that part of the tank to withstand the partial vacuum for which it is designed shall then be checked by withdrawing water from the tank or by air evacuation, with all vents closed, until the design partial vacuum is developed. Careful observations shall be made under the above condition of loading to determine whether any appreciable changes occur in the shape of the tank.

NC-6530 TEST GAGES

NC-6531 Indicating Gage and Its Location

An indicating gage shall be connected directly to the topmost part of the roof on the tank under test, except that, in the case of a tank which is designed for storage of gases or vapors alone and is to be tested only with air, this gage may be connected to the tank at some lower level. If the indicating gage is not readily visible to the operator controlling the pressure applied, an additional indicating gage shall be provided where it will be visible to the operator throughout the duration of the test. Means shall be provided so that the required test pressure will not be exceeded.

NC-6532 Recording Gage and Its Location

A recording gage shall also be used on each tank, and a record shall be kept of the pressures during all stages of the tests. This gage shall be connected either to the piping leading to the indicating gage or directly to the tank at a point near the indicating gage connection.

NC-6533 Accumulation of Static Head on Gages

In all cases in which a gage is mounted at a level lower than its connection to the tank or lower than some part of the piping leading to the gage, suitable precautions shall be taken to prevent accumulation of any static head of condensed moisture or water from other sources in the piping leads above the level of the gage.

NC-6534 Calibration of Pressure Test Gages

All test gages shall be calibrated against a standard dead weight tester or a calibrated master gage. The test gages shall be calibrated before each test or series of tests. A series of tests is that group of tests, using the same pressure test gage or gages, which are conducted within a period not exceeding two weeks.

NC-6600 SPECIAL TEST PRESSURE SITUATIONS

NC-6610 COMPONENTS DESIGNED FOR EXTERNAL PRESSURE

Components designed for external pressure only shall be subjected to an internal test pressure at 1.25 times the design external pressure. The pressure shall be

Page 310

under proper control so that the required test pressure is never exceeded by more than 6%.

NC-6620 PRESSURE TESTING OF COMBINATION UNITS

NC-6621 Pressure Chambers Designed to Operate Independently

Pressure chambers of combination units that have been designed to operate independently shall be pressure tested as separate vessels, that is, each chamber shall be tested without pressure in the adjacent chamber.

NC-6622 Common Elements Designed for a Maximum Differential Pressure

(a) When pressure chambers of combination units have their common elements designed for the maximum differential pressure that can occur during startup, operation, and shutdown, and the differential pressure is less than the higher of the Design Pressures of the adjacent chambers, the common elements shall be subjected to a pressure test of at least 1.25 times the maximum differential pressure.

(b) Following the test of the common elements, as required by NC-6622(a) and their inspection, the adjacent chambers shall be pressure tested (NC-6221). Care must be taken to limit the differential pressure between the chambers to the pressure used when testing the common elements.

NC-6900 PROOF TESTS TO ESTABLISH DESIGN PRESSURE

NC-6910 GENERAL REQUIREMENTS

NC-6911 Establishment by Test of Design Pressure

The Design Pressure for components, except those designed to NC-3200, and piping or component parts for which the strength cannot be computed with a satisfactory assurance of accuracy, shall be established in accordance with the requirements of this Subarticle, using one of the test procedures applicable to the type of loading and to the material used in construction.

NC-6911.1 Types of Proof Tests.

Provision is made in these rules for two types of tests to determine the internal Design Pressure:

(a) tests based on yielding of the part to be tested (these tests are limited to materials with a ratio of specified minimum yield to specified minimum ultimate strength of 0.625 or less);

(b) tests based on bursting of the part.

NC-6911.2 Purpose for Which Proof Tests May Be Used.

The tests in this Subarticle may be used only for the purpose of establishing the Design Pressure of those elements or component parts for which the thickness cannot be determined by means of the design rules given in this Subsection. The Design Pressure of all other elements or component parts shall not be greater than that determined by means of the applicable design rules.

NC-6911.3 Permissible Previous Pressurization of Component or Part.

The component or component part for which the Design Pressure is to be established shall not previously have been subjected to a pressure greater than $1\frac{1}{2}$ times the desired or anticipated Design Pressure, adjusted for Design Temperature as provided in NC-6911.9.

NC-6911.4 Test Requirements for Duplicate Components or Parts.

When the Design Pressure of a component or component part has been established by a proof test, duplicate parts of the same materials, design, and construction need not be proof tested but shall be given a hydrostatic test in accordance with NC-6200 or a pneumatic test in accordance with NC-6300. The dimensions and minimum thickness of the structure to be tested shall not vary materially from those actually used. A geometrically similar part may be qualified by a series of tests covering the complete size range of the pressure part.

NC-6911.5 Application of Pressure.

In the procedures given in NC-6921, NC-6923, and NC-6924, the hydrostatic pressure in the component or component

part shall be increased gradually until approximately one-half the anticipated Design Pressure is reached. Thereafter, the test pressure shall be increased in steps of approximately one-tenth or less of the anticipated Design Pressure until the pressure required by the test procedure is reached. The pressure shall be held stationary at the end of each increment for a sufficient time to allow the observations required by the test procedure to be made and shall be released to zero to permit determination of any permanent strain after any pressure increment that indicates an increase in strain or displacement over the previous equal pressure increment.

NC-6911.6 Check of Measurements.

As a check that the measurements are being taken on the most critical areas, the Inspector may require a lime wash

Page 311

or other brittle coating to be applied on all areas of probable high stress concentrations in the test procedures given in NC-6923 and NC-6924. The surfaces shall be suitably cleaned before the coating is applied in order to obtain satisfactory adhesion. The technique shall be suited to the coating material.

NC-6911.7 Determination of Design Pressure for Components or Parts Having Corrosion Allowance.

The test procedures in this Subarticle give the Design Pressure for the thickness of material tested. When the thickness as tested includes extra thickness as provided in NC-3121, the Design Pressure at which the component shall be permitted to operate shall be determined by multiplying the Design Pressure obtained from the test by the ratio

$$(t - c)/t$$

where

t = nominal thickness of the material at the weakest point, in.

c = allowance added for corrosion, erosion, and abrasion, in.

NC-6911.8 Determination of Yield Strength and Tensile Strength

(a) For proof tests based on yielding (NC-6921, NC-6923, or NC-6924), the yield strength (or yield point, for those materials which exhibit that type of yield behavior indicated by a "sharp-kneed" portion of the stress-strain diagram) of the material in the part tested shall be determined in accordance with the method prescribed in the applicable material specification and as described in ASTM E 8-1972. For proof tests based on bursting, NC-6922, the tensile strength instead of the yield strength of the material in the part tested shall be similarly determined.

(b) Yield or tensile strength so determined shall be the average from three or four specimens cut from the part tested after the test is completed. The specimens shall be cut from a location where the stress during the test has not exceeded the yield strength. The specimens shall not be flame cut because this might affect the strength of material. If yield or tensile strength is not determined by test specimens from the pressure part tested, alternative methods are given in NC-6921, NC-6922, NC-6923, and NC-6924 for evaluation of proof test results to establish the Design Pressure.

(c) When excess stock from the same piece of wrought material is available and has been given the same stress relieving heat treatment as the pressure part, the test specimens may be cut from this excess stock. The specimens shall not be removed by flame cutting or any other method involving sufficient heat to affect the properties of the specimen.

NC-6911.9 Design Pressure at Higher Temperatures.

The Design Pressure for components and component parts that are to operate at temperatures at which the allowable stress value of the material is less than at the test temperature shall be determined by the following formula:

$$P_o = P_t \left(\frac{S_o}{S_t} \right)$$

where

P_o	= Design Pressure at the Design Temperature, psig
P_t	= Design Pressure at test temperature, psig
S_o	= maximum allowable stress value at the Design Temperature, psi
S_t	= maximum allowable stress value at test temperature, psi

NC-6912 Retests

A retest shall be allowed on a duplicate component or component part if errors or irregularities are obvious in the test results.

NC-6913 Witnessing of Tests by Inspector

Tests to establish the Design Pressure of components or component parts shall be witnessed and approved by the Inspector.

NC-6914 Safety Precautions

Safety of testing personnel should be given serious consideration when conducting proof tests, and particular care should be taken during bursting tests in NC-6922.

NC-6920 PROCEDURES

NC-6921 Brittle Coating Test Procedure

(a) Subject to the limitations of NC-6911.1(a), this procedure may be used only for components and component parts under internal pressure, constructed of materials having a definitely determinable yield point. The component parts that require proof testing shall be coated with a lime wash or other brittle coating in accordance with NC-6911.6. Pressure shall be applied

in accordance with NC-6911.5. The parts being proof tested shall be examined between pressure increments for signs of yielding as evidenced by flaking of the brittle coating or by the appearance of strain lines. The application of pressure shall be stopped at the first sign of yielding or, if desired, at some lower pressure.

(b) The Design Pressure P in psig at test temperature for components or component parts tested under NC-6921 shall be computed as stipulated in (1) through (4) below:

(1) if the average yield strength is determined in accordance with NC-6911.8:

$$P = 0.5H \left(\frac{Y_s}{Y_a} \right)$$

(2) to eliminate the necessity of cutting tensile specimens and determining the actual yield strength of the material under test, one of the following formulas may be used to determine the Design Pressure:

(a) for carbon steel meeting an acceptable Specification in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1 with a specified minimum tensile strength of not over 70.0 ksi (480 MPa):

$$P = 0.5H \left(\frac{S}{S + 5000} \right) \quad (1)$$

(1)

(b) for any other acceptable material listed in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1:

$$(2) P = 0.4H$$

where

H = hydrostatic test pressure at which the test was stopped, psig

Y_s	= specified minimum yield strength, psi
Y_a	= actual average yield strength from test specimens, psi
S	= specified minimum tensile strength, psi

(3) when Eq. (1) or (2) is used, the material in the pressure part shall have no appreciable cold working or other treatment that would tend to raise the yield strength above the normal value;

(4) the Design Pressure at other temperatures shall be determined as provided in NC-6911.9.

NC-6922 Bursting Test Procedure

(a) This procedure may be used for components or component parts under internal pressure when constructed of any material permitted to be used under the rules of this Subsection. The Design Pressure of any component part proof tested by this method shall be established by a hydrostatic test to failure by rupture of a full size sample of such pressure part. The hydrostatic pressure at which rupture occurs shall be determined.

(b) The Design Pressure P in psig at test temperature for parts tested under NC-6922 shall be computed as stipulated in (1) through (3) below:

(1) parts constructed of materials other than cast materials:

$$P = \frac{B}{5} \times \frac{S}{S_{ave}}$$

or

$$P = \frac{D}{5} \times \frac{S}{S_{\max}} \quad (3)$$

(3)

(2) parts constructed of cast materials, except cast iron and cast nodular iron which are not permitted:

$$P = \frac{Bf}{5} \times \frac{S}{S_{\text{ave}}}$$

or

$$P = \frac{Bf}{5} \times \frac{S}{S_{\max}} \quad (4)$$

(4)

where

B	= bursting test pressure, psig
f	= casting quality factor
S	= specified minimum tensile strength, psi
S_{ave}	= average actual tensile strength of test specimens, psi
S_{max}	= maximum tensile strength of range of specification, psi

(3) the Design Pressure at other temperatures shall be determined as provided in NC-6911.9.

NC-6923 Strain Measurement Test Procedure

(a) Subject to limitations of NC-6911.1(a), this procedure may be used for components or component parts under internal pressure, constructed of any material permitted to be used under the rules of this Subsection. Strains shall be measured in the direction of the maximum stress at the most highly stressed parts (see NC-6911.6) by means of strain gages of any type capable

Page 313

of indicating strains to 0.00005 in./in. (0.005%). Pressure shall be applied as provided in NC-6911.5.

(b) After each increment of pressure has been applied, readings of the strain gages and the hydrostatic pressure shall be taken and recorded. The pressure shall be released and any permanent strain at each gage shall be determined after any pressure increment that indicates an increase in strain for this increment over the previous equal pressure increment. Only one application of each increment of pressure is required.

(c) Two curves of strain against test pressure shall be plotted for each gage line as the test progresses, one showing the strain under pressure and one showing the permanent strain when the pressure is removed. The test may be discontinued when the test pressure reaches the value H which will, by the formula, justify the desired Design Pressure but shall not exceed the pressure at which the plotted points for the most highly strained gage line reach the value given below for the material used:

- (1) 0.2% permanent strain for aluminum-base and nickel-base alloys;
- (2) 0.2% permanent strain for carbon low alloy and high alloy steels;
- (3) 0.5% strain under pressure for copper-base alloys.

(d) The Design Pressure P in psig at test temperature for parts tested under this paragraph, shall be computed as stipulated in (1) through (3) below:

(1) if the average yield strength is determined in accordance with NC-6911.8:

$$P = 0.5H \left(\frac{Y_s}{Y_a} \right) \quad (5)$$

(5)

(2) if the actual average yield strength is not determined by test specimens:

$$P = 0.4H \quad (6)$$

(6)

where

H	= hydrostatic test pressure at which the test was stopped in accordance with (c) above, psig
Y_s	= specified minimum yield strength, psi
Y_a	= actual average yield strength from test specimens, psi

(3) the Design Pressure at other temperatures shall be determined as provided in NC-6911.9.

NC-6924 Displacement Measurement Test Procedure

(a) Subject to the limitations of NC-6911.1(a), this procedure may be used only for components and component parts

under internal pressure, constructed of materials having a definitely determinable yield point. Displacement shall be measured at the most highly stressed parts (NC-6911.6) by means of measuring devices of any type capable of measuring to 0.001 in. (0.02 mm). The displacement may be measured between two diametrically opposed reference points in a symmetrical structure or between a reference point and a fixed base point. Pressure shall be applied as provided in NC-6911.5.

(b) After each increment of pressure has been applied, readings of the displacement and hydrostatic test pressure shall be taken and recorded. The pressure shall be released and any permanent displacement shall be determined after any pressure increment that indicates an increase in measured displacement for this increment over the previous equal pressure increment. Only one application of each increment is required. Care must be taken to ensure that the readings represent only displacements of the parts on which measurements are being made and do not include any slip of the measuring devices or any movement of the fixed base points or of the pressure part as a whole.

(c) Two curves of displacement against test pressure shall be plotted for each reference point as the test progresses, one showing the displacement under pressure and one showing the permanent displacement when the pressure is removed. The application of pressure shall be stopped when it is evident that the curve through the points representing displacement under pressure has deviated from a straight line.

(d) The pressure coincident with the proportional limit of the material shall be determined by noting the pressure at which the curve representing displacement under pressure deviates from a straight line. The pressure at the proportional limit may be checked from the curve of permanent displacement by locating the point where the permanent displacement begins to increase regularly with further increases in pressure. Permanent deformation at the beginning of the curve that results from the equalization of stresses and irregularities in the material may be disregarded.

(e) The Design Pressure P in psig at test temperature for parts tested under this paragraph shall be computed as stipulated in (1) through (4) below:

(1) if the average yield strength is determined in accordance with NC-6911.8:

Page 314

$$P = 0.5H \left(\frac{Y_s}{Y_a} \right) \quad (7)$$

(7)

(2) to eliminate the necessity of cutting tensile specimens and determining the actual yield strength of the material under test, Eq. (8) or (9) may be used to determine the Design Pressure:

(a) for carbon steel, meeting an acceptable specification in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1 with a specified minimum tensile strength of not over 70.0 ksi:

$$P = 0.5H \left(\frac{S}{S + 5000} \right) \quad (8)$$

(8)

(b) for any other acceptable material listed in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1:

$$(9) P = 0.4H$$

where

H	= hydrostatic test pressure coincident with the proportional limit of the weakest element of the component part test, psig
Y_s	= specified minimum yield strength, psi
Y_a	= actual average yield strength from test specimens, psi
S	= specified minimum tensile strength, psi

(3) when Eq. (8) or (9) is used, the material in the pressure part shall have had no appreciable cold working or other treatment that would tend to raise the yield strength above the normal value;

(4) the Design Pressure at other temperatures shall be determined as provided in NC-6911.9.

NC-6930 PROCEDURE FOR COMPONENTS HAVING CHAMBERS OF SPECIAL SHAPE SUBJECT TO COLLAPSE

(a) Pressure chambers of components, portions of which have a shape other than that of a complete circular cylinder or formed head, and, also, jackets of cylindrical vessels which extend over only a portion of the circumference, which are not fully staybolted as required by NC-3133 and NC-3329, shall withstand without excessive deformation a hydrostatic test of not less than 3 times the desired Design Pressure.

(b) The Design Pressure at other temperatures shall be determined as provided in NC-6911.9.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NC-7000

ARTICLE NC-7000 OVERPRESSURE PROTECTION

Page 315

Page 316

NC-7100 GENERAL REQUIREMENTS

NC-7110 SCOPE

(a) A system¹ shall be protected from the consequences arising from the application of conditions of pressure and coincident temperature that would cause either the Design Pressure or the Service Limits specified in the Design Specification to be exceeded.

(b) Pressure relief devices² are required when the operating conditions considered in the Overpressure Protection Report would cause the Service Limits specified in the Design Specification to be exceeded.

(c) Protection of components in the system from the effects of pressure increases of extremely short duration, such as water hammer resulting from the rapid closing of a valve, is beyond the scope of this Article. These effects shall be included in the Design Specification.

NC-7111 Definitions

(a) *Overpressure*, as used in this Article, can consist of either one of the following pressure changes:

(1) an increase in system fluid pressure resulting from thermal imbalances, excess pump flow, and other similar phenomena, capable of causing a system pressure increase of a sufficient duration to be compatible with the dynamic response characteristics of the pressure relief devices listed in this Article; or

¹ Wherever the word system appears in this Article, it refers to the component or group of components for which overpressure protection is provided as described in the Overpressure Protection Report.

² A pressure relief device is designed to open to prevent a rise of internal fluid pressure greater than a specified value, resulting from exposure to pressure transient conditions. It may also be designed to prevent excessive internal vacuum. It may be a pressure relief valve, a nonreclosing pressure relief device, or a vacuum relief valve.

(2) changes in differential pressure resulting from thermal imbalances, vapor condensation, and other similar phenomena, capable of causing an internal or external pressure increase of sufficient duration to be compatible with the dynamic response characteristics of the pressure relief devices listed in this Article.

(b) The basic definitions of pressure relief devices as specified in this Article are in accordance with ASME PTC 25 -1994, Pressure Relief Devices.

(c) *Primary pressure* is the pressure of the fluid at the inlet of the pressure relief device.

(d) *Secondary pressure* is that value of pressure existing in the passage between the actual discharge area and the outlet for which the discharge system of the pressure relief devices shall be designed.

NC-7120 INTEGRATED OVERPRESSURE PROTECTION

Overpressure protection of the system shall be provided by any of the following methods as an integrated overpressure protection:

(a) the use of pressure relief devices and associated pressure sensing elements;

(b) a design without pressure relief devices that does not exceed the Service Limits specified in the Design Specifications [NC-7110(b)].

NC-7130 VERIFICATION OF THE OPERATION OF RECLOSING PRESSURE RELIEF DEVICES

NC-7131 Construction

(a) Reclosing pressure relief devices shall be constructed so that potential impairment of the overpressure protection function from service exposure to fluids can be determined by test or examination.

(b) Reclosing pressure relief devices and their associated pressure sensing elements shall be so constructed that their correct operation can be demonstrated under service or test conditions, as may be required by regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

NC-7140 INSTALLATION

NC-7141 Pressure Relief Devices

- (a)* Pressure relief devices shall be as close as practicable to the major source of overpressure anticipated to arise within the system under the conditions summarized in the Overpressure Protection Report (NC-7200).
- (b)* The connection between a system and its pressure relief device shall have a minimum inside diameter equal to or greater than nominal inside diameter of the pressure relief device inlet. The opening in the connection shall be designed to provide direct and unobstructed flow between the system and the pressure relief device.
- (c)* The connection between a system and its safety valve shall be not longer than the face-to-face dimension of the corresponding tee fitting of the same dimension and pressure rating listed in ASME B16.5, ASME B16.9, or ASME B16.11. Alternatively, the connection shall not result in accumulative line losses greater than 2% of the relieving pressure.
- (d)* The connection between a system and its safety relief valve or relief valve shall not result in accumulated line losses greater than 3% of the relieving pressure.
- (e)* Safety, safety relief, and relief valves shall be installed in an upright position.
- (f)* The flow area of the discharge piping connected to a pressure relief device shall not be less than the flow area of the device outlets. Back pressure that may exist or develop shall not reduce the relieving capacity of the relieving device(s) below that required to protect the system; potential for flashing shall be considered.
- (g)* Valve installation not in accordance with (c), (d), (e), and (f) above may be used provided:
 - (1)* the NV Certificate Holder confirms that the valve design is satisfactory for the intended installation and satisfies the requirements of the valve Design Specification;
 - (2)* the valves are adjusted for acceptable performance and in conformance with the requirements of the valve Design Specification;
 - (3)* technical justification for the adequacy of the installation is provided in the Overpressure Protection Report, including verification that the requirements of (1) and (2) have been met.

NC-7142 Stop Valves

- (a)* No stop valve or other device shall be placed in such a location, relative to a pressure relief device, that it could reduce the overpressure protection below that required by the rules of this Article, unless such stop valves are constructed and installed with controls and interlocks so that the relieving capacity requirements of NC-7300 are met under all conditions of operation of both the system and the stop valves.
- (b)* Simple administrative control of stop valve position is not acceptable.
- (c)* Stop valves shall have independent and diverse interlocks to prevent valves from being closed during all conditions of system operation when the pressure relief device is needed to meet the requirements of NC-7300.
- (d)* Stop valves shall have independent and diverse interlocks to assure that the valves will automatically open and remain open during all conditions of system operation when the pressure relief device is needed to meet the requirements of NC-7300.
- (e)* Means shall be provided to permit verification of the operation of controls and interlocks.

NC-7143 Draining of Pressure Relief Devices

- (a)* A pressure relief device installation shall be fitted with a drain at its lowest point where liquid or residue can collect if such liquid or residue could interfere with proper relieving operation.
- (b)* If the design of a pressure relief device permits liquid or residue to collect on the discharge side of the disk and could interfere with proper relieving operation, the device shall be fitted with a drain to minimize the collection of liquid or

residue.

NC-7150 ACCEPTABLE PRESSURE RELIEF DEVICES

NC-7151 Pressure Relief Valves³

Pressure relief valves may be used in accordance with NC-7170 and NC-7500.

NC-7152 Vacuum Relief Valves

Vacuum relief valves may be used in accordance with NC-7170 and NC-7500.

NC-7153 Nonreclosing Pressure Relief Devices⁴

Nonreclosing pressure relief devices may be used in accordance with NC-7170 and NC-7600.

3 A pressure relief valve is a pressure relief device which is designed to reclose and prevent the further flow of fluid after normal conditions have been restored.

4 A nonreclosing pressure relief device is a pressure relief device designed to remain open after operation.

Page 323

NC-7160 UNACCEPTABLE PRESSURE RELIEF DEVICES

NC-7161 Deadweight Pressure Relief Valves

Deadweight valves shall not be used.

NC-7170 PERMITTED USE OF PRESSURE RELIEF DEVICES

NC-7171 Safety Valves⁵

Safety valves, meeting the requirements of NC-7510, may be used for:

- (a) steam service;
- (b) air and gas service.

NC-7172 Safety Relief Valves⁶

Safety relief valves, meeting the requirements of NC-7510, may be used for:

- (a) steam service;
- (b) air and gas service;
- (c) liquid service.

NC-7173 Relief Valves⁷

Relief valves, meeting the requirements of NC-7510, may be used for liquid service.

NC-7174 Pilot Operated Pressure Relief Valves⁸

Pilot operated pressure relief valves, meeting the requirements of NC-7520, may be used for:

- (a) steam service;
- (b) air and gas service, provided that the design is such that the main valve will open automatically at not over the set pressure and will not discharge its full rated capacity if some essential part of the actuator should fail;
- (c) liquid service.

5 A safety valve is a pressure relief valve actuated by inlet static pressure and characterized by rapid opening or pop action.

6 A safety relief valve is a pressure relief valve characterized by rapid opening or pop action, or by opening generally proportional to the increase in pressure over the opening pressure.

7 A relief valve is a pressure relief valve actuated by inlet static pressure and having a gradual lift generally proportional to the increase in pressure over the opening pressure.

8 A pilot operated pressure relief valve is a pressure relief valve in which the major relieving device is combined with and controlled by a self-actuated auxiliary pressure relief valve.

NC-7175 Power Actuated Pressure Relief Valves⁹

Power actuated pressure relief valves, meeting the requirements of NC-7530, may be used for:

(a) steam service;

(b) air and gas service, provided that the design is such that the main valve will open automatically at not over the set pressure and will not discharge its full rated capacity if some essential part of the pilot should fail;

(c) liquid service.

NC-7176 Safety Valves With Auxiliary Actuating Devices

Safety valves with auxiliary actuating devices, meeting the requirements of NC-7540, may be used for steam service.

NC-7177 Vacuum Relief Valves¹⁰

Vacuum relief valves, meeting the requirements of NC-7550, may be used for air and gas service.

NC-7178 Nonreclosing Devices

Rupture disk devices¹¹ may be used on air, gas, or steam service, except for main steam service, in accordance with NC-7600.

NC-7200 OVERPRESSURE PROTECTION REPORT

NC-7210 RESPONSIBILITY FOR REPORT

The provisions intended to meet the requirements of this Article shall be the subject of an Overpressure Protection Report prepared by the Owner or his Designee.

9 A power actuated pressure relief valve is a pressure relief valve in which the major relieving device is combined with and controlled by a device requiring an external source of energy.

10 A vacuum relief valve is a pressure relief device designed to admit fluid to prevent an excessive internal vacuum; it is designed to reclose and prevent further flow of fluid after normal conditions have been restored.

11 A rupture disk device is a nonreclosing pressure relief device actuated by inlet static pressure and designed to function by the bursting of a pressure containing disk.

Page 324

NC-7220 CONTENT OF REPORT

The Overpressure Protection Report shall define the protected systems and the integrated overpressure protection provided. As a minimum, the report shall include the following:

(a) identification of specific ASME Section III, Article NC-7000, Edition and Addenda and applicable Code Cases used in the design of the overpressure protection system;

(b) drawings showing arrangement of protected systems including the pressure relief devices;

(c) the analysis of the effect of the range of operating conditions, including the effect of discharge piping back pressure;

(d) an analysis of the conditions that give rise to the maximum pressure or vacuum relieving requirements, except when the basis for establishing relieving capacity is the loss of the heat sink of the protected system when the thermal input to the system is at a maximum;

- (e) the relief capacity required to prevent a pressure or vacuum rise in any component from exceeding the limitations of NC-7300;
- (f) the operating controls or safety controls of the protected system upon which the anticipated required relief capacity of (d) and the maximum pressure, vacuum, and temperature of (c) are predicted;
- (g) the redundancy and independence of the pressure relief devices and their associated pressure or vacuum sensors and controls employed to preclude a loss of overpressure protection in the event of a failure of any pressure relief device, sensing element, associated control, or external power sources;
- (h) the extent that an individual component can be isolated from the overall system overpressure protection and the analysis of the conditions under which additional individual overpressure protection is necessary;
- (i) the design secondary pressure including a justification of the value identified in the Design Specification for pressure relief devices;
- (j) the analysis of pressure transient conditions, including those associated with the response time of pressure or vacuum relief valves, taking into account the effect of liquid and two-phase flow;
- (k) consideration of set pressure and blowdown limitations, taking into account opening pressure tolerances and overpressure of the pressure relief device;
- (l) consideration of burst pressure tolerance and manufacturing design range of the rupture disk device;
- (m) verification that pressure relief devices are not required, if applicable. Verification shall include reference to each component's Design Report and applicable requirements in NC-3000 that demonstrate the calculated stress levels do not exceed the Service Limits specified in the component Design Specification for all system service loadings.

NC-7230 CERTIFICATION OF REPORT

The Report, after it has been reconciled with the requirements of this Article, shall be certified by one or more Registered Professional Engineers competent in the applicable field of design and qualified in accordance with the requirements of Appendix XXIII.

NC-7240 REVIEW OF REPORT AFTER INSTALLATION

- (a) Any modification of the installation from that used for the preparation of the Overpressure Protection Report shall be reconciled with the Overpressure Protection Report.
- (b) Modifications shall be documented in an addendum to the Overpressure Protection Report. The addendum shall contain a copy of the as-built drawing and shall include either:
- (1) a statement that the as-built system meets the requirements of the Overpressure Protection Report; or
 - (2) a revision to the Overpressure Protection Report to make it agree with the as-built system; or
 - (3) a description of the changes made to the as-built system to make it comply with the Overpressure Protection Report.
- (c) The addendum shall be certified by one or more Registered Professional Engineers competent in the applicable field of design and qualified in accordance with the requirements of Appendix XXIII.

NC-7250 FILING OF REPORT

A copy of the Overpressure Protection Report shall be filed at the nuclear power plant site prior to the Inspector signing the Owner's Data Report. The report shall be made available to the Authorized Inspector and the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

NC-7300 RELIEVING CAPACITY REQUIREMENTS

NC-7310 EXPECTED SYSTEM PRESSURE TRANSIENT CONDITIONS

[98]

NC-7311 Relieving Capacity of Pressure Relief Devices

(a) The total relieving capacity of the pressure relief devices (certified in accordance with NC-7700, intended for overpressure protection within the scope of this Subsection, and credited in conformance with NC-7500 or NC-7600) shall take into account any losses due to fluid flow through piping and other components.

(b) The total relieving capacity shall be sufficient to prevent a rise in pressure of more than 10% or 3 psi, whichever is greater, above the Design Pressure of any component within the pressure retaining boundary of the protected system under any expected system pressure transient conditions as summarized in the Overpressure Protection Report (NC-7200).

(c) The rated capacity of each vacuum relief valve shall not be less than that required to prevent a differential pressure in excess of the value specified in the Design Specification and in the Overpressure Protection Report.

[98]

NC-7312 Relieving Capacity of Pressure Relief Devices Used With Pressure Reducing Devices

When using pressure reducing devices, the combined relieving capacity of the pressure relief devices shall be sufficient to meet the requirements of NC-7311 when:

(a) pressure reducing devices and their bypass valves are fully open, and;

(b) all discharge paths are blocked on the low pressure side of the pressure reducing device.

NC-7313 Required Number and Capacity of Pressure Relief Devices

(a) The required relieving capacity for main steam and feedwater systems within the scope of this Subsection shall be provided by the use of at least two pressure relief devices.

12 Expected system pressure transient conditions are those associated with normal system transient operation.

(b) Other systems or components requiring individual protection may be served by one or more devices except when power actuated pressure relief valves are used, in which case at least two valves shall be used to contribute to the required relieving capacity.

(c) When more than one device is used, no device shall have a capacity less than 50% of the device with the largest capacity.

NC-7314 Required Number and Capacity of Pressure Relief Devices for Isolatable Components Requiring Overpressure Protection

The required relieving capacity for overpressure protection of an isolatable component shall be provided by the use of at least one pressure relief device meeting the requirements of NC-7500 or NC-7600.

NC-7315 Relieving Capacity of Vacuum Relief Valves

(a) The capacity of each vacuum relief valve shall not be less than that required to prevent a differential pressure in excess of the value specified in the Design Specification.

(b) At least two independent vacuum relief valves shall be provided on each system. The capacity of each vacuum relief valve shall not be less than that required to protect the system.

(c) Systems designed to withstand the maximum differential pressure do not require vacuum relief valves.

NC-7320 UNEXPECTED SYSTEM EXCESS PRESSURE TRANSIENT CONDITIONS¹³

[98]

NC-7321 Relieving Capacity of Pressure Relief Devices

(a) The total relieving capacity of the pressure relief devices (certified in accordance with NC-7700, intended for overpressure protection within the scope of this Subsection, and credited in conformance with NC-7500 or NC-7600) shall take into account any losses due to fluid flow through piping and other components.

13Unexpected system excess pressure transient conditions are those associated with unusual or abnormal system transients, but still considered to be within the design basis.

(b) The total relieving capacity shall be sufficient to prevent a rise in pressure of more than 10% or 3 psi, whichever is greater, above the Design Pressure of any component within the pressure retaining boundary of the protected system under each of the unexpected

Page 326

system excess pressure transient conditions specified in the Overpressure Protection Report.

[98]

NC-7322 Relieving Capacity of Vacuum Relief Valves

(a) The capacity of each vacuum relief valve shall not be less than that required to prevent a differential pressure in excess of the value specified in the Design Specification of the system being protected.

(b) At least two independent vacuum relief valves shall be provided on each system. The capacity of each vacuum relief valve shall not be less than that required to protect the system.

(c) Systems designed to withstand the maximum differential pressure do not require vacuum relief valves.

NC-7330 SYSTEM FAULTED CONDITIONS

This Article does not provide rules for overpressure protection of system faulted conditions.

NC-7400 SET PRESSURES OF PRESSURE RELIEF DEVICES

NC-7410 SET PRESSURE LIMITATIONS FOR EXPECTED SYSTEM PRESSURE TRANSIENT CONDITIONS

The stamped set pressure of at least one of the pressure relief devices connected to the system shall not be greater than the Design Pressure of any component within the pressure retaining boundary of the protected system. Additional pressure relief devices may have higher stamped set pressure settings, but in no case shall these set pressures be such that the total system pressure exceeds the system limitations specified in NC-7310.

NC-7420 SET PRESSURE LIMITATION FOR UNEXPECTED SYSTEM EXCESS PRESSURE TRANSIENT CONDITIONS

The establishment of the stamped set pressure shall take into account the requirements of NC-7320.

NC-7500 OPERATING AND DESIGN REQUIREMENTS FOR PRESSURE AND VACUUM RELIEF VALVES

NC-7510 SAFETY, SAFETY RELIEF, AND RELIEF VALVES

NC-7511 General Requirements

NC-7511.1 Spring Loaded Valves.

Valves shall open automatically by direct action of the fluid pressure as a result of forces acting against a spring.

NC-7511.2 Balanced Valves.

Balanced valves, whose operation is independent of back pressure, may be used if means are provided to verify the integrity of the balancing device.

[98]

NC-7511.3 Antisimmer-Type Valves.

Valves that are fitted with antisimmer devices that serve to raise the set pressure of the valve during normal operation of the system may be used, provided:

(a) the design is such that the valve opens automatically and discharges its certified capacity at 10% or 3 psi, whichever is greater, of the system design pressure in the event any item of the auxiliary loading device should fail;

(b) the operating signal and energy source provisions are such that the valve reverts to its normal set pressure in the event of any failure of signal or loss of energy source;

(c) the auxiliary loading force imposed on such valves does not raise the set pressure of the valve by more than 10% or 3 psi, whichever is greater;

(d) the auxiliary loading force which augments the force exerted by the valve spring is automatically unloaded at a pressure not greater than the set pressure of the valve.

[98]

NC-7512 Safety Valve Operating Requirements

NC-7512.1 Antichattering and Lift Requirements

(a) Safety valves shall be constructed to operate without chattering and to attain rated lift at a pressure which does not exceed the set pressure by more than 3% or 2 psi (13.8 kPa), whichever is greater.

(b) For valves used for main steam service, conformance with (a) above shall be established for each production valve by testing on steam at the stamped set pressure. The test shall take into account valve discharge piping back pressure as specified in the valve Design Specification.

Page 327

NC-7512.2 Set Pressure Tolerance

(a) The set pressure tolerance plus or minus shall not exceed the following: 2 psi (13.8 kPa) for pressures up to and including 70 psi (483 kPa), 3% for pressures over 70 psi (483 kPa) up to and including 300 psi (2070 kPa), 10 psi (69 kPa) for pressures over 300 psi (2070 kPa) up to and including 1000 psi (6900 kPa), and 1% for pressures over 1000 psi (6900 kPa). The set pressure tolerance shall apply unless a greater tolerance is established as permissible in the Overpressure Protection Report (NC-7200) and in the safety valve Design Specification (NCA-3250).

(b) Conformance with the requirements of (a) shall be established for each production valve by test. Steam valves shall be tested on steam.

NC-7512.3 Blowdown

(a) Safety valves shall be adjusted to close after blowing down to a pressure not lower than that specified in the valve Design Specification (NCA-3250) and the basis for the setting is covered in the Overpressure Protection Report (NC-7200).

(b) For valves used for main steam service, conformance with (a) shall be established for each production valve by testing on steam at the stamped set pressure. The test shall take into account valve discharge piping back pressure as specified in the valve Design Specification (NCA-3250).

(c) For valves used for other than main steam service, the adjustment shall be determined by test or proration from the Certificate Holder's blowdown test data.

NC-7513 Safety Relief and Relief Valve Operating Requirements

Safety relief and relief valves shall be constructed to attain rated lift at a pressure which does not exceed the set pressure

by more than 10% or 3 psi (20.6 kPa), whichever is greater.

NC-7513.1 Set Pressure Tolerance

(a) The set pressure tolerance plus or minus from the set pressure of safety relief and relief valves shall not exceed 2 psi (13.8 kPa) for pressures up to and including 70 psi and 3% for pressures above 70 psi (483 kPa).

The set pressure tolerance shall apply unless a greater tolerance is established as permissible in the Overpressure Protection Report (NC-7200) and in the valve Design Specification (NCA-3250).

(b) Conformance with the requirements of (a) shall be established for each production valve by test. Steam valves shall be tested on steam, air or gas valves on air or gas, and liquid valves on liquid.

NC-7513.2 Blowdown.

Safety relief and relief valves shall be adjusted to close after blowing down to a pressure not lower than that specified in the valve Design Specification (NCA-3250) and the basis for the setting shall be covered in the Overpressure Protection Report (NC-7200). The adjustment shall be determined by test or by proration from the Certificate Holder's blowdown test data.

NC-7514 Credited Relieving Capacity

The credited relieving capacity of safety, safety relief, and relief valves shall be based on the certified relieving capacity. In addition, the capacity can be prorated as permitted by NC-7700.

NC-7515 Sealing of Adjustments

Means shall be provided in the design of all valves for sealing all adjustments or access to adjustments which can be made without disassembly of the valve. For a pilot operated pressure relief valve, an additional seal shall be provided to seal the pilot and main valve together. Seals shall be installed by the Certificate Holder at the time of initial adjustment. Seals shall be installed in a manner to prevent changing the adjustment or disassembly of the valve without breaking the seal. The seal shall serve as a means of identifying the Certificate Holder making the initial adjustment.

NC-7520 PILOT OPERATED PRESSURE RELIEF VALVES

NC-7521 General Requirements

Pilot operated pressure relief valves shall operate independently of any external energy source.

NC-7522 Operating Requirements

NC-7522.1 Actuation.

The pilot control device shall be actuated directly by the fluid pressure of the protected system.

NC-7522.2 Response Time.

The Overpressure Protection Report (NC-7200) shall include the effects of divergence between opening (set) and closing (blowdown) pressures of the pilot valve and the pressures at which the main valve attains rated lift and closes. These divergences are caused by the inherent time delay (e.g., response time) between the operation of the pilot and the main valve, and the rate of the system

Page 328

pressure change. The limits for response time shall be specified in the Design Specification (NCA-3250).

NC-7522.3 Main Valve Operation.

The main valve shall operate in direct response to the pilot control device. The valve shall be constructed to attain rated lift under stable conditions at pressures which do not exceed the set pressure by more than 3% or 2 psi (13.8 kPa),

whichever is greater, for steam, and 10% or 3 psi (20.6 kPa), whichever is greater, for air, gas, or liquid service.

NC-7522.4 Sensing Mechanism Integrity.

For other than spring loaded direct acting pilot control devices, means shall be provided to detect failure of the pressure sensing element, such as bellows, when operation of the pilot control device is dependent upon the integrity of a pressure sensing element.

NC-7522.5 Set Pressure Tolerance

- (a) The set pressure tolerance shall apply only to the pilot valve.
- (b) The set pressure tolerance plus or minus shall not exceed the following:
 - (1) 2 psi (13.8 kPa) for pressures up to and including 70 psi (483 kPa);
 - (2) 3% for pressures over 70 psi (483 kPa) up to and including 300 psi (2070 kPa);
 - (3) 10 psi (69 kPa) for pressures over 300 psi (2070 kPa) up to and including 1000 psi (6900 kPa); and
 - (4) 1% for pressures over 1000 psi for steam, air, and gas valves.

The set pressure tolerance as stated shall apply unless a greater tolerance is established as permissible in the Overpressure Protection Report (NC-7200) and the valve Design Specification.

(c) Conformance with the requirements of (b) above shall be established for each production valve by test. Steam valves shall be tested on steam, air or gas valves on air or gas, and liquid valves on liquid.

NC-7522.6 Blowdown

- (a) The blowdown requirements shall only apply to the pilot valve.
- (b) Pilot valves shall be adjusted to close after blowing down to a pressure not lower than that specified in the valve Design Specification (NCA-3250) and the basis for the setting is covered in the Overpressure Protection Report (NC-7200).
- (c) The adjustment shall be determined by test or by proration from the Certificate Holder's blowdown test data.

NC-7523 Credited Relieving Capacity

Except as required in NC-7523.1 and NC-7523.2, the credited relieving capacity of pilot operated pressure relief valves shall be based on the certified relieving capacity. In addition, the capacity may be prorated as permitted in NC-7700.

NC-7523.1 System Upset Conditions.

For system upset conditions in main steam service, the relieving capacity with which these values are credited shall be not more than:

- (a) the stamped relieving capacity of the smaller one when two valves are installed;
- (b) the stamped relieving capacity of the smaller two where three valves are installed;
- (c) three-fourths of the total stamped relieving capacity where more than three valves are installed.

NC-7523.2 System Emergency Conditions.

For system emergency conditions in main steam service, the relieving capacity with which these valves are credited shall be not more than:

- (a) the relieving capacity of the valve with smaller stamped capacity where two valves are installed;
- (b) the relieving capacity of all except the valve with the largest stamped capacity where more than two valves are

installed.

NC-7524 Sealing of Adjustments

The sealing requirements of NC-7515 shall apply.

NC-7530 POWER ACTUATED PRESSURE RELIEF VALVES

NC-7531 General Requirements

Power actuated pressure relief valves, which depend upon an external energy source such as electrical, pneumatic, or hydraulic systems and which respond to signals from pressure or temperature sensing devices, may be used, provided the requirements of this Subsubarticle are met.

NC-7532 Operating Requirements

NC-7532.1 Response Time.

In systems protected by power operated pressure relief valves, consideration shall be given to the time lapse between the signal to open and achieving the fully opened position, and the time lapse between the signal to close and achieving the fully closed position.

Page 329

NC-7532.2 Sensors, Controls, and External Energy Sources

(a) The sensors, controls, and external energy sources for valve operation shall have redundancy and independence at least equal to that required for the control and safety protection systems associated with the system.

(b) The relief valve and its auxiliary devices treated as a combination shall comply with the following requirements.

(1) The valve opening pressure shall be controlled within a tolerance of $\pm 1\%$ of the set pressure when the automatic control is in use.

(2) The valve blowdown shall be controlled to a pressure not lower than that specified in the valve Design Specification (NCA-3250).

NC-7533 Certified Relieving Capacity

The power actuated pressure relief valve certified relieving capacity and the proration of capacity shall be as determined by NC-7700.

NC-7534 Credited Relieving Capacity

NC-7534.1 Expected System Pressure Transient Conditions.

For expected system pressure transient conditions, the relieving capacity with which these valves are credited shall be not more than:

(a) the certified relieving capacity of the smaller one when two valves are installed;

(b) one-half of the total certified relieving capacity when three or more valves are installed.

NC-7534.2 Unexpected System Excess Pressure Transient Conditions.

For unexpected system excess pressure transient conditions, the relieving capacity with which these valves are credited shall not be more than:

(a) the relieving capacity of the valve with the smaller stamped capacity where two valves are installed;

(b) the relieving capacity of all except the valve with the largest certified capacity for valves where three through ten

valves are installed;

(c) the relieving capacity of all except two valves of the largest certified capacity where more than ten valves are installed.

NC-7540 SAFETY VALVES WITH AUXILIARY ACTUATING DEVICES

NC-7541 General Requirements

Safety valves with auxiliary actuating devices which operate independently of the spring loading of the valve may be used, provided the requirements of NC-7510 are met except as modified by this Subsubarticle.

NC-7542 Construction

(a) The construction shall be such that the valve opens automatically by direct action of the fluid at a pressure not higher than the safety valve set pressure and relieves at the relieving capacity in the event of failure of any essential part of the valve's auxiliary devices.

(b) The construction of the auxiliary actuating device shall be such that the safety valve will not be prevented from operating as defined in NC-7510 when the auxiliary actuating device is deenergized.

NC-7543 Expected System Pressure Transient Conditions

For expected system pressure transient conditions, credit for capacity (NC-7546) can be taken for valves opening at the setpoint of the auxiliary actuating device in accordance with (a) and (b) below.

(a) When two valves are installed, the valve of the smaller certified capacity is credited with opening at the setpoint of the auxiliary actuating device. The valve with the larger certified capacity is credited with opening at the safety valve set pressure.

(b) For groups of more than two valves all of the same certified capacity, half the valves in a group containing an even number of valves, or the number of valves in the group minus one and divided by two for a group containing an odd number of valves, are credited with opening at the setpoint of the auxiliary actuating device.

NC-7544 Unexpected System Excess Pressure Transient Conditions

For unexpected system excess pressure transient conditions, credit for capacity may be taken for valves opening at the setpoint of the auxiliary actuating device in accordance with the following.

(a) When two valves are installed, the valve with the smaller certified capacity may be credited with opening at the setpoint of the auxiliary actuating device. The valve with the larger certified capacity shall be credited with opening at the safety valve set pressure.

(b) When three through ten valves are installed, credit may be given for opening at the setpoint of the auxiliary actuating device for all valves except the one with the largest certified capacity. The valve assumed not to open at the setpoint of the auxiliary actuating device

Page 330

shall be credited with opening at the safety valve set pressure.

(c) When more than ten valves are installed, credit may be given for opening at the setpoint of the auxiliary actuating device for all valves except for two of the largest certified capacity. The two valves assumed not to open at the setpoint of the auxiliary actuating device shall be credited with opening at the safety valve set pressure.

NC-7545 Auxiliary Device Sensors and Controls

The sensors, controls, and external energy sources for the auxiliary actuating device shall comply with the requirements of NC-7530.

NC-7546 Certified Relieving Capacity

The certified relieving capacity and proration of capacity for safety valves with auxiliary actuating devices shall be determined by NC-7700.

NC-7547 Credited Relieving Capacity

The relieving capacities with which these valves are credited shall be:

(a) for valves credited with opening at the auxiliary actuating device setpoint, the capacity at the lower relieving pressure as determined by the rules of NC-7700 (this shall specifically include the 90% of average tested capacity inherent in the Code Certification procedure);

(b) for valves credited with opening at the safety valve set pressure, the stamped capacity as determined by the rules of NC-7700.

NC-7548 Response Time

For valves credited with opening at the auxiliary actuating device setpoint, consideration shall be given to the time delay between the signal to open and achieving the fully opened position and the time delay between the signal to close and achieving the fully closed position.

NC-7550 VACUUM RELIEF VALVES

NC-7551 General Requirements

Vacuum relief valves shall meet the construction requirements applicable to Class 2 valves and the additional requirements of this Article.

NC-7552 Types Permitted

(a) Balanced self-actuating horizontally installed swinging disk valves are permitted.

(b) Vertically installed vacuum disk or pallet-type valves are permitted.

(c) All vacuum relief valves shall have provisions for adjustment of the differential pressure.

NC-7553 Operating Requirements

Vacuum relief valves, which are operated by indirect means depending on an external energy source, such as electrical, pneumatic, or hydraulic systems, are not acceptable unless at least two independent external power-operated valves and control systems are employed so that the required relieving capacity is obtained if any one of the valves or systems should fail to operate.

NC-7600 NONRECLOSING PRESSURE RELIEF DEVICES

NC-7610 RUPTURE DISK DEVICES

NC-7611 General Requirements

Rupture disk devices certified in accordance with NC-7720 and NC-7750 are subject to the following:

(a) rupture disk devices may be used as the sole pressure relief devices, except for main steam or liquid service (NC-7625);

(b) rupture disk devices may be used on the inlet side of pressure relief valves only when such valves are of the full bore¹⁴ type (NC-7623);

(c) rupture disk devices may be used in conjunction with pressure relief valves on the outlet side (NC-7624).

¹⁴ A pressure relief valve which has no protrusions in the bore and wherein the valve disk lifts to an extent sufficient for the minimum area, at any section at or below the body seat, to become the

NC-7612 Burst Pressure Tolerance

The burst pressure tolerance at the specified disk temperature¹⁵ shall not exceed ± 2 psi for stamped burst pressure up to and including 40 psi and $\pm 5\%$ for stamped burst pressure above 40 psi as established by the rules of NC-7613, unless other values have

Page 331

been established in the Design Specification and are covered in the Overpressure Protection Report.

NC-7613 Tests to Establish Stamped Burst Pressure

(a) Every rupture disk shall have a stamped burst pressure established by rules of NC-7612 within a manufacturing design range,¹⁶ at a specified disk temperature, and shall be stamped with a lot number.

(b) Each lot of rupture disks¹⁷ shall be tested in accordance with one of the following methods. All tests of disks for a given lot shall be made in a holder of the same form and pressure area dimensions as that being used in service.

(1) At least two sample rupture disks from each lot of rupture disks shall be burst at the specified disk temperature. The stamped burst pressure shall be determined so that the sample rupture disk burst pressures are within the tolerance specified by NC-7612.

(2) At least four sample rupture disks, but not less than 5% from each lot of rupture disks, shall be burst at four different temperatures distributed over the applicable temperature range for which the disks will be used. These data shall be used to establish a smooth curve of burst pressure vs. temperature for the lot of disks. The burst pressure for each data point shall not deviate from the curve more than the burst pressure tolerance specified in NC-7612.

The value for the stamped burst pressure shall be established from the curve for a specified disk temperature.

(3) For prebulged solid metal disks or graphite disks only, at least four sample rupture disks using one size of disk from each lot of material shall be burst at four different temperatures, distributed over the applicable temperature range for which this material will be used. These data shall be used to establish a smooth curve of burst pressure vs. temperature for the lot of material. The burst pressure for each data point shall not deviate from the curve more than the burst pressure tolerance specified in NC-7612.

16 The manufacturing design range is a range of pressure within which the stamped burst pressure must fall. This range is included in the Design Specification and the Overpressure Protection Report.

17 A lot of rupture disks is those disks manufactured of material at one time, of the same size, thickness, type, heat, and manufacturing process including heat treatment.

At least two disks from each lot of disks, made from this lot of material and of the same size as those to be used, shall be burst at the ambient temperature to establish the room rating of the lot of disks. The curve shall be used to establish the stamped rating at the specified disk temperature for the lot of disks.

NC-7614 Burst Pressure in Relation to Pressure Relief Valve Set Pressure

The burst pressure of a rupture disk may be either lower or higher than the set pressure of the associated pressure relief valve, but in no case shall the rupture disk burst pressure and valve set pressure be such that the total accumulated pressure during full capacity relief exceeds the permitted limit (NC-7400).

NC-7620 INSTALLATION REQUIREMENTS

NC-7621 Provisions for Venting or Draining

When a rupture disk is used in conjunction with a pressure relief valve, the space between the rupture disk and the associated pressure relief valve shall be vented and/or drained. This space shall be provided with means to monitor its internal pressure during service periods.

NC-7622 System Obstructions

When the release of rupture disk material may occur, piping and other components downstream of the rupture disk shall be constructed such that no obstruction can be caused nor the function of a pressure relief valve impaired.

NC-7623 Rupture Disk Devices at the Inlet Side of Pressure Relief Valves

A rupture disk device may be installed at the inlet side of a pressure relief valve if the following provisions are met:

- (a) the combination of the pressure relief valve and the rupture disk device capacity shall meet the requirements of NC-7300;
- (b) the stamped burst pressure at the specified disk temperature of the rupture disk does not exceed the limits of NC-7400 ;
- (c) the opening provided through the rupture disk after burst is sufficient to permit a flow equal to the capacity of the valve, and there is no chance of interference with proper functioning of the valve; but in no case shall this area be less than the area of the inlet of the valve unless the capacity and functioning of the specific combination of rupture disk and valve have been established by test in accordance with NC-7700.

Page 332

NC-7624 Rupture Disk Devices at the Outlet Side of Pressure Relief Valves

A rupture disk device may be installed at the outlet side of pressure relief valves if the following provisions are met:

- (a) the set pressure of the valve is independent of back pressure; or for unbalanced valves the set pressure of the valve plus the stamped burst pressure of the rupture disk plus any pressure in the outlet piping does not exceed the limits of NC-7400;
- (b) the relieving capacity meets the requirements of NC-7300;
- (c) the stamped burst pressure of the rupture disk at the specified disk temperature plus any pressure in the outlet piping from the rupture disk device shall not exceed the secondary Design Pressure of the pressure relief valve and the Design Pressure of any pipe or fittings between the valve and the rupture disk device. However, in no case shall the stamped burst pressure of the rupture disk at the operating temperature plus any pressure in the outlet piping from the rupture disk device exceed the limits of NC-7400;
- (d) the opening provided through the rupture disk device after burst is sufficient for the pressure relief valve to flow its certified capacity.

NC-7625 Rupture Disk Devices Used as Sole Pressure Relief Device

Rupture disk devices may be used as the sole pressure relief device if the following provisions are met:

- (a) at least two rupture disk devices are used in series as the sole pressure relief device for services where release of the contents of the protected system is acceptable to the enforcement authorities having jurisdiction at the nuclear power plant site;
- (b) the rupture disk device is sized to meet the requirements of NC-7300;
- (c) the stamped burst pressure at the specified temperature of the rupture disk does not exceed the limits of NC-7400;
- (d) the space between the two rupture disk devices is monitored for pressure buildup, and a means of draining and/or venting is provided to check for rupture disk leakage or burst¹⁸
- (e) the distance between the rupture disks is designed so that the first disk will not contact the second disk at rupture.

¹⁸ Rupture disks will not burst at Design Pressure if back pressure builds up in the space between the two rupture disks. This will occur should leakage develop in the rupture disk due to corrosion or other causes.

NC-7700 CERTIFICATION

NC-7710 RESPONSIBILITY FOR CERTIFICATION OF PRESSURE AND VACUUM RELIEF VALVES

(a) The Certificate Holder shall be responsible for having the relieving capacity of his valves certified as prescribed in this Subarticle.

(b) Capacity certification which is obtained in compliance with other Subsections and which complies with this Subsection may be considered as qualified for capacity certification under the rules of this Subsection, and the valve may be stamped with the appropriate symbol of this Subsection.

NC-7720 RESPONSIBILITY FOR CERTIFICATION OF NONRECLOSING PRESSURE RELIEF DEVICES

When rupture disk devices are used at the inlet of pressure relief valves, the manufacturer of the rupture disk devices or Certificate Holder shall be responsible for having the relieving capacity of the combination determined.

NC-7730 CAPACITY CERTIFICATION OF PRESSURE RELIEF VALVES - COMPRESSIBLE FLUIDS

NC-7731 General Requirements

NC-7731.1 Capacity Certification.

Capacity certification procedures shall be as required in NC-7732 through NC-7737.

NC-7731.2 Test Media

(a) Capacity certification tests of pressure relief valves for steam service shall be conducted with dry saturated steam. For test purposes, the limits of 98% minimum quality and 20°F maximum superheat shall apply. Capacity shall be corrected to the dry saturated condition from within these limits.

(b) Capacity certification tests for pressure relief valves for air and gas service shall be conducted with air, gas, or dry saturated steam.

[98]

NC-7731.3 Test Pressure

(a) Capacity certification tests of pressure relief valves for main steam service shall be conducted at a pressure which does not exceed the set pressure by more than 3% or 2 psi (13.8 kPa), whichever is greater.

Page 333

(b) Capacity certification tests of pressure relief valves with set pressures of 15 psig and higher for air, gas, or steam service other than main steam service shall be conducted at a pressure which does not exceed the set pressure by more than 10% or 3 psi, whichever is greater.

(c) Capacity certification tests for air or gas service with set pressures of 3 psig up to but not including 15 psig shall be conducted in accordance with the requirements of NC-7731 through NC-7734. When tests are performed in accordance with NC-7734, the capacity shall be determined at no more than 2 psi above the actual set pressure.

[98]

[98]

NC-7731.4 Blowdown

(a) Valves set at or above 15 psig, having an adjustable blowdown construction, shall be adjusted prior to capacity certification testing so that the blowdown does not exceed 5% of the set pressure.

(b) Valves set below 15 psig, having adjustable blowdown construction, shall be adjusted prior to capacity certification testing so that blowdown does not exceed 3 psi and shall not be less than 0.5 psi.

[98]

NC-7731.5 Drawings.

Prior to capacity certification tests, the Certificate Holder shall submit drawings showing the valve construction to the Authorized Observer. The Authorized Observer shall submit the drawings and all test results to the ASME designee for review and acceptance.

NC-7731.6 Design Changes.

When changes are made in the design of a pressure relief valve which affect the flow path, lift, or performance characteristics, new tests shall be performed in accordance with this Subarticle.

NC-7732 Flow Model Test Method - Pilot or Power Operated Valves

NC-7732.1 Flow Capacity.

When test facility limitations make it impossible to perform capacity tests of the full-scale pressure relief valves, flow models of three different sizes may be utilized as a basis for capacity certification. Such flow models shall be sized consistent with the capabilities of the accepted test laboratory where the tests will be conducted and shall accurately model those features, such as orifice size, valve lift, and internal flow configuration, which affect flow capacity. The test models need not be functional pressure relief valves, provided that other tests are conducted to demonstrate proper function of the valve design as prescribed in NC-7732.2. The relieving capacity of valve designs certified by use of flow models shall be established by the coefficient of discharge method similar to that outlined in NC-7734. The certified relieving capacity of all sizes and pressures of a given design for which the value of K has been established, based on flow model tests in accordance with the method of NC-7734, shall not exceed the value calculated by the appropriate formula in NC-7734.2 multiplied by the coefficient K .

NC-7732.2 Demonstration of Function.

The function of three valves of the design to be certified shall be demonstrated by tests. Such tests may be performed in conjunction with the capacity certification tests outlined above or as separate tests using production valves. The purpose of these tests is to demonstrate to the satisfaction of an ASME designee that the valve will open at set pressure within the required opening pressure tolerance, will achieve full lift, and will reclose within required blowdown. If required by test facility limitations, these tests may be conducted at reduced flow capabilities. Measurement of valve blowdown may not be possible.

[98]

NC-7733 Slope Method

(a) For pressure relief valves of a specific design, four valves of each combination inlet size and orifice size shall be tested. These four valves shall be set at pressures that will cover the appropriate range of pressures for which the valves are to be used or within the range of the authorized test facility.

(b) The instantaneous slope of each test point shall be calculated and averaged, where slope is defined as follows.

(1) For valves with set pressures of 15 psig and greater, slope is defined as the measured capacity divided by the absolute inlet pressure.

(2) For valves with set pressures of 3 psig up to but not including 15 psig, slope is defined as the measured capacity divided by the quantity,

$$F[(P)(P - P_o)]^{1/2}$$

where

$$F = \sqrt{\left(\frac{k}{k-1}\right) (r^{2/k}) \left[\frac{1 - (r)^{\frac{k-1}{k}}}{1-r} \right]}$$

P = inlet pressure, psi

P_o = discharge pressure, psi

Page 334

k = ratio of specific heats, C_v/C_p

r = pressure ratio, P_o/P

(c) If any of the experimentally determined slopes fall outside of a range of $\pm 5\%$ of the average slope, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average slope shall be determined, excluding the replaced valve test results. If any individual slope is now outside of the $\pm 5\%$ range, then the tests shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design.

(d) For valves with set pressures of 15 psig and greater, the certified capacity shall be 90% of the average slope multiplied by the flow rating pressure, psia.

(e) For valves with set pressures of 3 psig up to but not including 15 psig, the certified capacity shall be 90% of the average slope multiplied by the quantity,

$$F[(P)(P - P_o)]^{1/2}$$

(f) In addition, demonstration of function tests shall be conducted as prescribed in NC-7732.2.
[98]

NC-7734 Coefficient of Discharge Method

A coefficient K may be established for a specific pressure relief valve design according to the procedure given in the following subparagraphs.

NC-7734.1 Number of Valves to Be Tested.

For each design, at least three valves for each of three different sizes shall be submitted for test. Each valve of a given size shall be set at a different pressure.

size shall be set at a different pressure.

[98]

NC-7734.2 Establishment of Coefficient of Discharge

(a) Tests shall be made on each pressure relief valve to determine its lift, opening and blowdown pressures, and capacity in terms of the fluid used in the test. A coefficient of discharge K_D shall be established for each test run as follows:

$$K_D = \frac{\text{Actual Flow}}{\text{Theoretical Flow}} = \text{Coefficient of Discharge}$$

where Actual Flow is determined quantitatively by test, and Theoretical Flow is calculated by the following formula.

(1) For valves with set pressures of 15 psig and greater. For test with dry saturated steam:

$$W_T = 51.5AP$$

For pressures over 1500 psig (10 MPa) and up to 3200 psig (20 MPa), the value of W_T calculated by the above equation, shall be corrected by being multiplied by the following factor:

$$\frac{(0.1906P - 1000)}{(0.2292P - 1061)}$$

For test with air:

$$W_T = 356AP\sqrt{M/T}$$

For test with gas:

$$W_T = CAP\sqrt{M/ZT}$$

where

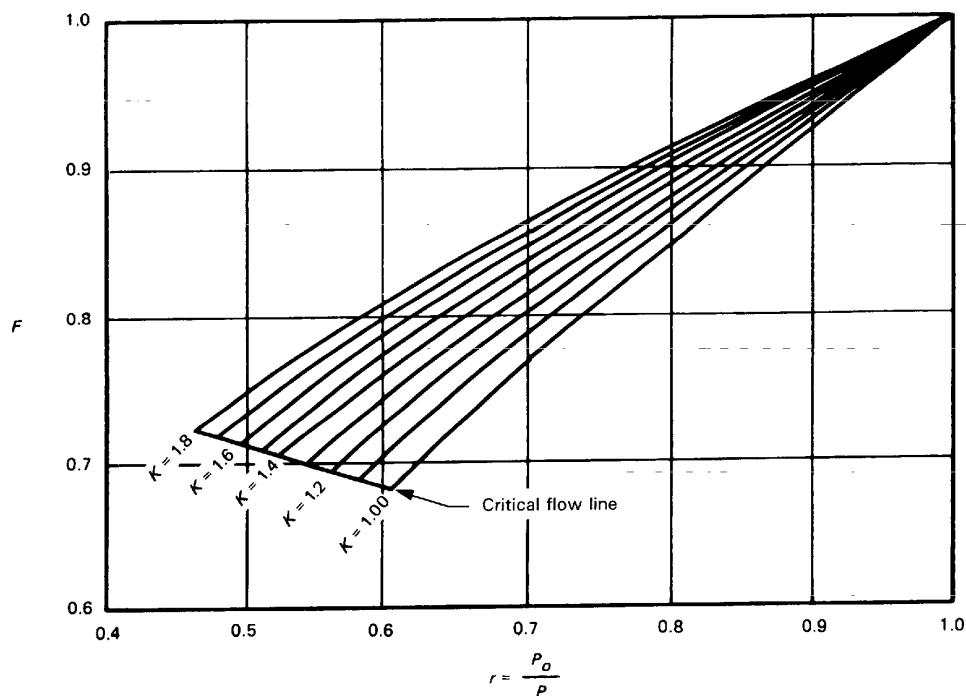
W_T	= Theoretical Flow, lb/hr
C	= constant for gas or vapor which is a function of the ratio of specific heats, k
k	= C_p/C_v , ratio of specific heats (see Fig. XVIII-1110-1)
A	= actual discharge area through the valve at developed lift, sq in.
P	= (set pressure $\times$ 1.03) plus atmospheric pressure, psia, or set pressure plus 2 psi plus atmospheric pressure, whichever is greater, for test pressures determined by NC-7731.3(a) = (set pressure $\times$ 1.10) plus atmospheric pressure, psia, or set pressure plus 3 psi plus atmospheric pressure, whichever is greater, for test pressures determined by NC-7731.3(b)
M	= molecular weight
T	= absolute temperature at inlet, $^{\circ}\text{F} + 460$
Z	= compressibility factor corresponding to P and T

The average of the coefficients of discharge K_D of the tests required shall be multiplied by 0.90, and their product shall be taken as the coefficient K of that design. The coefficient of the design shall not be greater than 0.876 (the product of 0.9×0.975).

(2) For valves with set pressures of 3 psig up to but not including 15 psig. The following formula may be used for other than saturated steam flow:

$$W = 735FA \left[\frac{MP(P - P_o)}{T} \right]^{1/2}$$

$$Q = 279,000FA \left[\frac{P(P - P_o)}{MT} \right]^{1/2}$$



[98]

FIG. NC-7734.2(a)-1 VALUES OF F FOR NONCHOKING FLOW

where

$$F = \sqrt{\left(\frac{k}{k-1}\right) (r^{2/k}) \left[\frac{1 - (r)^{\frac{k-1}{k}}}{1-r} \right]}$$

or is obtained from Fig. NC-7754.2(a)-1.

A	= flow area, sq in.
M	= molecular weight
P	= inlet pressure, psi
P_o	= discharge pressure, psi
T	= temperature, deg. Rankin
k	= ratio of specific heats, c_p/c_v
r	= pressure ratio, P_o/P
Q	= cu ft/hr at 14.7 psi and 60°F
W	= lb/hr

The average of the coefficients of discharge K_d of the tests required shall be multiplied by 0.90 and their product shall be the coefficient K of that design. The coefficient of the design shall not be greater than 0.876 (the product of 0.90×0.975).

(b) If any of the experimentally determined coefficients fall outside of a range of $\pm 5\%$ of the average coefficient, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average coefficient shall be determined, excluding the replaced valve test results. If any individual coefficient is now outside of the $\pm 5\%$ range, then the test shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design.

[98]

NC-7734.3 Calculation of Certified Capacity

(a) The certified capacity of all sizes and pressures of a given design, for which the value of K has been established under the provisions of NC-7734.2 and which are manufactured subsequently, shall not exceed the value calculated by the appropriate formula multiplied by the coefficient K .

(b) The coefficient shall not be applied to valves whose beta ratio (the ratio of valve throat and inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that individual coefficients of discharge, K_d , for valves of the extreme ends of a larger range is within $\pm 5\%$ of the average coefficient, K . For designs where lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio (L/D).

NC-7734.4 Demonstration of Function.

Tests shall be conducted as prescribed in NC-7732.2.

NC-7735 Single Valve Method

NC-7735.1 Valve Capacity Within Test Facility Limits

(a) When a single valve is to be capacity tested, the certified capacity may be based on three separate tests associated with each set pressure for which capacity certification is required.

(b) The certified capacity associated with each set pressure shall not exceed 90% of the average capacity established by the tests. Failure of the individual test capacities to fall within $\pm 5\%$ of the average capacity associated with each set pressure shall be cause for rejection of the test. The reason for the failure shall be determined and the test repeated.

(c) Should additional valves of the same design be constructed at a later date, the results of the tests on the original valve may be included as applicable to the particular test method selected.

NC-7735.2 Valve Capacity in Excess of Test Facility Limits.

For valves whose capacity exceeds that of the test facility, the certified capacity may be based on a flow coefficient K (NC-7734.2) determined from either blocked open flow tests or flow model tests, provided the orifice area is such that choked flow conditions are obtained. The certified capacity shall be calculated as directed in NC-7734.3.

NC-7735.3 Valve Demonstration of Function.

The proper operation of the valve shall be demonstrated as prescribed in NC-7732.2.

NC-7736 Proration of Capacity

(a) The capacity of a pressure relief valve applied to a system may be prorated to an overpressure greater than the overpressure for which the valve design is certified. This overpressure shall be within the allowable limits of the system.

(b) Depending on the method used for the initial capacity certification:

(1) the prorated capacity shall be 90% of the average slope determined in NC-7733 multiplied by the prorated relieving pressure (psia), or;

(2) the prorated capacity shall be calculated using the appropriate formula from NC-7734.2 (where P is the prorated relieving pressure (psia) multiplied by the coefficient K .

NC-7737 Capacity Conversions

The relieving capacity of pressure relief valves for fluids other than the fluid used for certification shall be determined by the method of conversion given in Appendix XVIII-1000, except that valves for steam service shall be tested on steam.

NC-7738 Laboratory Acceptance of Pressure Relieving Capacity Tests

Tests shall be conducted at a place where the testing facilities, methods, procedures, and Authorized Observer (person

supervising the tests) meet the applicable requirements of ASME PTC 25-1994, Pressure Relief Devices. The tests shall be made under the supervision of and certified by an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation of an ASME designee. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designee for review and acceptance.¹⁹

19 Valve capacities are published in "Pressure Relief Device Certifications." This publication may be obtained from the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, OH 43229.

NC-7739 Laboratory Acceptance of Demonstration of Function Tests

The NV Certificate Holder shall assure that the tests are conducted at a place where the testing facilities, methods, and procedures provide for sufficient testing

Page 337

capacity and range of fluid properties so that the testing requirements of NC-7732.2 are met.

NC-7740 CAPACITY CERTIFICATION OF PRESSURE RELIEF VALVES - INCOMPRESSIBLE FLUIDS

NC-7741 General Requirements

NC-7741.1 Capacity Certification.

Capacity certification procedures shall be as required in NC-7742 through NC-7745.

NC-7741.2 Test Medium.

The test medium to be used for capacity certification shall be water at a temperature between 40°F (4°C) and 125°F (52°C).

NC-7741.3 Test Pressure.

Tests shall be conducted at pressures which do not exceed the set pressure by more than 10% or 3 psi (20.6 kPa), whichever is greater.

NC-7741.4 Blowdown.

Blowdown shall be recorded at time of the test.

NC-7741.5 Drawings.

Prior to capacity certification tests, the Certificate Holder shall submit drawings showing the valve construction to the Authorized Observer. The Authorized Observer shall submit the drawings and all test results to the ASME designee for review and acceptance.

NC-7741.6 Design Changes.

When changes are made in the design of a pressure relief valve in such a manner as to affect the flow path, lift, or performance characteristics of the valve, new tests in accordance with this Subarticle shall be performed.

NC-7742 Slope Method

Four valves of each combination of pipe size and orifice size shall be tested. These four valves shall be set at pressures which cover the appropriate range of pressures for which the valves are to be used or within the range of the test facility. The instantaneous slope of each test point shall be calculated and averaged, where slope is defined as the measured capacity divided by the square root of the difference between the flow rating pressure and the valve discharge pressure. If any of the experimentally determined slopes fall outside of a range of $\pm 5\%$ of the average slope, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average slope

shall be determined, excluding the replaced valve test results. If any individual slope is now outside of the $\pm 5\%$ range, then the tests shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design. The certified capacity shall be 90% of the average slope multiplied by the square root of the difference between the flow rating pressure and the valve discharge pressure.

NC-7743 Coefficient of Discharge Method

Instead of individual capacity tests or the capacity curve method, a coefficient K may be established for a specific pressure relief valve design in accordance with the following subparagraphs.

NC-7743.1 Number of Valves to Be Tested.

For each design, three valves for each of three different sizes shall be tested, for a total of nine valves. Each valve of a given size shall be set at a different pressure.

NC-7743.2 Establishment of Coefficient of Discharge

(a) Tests shall be made on each relief valve to determine its lift, opening and closing pressures, and actual capacity in terms of pounds of water per hour. A coefficient of discharge K_D shall be established for each test run as follows:

$$K_D = \frac{\text{Actual Flow}}{\text{Theoretical Flow}} = \text{Coefficient of Discharge}$$

where Actual Flow is determined quantitatively by test and Theoretical Flow is calculated by the following formula. For test with water:

$$W_t = 2407A \sqrt{(P - P_d)w}$$

where

W_t	= Theoretical Flow, lb/hr
A	= actual minimum discharge area through the valve at developed lift, sq in.
P	= (set pressure $\times 1.10$) plus atmospheric pressure, psia, or set pressure plus 3 psi plus atmospheric pressure, whichever is greater
P_d	= pressure at discharge from valve, psia
w	= density of water at valve inlet conditions, lb/cu ft

The average of the coefficients of discharge K_D of the tests shall be multiplied by 0.90 and the product shall be taken as the coefficient K of the design. The coefficient of the design shall not be greater than 0.876 (the product of 0.9×0.975).

Page 338

(b) If any of the experimentally determined coefficients fall outside of a range of $\pm 5\%$ of the average coefficient, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average coefficient shall be determined, excluding the replaced valve test results. If any individual coefficient is

now outside of the $\pm 5\%$ range, then the test shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design.

NC-7743.3 Calculation of Certified Capacity

(a) The certified capacity of all sizes and pressures of a given design for which the value of K has been established under the provisions of NC-7744.2 shall not exceed the value calculated by the theoretical formula above multiplied by the coefficient K .

(b) The coefficient shall not be applied to valves whose beta ratio (the ratio of valve throat and inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that individual coefficients of discharge, K_d , for valves of the extreme ends of a larger range is within $\pm 5\%$ of the average coefficient, K . For designs where lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio (L/D).

NC-7744 Single Valve Method

Where a single valve at a single pressure is to be capacity tested, the capacity rating may be based on three separate tests of the single valve at the specified set pressure. The certified capacity rating of the valve shall not exceed 90% of the average capacity established by the tests. Failure of the individual test capacities to fall within $\pm 5\%$ of the average capacity may be cause for rejection of the test. The reason for the failure shall be determined and the test repeated.

Should additional valves of the same design be constructed at a later date, the results of the tests on the original valve may be included as applicable to the particular test method selected.

NC-7745 Laboratory Acceptance of Pressure Relieving Capacity Tests

Tests shall be conducted at a place where the testing facilities, methods, procedures, and Authorized Observer (person supervising the tests) meet the applicable requirements of ASME PTC 25-1994, Pressure Relief Devices. The tests shall be made under the supervision of and certified by an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation of an ASME designee. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designee for review and acceptance.¹⁷

NC-7746 Proration of Capacity

(a) The capacity of a pressure relief valve applied to a system may be prorated to an overpressure greater than the overpressure for which the valve design is certified. This overpressure shall be within the allowable limits of the system.

(b) Depending on the method used for the initial capacity certification:

(1) the prorated capacity shall be 90% of the average slope determined in NC-7742 multiplied by the prorated relieving pressure (psia), or;

(2) the prorated capacity shall be calculated using the appropriate formula from NC-7743.2 [where P is the prorated relieving pressure (psia) multiplied by the coefficient K].

NC-7747 Capacity Conversion

The rated pressure relieving capacity of pressure relief valves for liquids other than the liquids used for certification shall be determined by the method of conversion given in Appendix XVIII-1000. This conversion is not valid for liquid flashing valve operating conditions.

NC-7750 CAPACITY CERTIFICATION OF VACUUM RELIEF VALVES

NC-7751 General Requirements

NC-7751.1 Capacity Certification.

Capacity certification procedures shall be as required in NC-7752 through NC-7755.

NC-7751.2 Test Media.

Capacity certification tests for vacuum relief valves for air and gas service shall be conducted with dry steam, air, or gas. For steam test purposes the limits of 98% minimum quality and 20°F maximum superheat shall apply. Capacity shall be corrected to dry saturated condition from these limits.

NC-7751.3 Test Method and Pressure.

Capacity tests may be conducted by pressurizing the valve instead of using a vacuum, provided the inlet conditions of

Page 339

the valve (not the vessel) are known and the inlet pressure is not greater than 5 psi (35 kPa), and the direction of flow through the valve is the same on pressure as is experienced on vacuum. Tests shall be conducted at twice the set pressure or 1 psi (7 kPa), whichever is greater.

NC-7751.4 Blowdown.

Blowdown shall be recorded at the time of the test.

NC-7751.5 Drawings.

Prior to a test, the Certificate Holder shall submit drawings showing the valve construction to the Authorized Observer. The Authorized Observer shall submit the drawings and test results to the ASME designee for review and acceptance.

NC-7751.6 Design Change.

When changes are made in the design of a vacuum relief valve in such a manner as to affect the flow path, lift, or performance characteristics of the valve, new tests in accordance with this Article shall be performed.

NC-7752 Single Valve Method

(a) When a single valve at a single pressure is to be capacity tested, the capacity rating may be based on three separate and distinct tests of the single valve at the specified set pressure. The certified capacity rating of the valve shall not exceed 90% of the average capacity established by the tests. Failure of the individual test capacities to fall within $\pm 5\%$ of the average capacity shall be cause for rejection of the test. The reason for the failure shall be determined and the test repeated.

(b) Should additional valves of the same design be constructed at a later date, the results of the test on the original valve may be included as applicable to the particular test method selected.

NC-7753 Slope Method

Four valves of each combination of pipe size and orifice size shall be tested. These four valves shall be set at pressures which cover the appropriate range of pressures for which the valves are to be used or set within the range of the test facility. The slope of each test shall be calculated and averaged, where slope is defined as the measured capacity divided by the quantity, $F[(P)(P - P_o)]^{1/2}$

where

$$F = \sqrt{\left(\frac{k}{k-1}\right) (r^{2/k}) \left[\frac{1 - (r)^{\frac{k-1}{k}}}{1-r} \right]}$$

P	= inlet pressure, psi
P_o	= discharge pressure, psi
k	= ratio of specific heats, c_v/c_p
r	= pressure ratio, P_o/P

If any of the experimentally determined slopes fall outside of a range of $\pm 5\%$ of the average slope, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average slope shall be determined, excluding the replaced valve test results. If any individual slope is now outside of the $\pm 5\%$ range, then the tests shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design. The certified capacity shall be 90% of the average slope multiplied by the quantity, $F[(P)(P - P_o)]^{1/2}$

NC-7754 Coefficient of Discharge Method

A coefficient K may be established for a specific vacuum relief valve design in accordance with NC-7754.1 and NC-7754.2.

NC-7754.1 Number of Valves to Be Tested.

For each design, three valves of three different sizes, a total of nine valves, shall be tested. Each valve of a given size shall be set at a different pressure.

NC-7754.2 Establishment of Coefficient of Discharge

(a) Tests shall be made on each relief valve to determine its lift, opening and closing pressures, and actual capacity. A coefficient of discharge K_D shall be established for each run as follows:

$$K_D = \frac{\text{Actual Flow}}{\text{Theoretical Flow}} = \text{Coefficient of Discharge}$$

where Actual Flow is determined quantitatively by test, and Theoretical Flow is calculated from the appropriate equation for the test fluid. The following formula may be used for other than saturated steam flow:

Page 340

$$W = 735FA \left[\frac{MP(P - P_o)}{T} \right]^{1/2}$$

$$Q = 279,000FA \left[\frac{P(P - P_o)}{MT} \right]^{1/2}$$

where

$$F = \sqrt{\left(\frac{k}{k-1}\right) (r^{2/k}) \left[\frac{1 - (r)^{\frac{k-1}{k}}}{1-r} \right]}$$

or is obtained from Fig. NC-7754.2(a)-1.

A	= flow area, sq in.
M	= molecular weight
P	= inlet pressure, psi
P_o	= discharge pressure, psi
T	= temperature, deg. Rankin
k	= ratio of specific heats, c_v/c_p
r	= pressure ratio, P_o/P
Q	= cu ft/hr at 14.7 psi and 60°F
W	= lb/hr

The average of the coefficients of discharge K_D of the tests required shall be multiplied by 0.90 and their product shall be the coefficient K of that design. The coefficient of the design shall not be greater than 0.876 (the product of 0.9×0.975).

(b) If any of the experimentally determined coefficients fall outside of a range of $\pm 5\%$ of the average coefficient, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average coefficient shall be determined, excluding the replaced valve test results. If any individual coefficient is now outside of the $\pm 5\%$ range, then the test shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design.

NC-7754.3 Calculation of Relieving Capacity

(a) The certified relieving capacity of all sizes and pressures of a given design, for which the value of K has been established, shall be calculated by the appropriate formula given above multiplied by the coefficient K . Values obtained from pressurized tests may be converted to equivalent vacuum from the above equation.

(b) The coefficient shall not be applied to valves whose beta ratio (the ratio of valve throat and inlet diameter) lies

outside the range of 0.15 to 0.75, unless tests have demonstrated that individual coefficients of discharge, K_d , for valves of the extreme ends of a larger range is within $\pm 5\%$ of the average coefficient, K . For designs where lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio (L/D).

NC-7755 Laboratory Acceptance of Relieving Capacity Tests

Tests shall be conducted at a place where the testing facilities, methods, procedures, and person supervising the tests (Authorized Observer) meet the applicable requirements of ASME PTC 25-1994, Pressure Relief Devices. The tests shall be made under the supervision of and certified by an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation of an ASME designee. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designee for review and acceptance.¹⁷

NC-7760 CAPACITY DETERMINATION OF RUPTURE DISK DEVICES

NC-7761 General Requirements

NC-7761.1 Test Media

(a) Capacity tests of rupture disk devices for steam service shall be conducted with dry saturated steam. For test purposes, the limits of 98% minimum quality and 20°F (-7°C) maximum superheat shall apply. Capacity shall be corrected to the dry saturated condition from within these limits.

(b) Capacity tests for rupture disk devices for air and gas service shall be conducted with air, gas, or dry saturated steam.

NC-7761.2 Test Pressure

(a) Capacity tests of rupture disk devices shall be conducted at a pressure not exceeding 110% of the stamped burst pressure.

(b) Capacity tests of rupture disk devices used at the inlet side of pressure relief valves shall be conducted at a pressure not exceeding 110% of the valve set pressure.

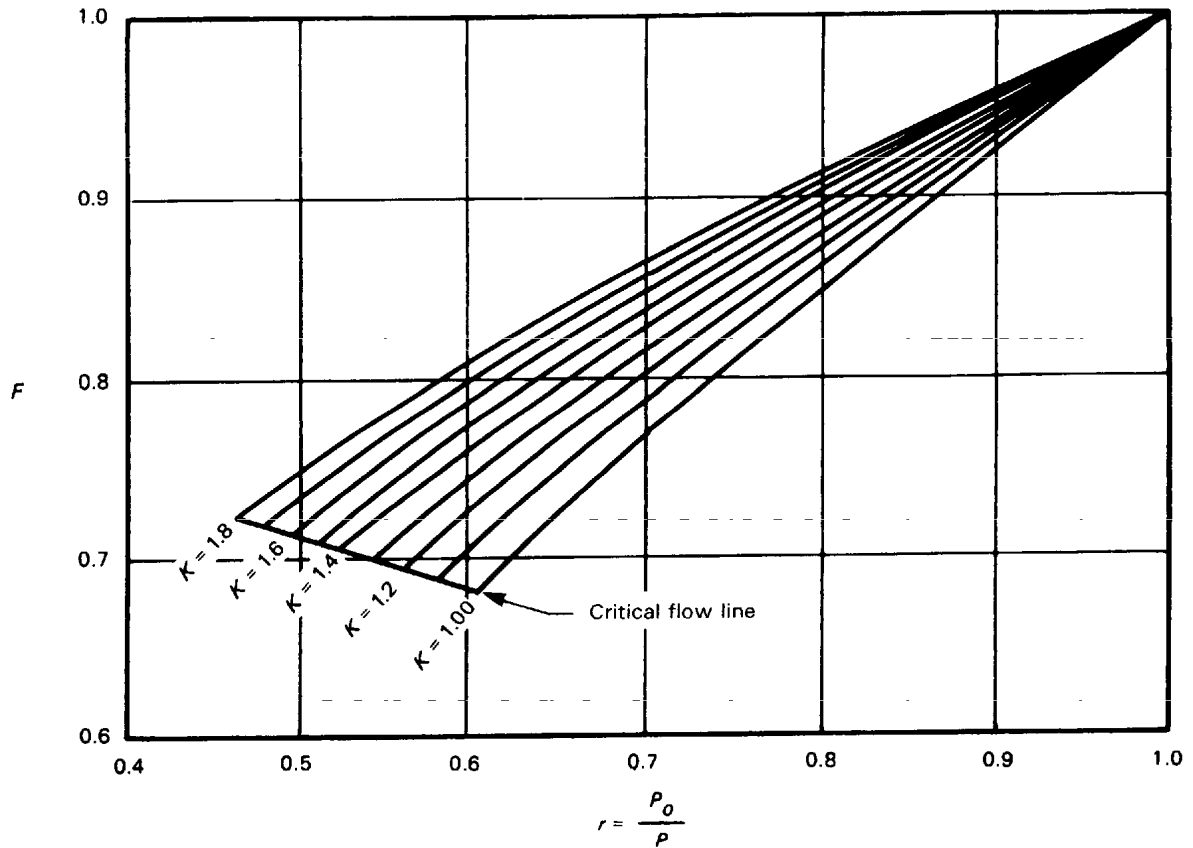


FIG. NC-7754.2(a)-1 VALUES OF F FOR NONCHOKING FLOW

FIG. NC-7754.2(a)-1 VALUES OF F FOR NONCHOKING FLOW

NC-7762 Capacity Determination of Rupture Disk Devices in Combination With Pressure Relief Valves

NC-7762.1 Capacity Determination Without Flow Test

(a) The rated capacity of the combination of a pressure relief valve when installed with a rupture disk device at the inlet side of the valve shall not exceed 80% of the certified capacity of the valve. Alternatively, the capacity of such a combination shall be established in accordance with NC-7762.2.

(b) The rated capacity of the combination of a pressure relief valve when installed with a rupture disk device at the outlet of the valve shall be the certified capacity of the valve.

NC-7762.2 Capacity of Pressure Relief Valves in Combination With a Rupture Disk Device at the Inlet.

For each combination of pressure relief valve design and rupture disk device design, the Certificate Holder or the rupture disk device manufacturer shall have the capacity of the combination determined as prescribed in (a) and (b) below.

(a) The Certificate Holder or the rupture disk device manufacturer shall submit for tests the smallest rupture disk device size with the equivalent size of pressure relief valve that is intended to be used as a combination device. The pressure relief valve to be tested shall have the largest orifice used in the particular inlet size.

(b) Tests shall be performed in accordance with the requirements of (1) through (5) below. The rupture disk device and pressure relief valve combination to be tested shall be arranged to duplicate the combination assembly design.

(1) The test shall be made using the minimum burst pressure of the rupture disk device design that is to be used in combination with the pressure relief valve design. The stamped bursting pressure shall be between 90-100% of the stamped set pressure of the valve.

(2) The test procedure to be used shall be as follows:

Page 342

(a) The pressure relief valve by itself shall be tested for capacity without the rupture disk device at a pressure 10% above the valve set pressure.

(b) The rupture disk device shall then be installed in front of the pressure relief valve and the disk burst to operate the valve. The capacity test shall be performed on the combination at 10% above the valve set pressure duplicating the test of (a) above.

(3) The tests shall be repeated with two additional rupture disks of the same nominal rating for a total of three rupture disks to be tested with the single valve. The results of the test capacity shall fall within a range of 10% of the average capacity of the three tests. Failure to meet this requirement shall be cause to require retest for determination of cause of the discrepancies.

(4) From the results of the tests, a Combination Capacity Factor shall be determined. The Combination Capacity Factor is the ratio of the average capacity which is determined by the combination tests to the capacity which is determined by the test of (a) above. The Combination Capacity Factor shall be used as a multiplier to the certified capacity of the pressure relief valve in all sizes of the design, except when a different factor has been established for larger sizes and other pressures in accordance with NC-7762.3. The value of the Combination Capacity Factor shall not be greater than one. The Combination Capacity Factor shall apply only to combinations of the same design and manufacture of the pressure relief valve and the same design and manufacture of the rupture disk device as those tested.

(5) The test laboratory shall submit the test results to ASME designee for acceptance of the Combination Capacity Factor.

NC-7762.3 Optional Testing of Rupture Disk Devices and Pressure Relief Valves

(a) If desired, a Certificate Holder or a rupture disk manufacturer may conduct tests in the same manner as given in NC-7762.2 using the next two larger sizes of the same design of rupture disk device and pressure relief valve to determine a Combination Capacity Factor applicable to larger sizes. If a greater Combination Capacity Factor is established and can be approved, it may be used for all larger sizes of the combination, but the Factor shall not be greater than one.

(b) If desired, additional tests may be conducted at higher pressures in accordance with NC-7762.2 to establish a maximum Combination Capacity Factor to be used at all pressures higher than the highest tested, but the Factor shall not be greater than one.

NC-7763 Capacity of Rupture Disk Devices

NC-7763.1 Calculated Capacity

(a) The calculated capacity of a rupture disk device shall not exceed a value based on the applicable theoretical formula (Appendix XVIII) for the various media multiplied by a value for K of 0.62. The area A in the theoretical formula shall be the minimum net flow area existing after disk burst.

(b) The minimum net flow area is the calculated net area after a complete burst of the disk, with appropriate allowance for any structural members which may reduce the net flow area through the rupture disk device. The net flow area for sizing purposes shall not exceed the nominal pipe size area of the rupture disk device.

NC-7763.2 Tested Capacity.

A manufacturer may have the capacity of a given rupture disk device design approved for K_D in general accordance with the procedures of NC-7730, as applicable.

NC-7764 Laboratory Acceptance of Pressure Relieving Capacity Tests

Tests shall be conducted at a place where the testing facilities, methods, procedures, and Authorized Observer (person supervising the tests) meet the applicable requirements of ASME PTC 25-1994, Pressure Relief Devices. The tests shall be made under the supervision of and certified by an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation of an ASME designee. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designee for review and acceptance.¹⁷

NC-7800 MARKING, STAMPING, AND DATA REPORTS

NC-7810 PRESSURE AND VACUUM RELIEF VALVES

NC-7811 Marking and Stamping

Each pressure relief valve shall be plainly marked by the Certificate Holder with the required data below in such a way that the marking will not be obliterated in service. The data shall be in characters not less than $\frac{3}{32}$ in. high. The marking shall be placed on the valve or on a nameplate securely fastened to the valve. The Code NV Symbol shall be stamped on the valve or

Page 343

nameplate, but the other required data may be stamped, etched, impressed, or cast. The marking shall include the following:

- (a) name, or an acceptable abbreviation, of the Certificate Holder
- (b) Certificate Holder's design or type number
- (c) size _____ (NPS, the nominal pipe size) of the valve inlet
- (d) set pressure _____ psi
- (e) certified capacity and overpressure in percent or psi in accordance with NC-7700

Pressure Relief Valves:

- lb/hr of saturated steam for valves certified on steam, or
- scfm (standard cubic feet per minute) at 60°F and 14.7 psia of air for valves certified on air or gas, or
- gal/min of water at 70°F for valves certified on water

Vacuum Relief Valves:

- scfh (standard cubic feet per hour) at 60°F and 14.7 psi
- (f) applicable official Code Symbol Stamp, as shown in Table NCA-8100-1

In addition to the above, each pressure relief valve shall have a separate nameplate attached to the component that includes the marking requirements of NCA-8220 and NC-3593.2.

NC-7812 Report Form for Pressure and Vacuum Relief Valves

A Data Report Form NV-1 shall be filled out and signed by the Certificate Holder and signed by the Inspector for each pressure and vacuum relief valve stamped with the Code NV Symbol.

NC-7820 RUPTURE DISK DEVICES

NC-7821 Rupture Disks

Every rupture disk shall be plainly marked by the manufacturer in such a way that the marking will not be obliterated in service. The rupture disk marking may be placed on the flange of the rupture disk or on a metal tab permanently attached thereto.²⁰ The marking shall include the following:

20 In lieu of marking all of the listed items on the flange or tab of each rupture disk, the marking may consist of a manufacturer's coding number sufficient to identify each rupture disk with a certificate or tab which includes the required information and is supplied with each lot of rupture disks.

- (a) name or identifying trademark of the manufacturer
- (b) manufacturer's design or type number
- (c) lot number
- (d) size _____ in.
- (e) stamped bursting pressure _____ psi
- (f) specified disk temperature _____ °F
- (g) capacity _____ lb/hr of saturated steam/hr or standard cu ft/min of air (60°F and 14.7 psia)
- (h) year built

NC-7822 Disk Holders (If Used)

Rupture disk holders shall be marked with the following:

- (a) name or identifying trademark of the manufacturer
- (b) manufacturer's design or type number
- (c) size _____ in.
- (d) year built
- (e) serial number

NC-7830 PRESSURE RELIEF VALVE IN COMBINATION WITH RUPTURE DISK DEVICES

NC-7831 Marking When Capacity Is Approved in Accordance With NC-7762.1

The marking shall be placed either on the valve or the rupture disk holder or on a plate or plates securely fastened to the valve or the rupture disk holder. The marking shall include a Combination Capacity Factor of 0.8.

NC-7832 Marking When Capacity Is Approved in Accordance With NC-7762.2

The following marking shall be in addition to the marking required by NC-7811 and NC-7822. The marking shall be placed on the valve or the rupture disk holder or on a plate or plates securely fastened to the valve or the rupture disk holder. The marking shall include the following:

- (a) name of the Certificate Holder
- (b) design or type or serial number of valve
- (c) name of manufacturer of rupture disk device

(d) design or type designation of rupture disk device

(e) approved Combination Capacity Factor

Page 344

NC-7840 CERTIFICATE OF AUTHORIZATION TO USE CODE SYMBOL STAMP

Each pressure and vacuum relief valve within the scope of this Article shall be constructed by a Certificate Holder possessing a Code NV Symbol Stamp and a valid Certificate of Authorization. Pressure and vacuum relief valves shall have the Code NV Symbol applied in accordance with the rules of NC-8100.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NC-8000

ARTICLE NC-8000 NAMEPLATES, STAMPING, AND REPORTS

Page 345

NC-8100 GENERAL REQUIREMENTS

The requirements for nameplates, stamping, and reports shall be as given in NCA-8000.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NC SI UNITS

SI UNITS

Page 347

The 1998 Edition of the Boiler and Pressure Vessel Code is based on U.S. Customary (ft-lb) units of measurement which are to be regarded as the standard. This supplement is provided as a convenience to the Code user and contains SI conversion factors for units contained in the Code.

Page 348

Page 349

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

Quantity	Unit	Symbol	Other Units or Limitations
Space and Time			
plane angle	radian	rad	degree (decimalized)
length	meter	m	
area	square meter	m ²	
volume	cubic meter	m ³	liter (L) for liquid only (use without prefix other than in milliliter, mL)
time	second	s	minute (min), hour (h), day (d), week, and year
Periodic and Related Phenomena			
frequency	hertz	Hz	revolutions per second (r/s)
rotational frequency	revolutions per second	s ⁻¹	revolutions per minute (r/m)
Mechanics			
mass	kilogram	kg	
density	kilogram per cubic meter	kg/m ³	
moment of inertia	kilogram · meter ²	kg · m ²	
force	newton	N	
moment of force (torque)	newton-meter	N · m	
pressure and stress	pascal	Pa	(pascal = newton per square meter)
energy, work	joule	J	kilowatt-hour (kW · h)
power	watt	W	
impact strength	joule	J	
section modulus	meter ³	m ³	
moment of section (second moment of area)	meter ⁴	m ⁴	
fracture toughness	Pa · $\sqrt{m}$		
Heat			
temperature — thermodynamic [Note (2)]	kelvin	K	degree Celsius (°C)
temperature — other than thermodynamic	degree Celsius	°C	kelvin (K)
linear expansion coefficient	meter per meter-kelvin	K ⁻¹	°C ⁻¹
quantity of heat	joule	J	
heat flow rate	watt	W	
thermal conductivity	watt per meter-kelvin	W/(m · K)	W/(m · °C)
thermal diffusivity	square meter per second	m ² /s	
specific heat capacity	joule per kilogram-kelvin	J/(kg · K)	J/(kg · °C)
Electricity and Magnetism			
electric current	ampere	A	
electric potential	volt	V	
current density	ampere per meter ²	A/m ²	
magnetic field strength	ampere per meter	A/m	

NOTES:

- (1) Conversion factors between SI units and U.S. customary are given in SI-1, "ASME Orientation and Guide for Use of SI (Metric) Units," and ASTM E 380.
- (2) Preferred use for temperature and temperature interval is degrees Celsius (°C), except for thermodynamic and cryogenic work where kelvins may be more suitable. For temperature interval, 1 K = 1°C exactly.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

COMMONLY USED CONVERSION FACTORS
(For Others See ASTM E 380) [See Note (1)]

Quantity	To Convert From	To	Multiply by [Note (2)]	
plane angle	degree	rad	1.745 329	E-02
length	in	m	2.54*	E-02
	ft	m	3.048*	E-01
	yd	m	9.144*	E-01
area	in ²	m ²	6.451 6*	E-04
	ft ²	m ²	9.290 304*	E-02
	yd ²	m ²	8.361 274	E-01
volume	in ³	m ³	1.638 706	E-05
	ft ³	m ³	2.831 685	E-02
	US gallon	m ³	3.785 412	E-03
	Imperial gallon	m ³	4.546 09	E-03
	liter	m ³	1.0*	E-03
mass	lbm	kg	4.535 924	E-01
	ton (metric) (mass)	kg	1.000 00*	E+03
	ton (short 2000 lbm)	kg	9.071 847	E+02
force	kgf	N	9.806 65*	E+00
	lbf	N	4.448 222	E+00
bending, torque	kgf · m	N · m	9.806 65*	E+00
	lbf · in	N · m	1.129 848	E-01
	lbf · ft	N · m	1.355 818	E+00
pressure, stress	kgf/m ²	Pa	9.806 65*	E+00
	lbf/ft ²	Pa	4.788 026	E+01
	lbf/in ² (psi)	Pa	6.894 757	E+03
	kips/in ²	Pa	6.894 757	E+06
	bar	Pa	1.0*	E+05
energy, work	Btu (IT) [Note (3)]	J	1.055 056	E+03
	ft · lbf	J	1.355 818	E+00
power	hp (550 ft · lbf/s)	W	7.456 999	E+02
fracture toughness	ksi $\sqrt{\text{in}}$	Pa · $\sqrt{\text{m}}$	1.098 843	E+06
temperature	°C	K	$t_K = t_C + 273.15$	
	°F	K	$t_K = (t_F + 459.67)/1.8$	
	°F	°C	$t_C = (t_F - 32)/1.8$	
temperature interval	°C	K	1.0*	E+00
	°F	K or °C	5.555 555	E-01

NOTES:

- (1) Care should be taken when converting formulas or equations that contain constant terms or factors. The value of these terms must be understood and may also require conversion.
- (2)(a) Relationships that are exact in terms of the base units are followed by a single asterisk.
- (b) The factors are written as a number greater than 1 and less than 10 with 6 or less decimal places. The number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example: 3.523 907 E-02 is $3.523\ 907 \times 10^{-2}$ or 0.035 239 07.
- (3) International Table

COMMONLY USED CONVERSION FACTORS

July 1, 1998
American Society Of Mechanical Engineers
SEC III D1 ND A98
1998 Addenda Summary of Changes

Page XXV

Changes given below are identified on the pages by a margin note, **98**, placed next to the affected area.

Page	Location	Change
26	ND-2431.2	Subparagraphs (b) and (d) corrected by Errata
29	ND-2539.4	In the second sentence, ND-5000 corrected by Errata to read ND-5320
64	ND-3324.2	In the nomenclature for L , reference to Table ND-3332.3-1 corrected by Errata to read Table ND-3332.2-1
81	ND-3329.3	In subpara. (b)(5), reference to ND-3356(d) corrected by Errata to read ND-3356(c)
92	ND-3352.1	In subpara. (c), reference to ND-5211(c) corrected by Errata to read ND-5211.1(c)
96	ND-3356.2	Reference to ND-3824 corrected by Errata to read ND-4246
102	ND-3411.2	Subparagraph (a) revised
104, 105	ND-3432.1	In subpara. (c), reference to ND-1150 corrected by Errata to read ND-1130
135	ND-3611.1	Revised
	ND-3611.2	In subpara. (c)(1), heading corrected by Errata
140	ND-3641.1	Nomenclature for A corrected by Errata
142	ND-3643.1	(1) In subpara. (c)(2)(b), reference to Fig. ND-3643-2(b)-2 corrected by Errata to read Fig. ND-3643.2(b)-2 (2) In subpara. (c)(5)(b), reference to Fig. ND-3643.3(b)-2 corrected by Errata to read Fig. ND-3643.2(b)-2
157	ND-3653.3	In the nomenclature for Z in subpara. (d), the reference to Table ND-3673.2(b)-1 corrected by Errata to read Fig. ND-3673.2(b)-1
163, 164	ND-3673.2	(1) Subparagraph (b) revised (2) New subparas. (c) through (k) added (3) Former subparas. (c), (d), (e), and (f) redesignated as (l), (m), (n), and (o), respectively
	ND-3673.5	In the nomenclature for S_E in subpara. (a), reference to ND-3652.3(a) corrected by Errata to read ND-3653.2(a)
169	Fig. ND-3673.2(b)-2	General Note (b) corrected by Errata

Page	Location	Change
194	Table ND-3923.1-1	In Column 2, third entry corrected by Errata
198	ND-3932.3	In subpara. (b), reference to ND-3922(b) corrected by Errata to read ND-3922.2(b)
213	ND-4213.2	Reference to subparas. (a) through (g) corrected by Errata to read (a) through (f)
216	ND-4223.1	Subparagraph (b) corrected by Errata
233	ND-4246.6	In subpara. (c), reference to Fig. ND-3361-1 corrected by Errata to read Fig. ND-3361.1-1
236	ND-4247.6	In subpara. (c), reference to Fig. ND-3361-1 corrected by Errata to read Fig. ND-3361.1-1
244	ND-4424	Second sentence corrected by Errata
256, 257	Table ND-4622.7(b)-1	Note (2) corrected by Errata
272	ND-5440	In subpara. (b), reference to ND-5240(c) corrected by Errata to read ND-5420(c)
290	ND-6921	Subparagraphs (b)(2)(a) and (b)(2)(b) corrected by Errata
291	ND-6924	Subparagraphs (e)(2)(a) and (e)(2)(b) corrected by Errata

NOTE:

Volume 42 of the Interpretations to Section III, Divisions 1 and 2, of the ASME Boiler and Pressure Vessel Code follows the last page of the Edition to Subsection NCA.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 ND INTRO

INTRODUCTION

1998 ASME
BOILER &
PRESSURE VESSEL CODE
AN INTERNATIONAL CODE

III

Division 1 -
Subsection ND

Class 3
Components

RULES FOR
CONSTRUCTION
OF NUCLEAR
POWER PLANT
COMPONENTS

[ASME logo] The American Society of
Mechanical Engineers

**IMPORTANT INFORMATION ON THE 1998 BOILER AND PRESSURE VESSEL CODE
ADDENDA DISTRIBUTION SCHEDULE**

There is a change in the way the Addenda to the 1998 Edition of the ASME Boiler and Pressure Vessel Code are distributed. The 1998 Edition, published July 1, 1998, incorporates the 1998 Addenda revisions, additions, or deletions. There will be no separate 1998 Addenda issued in a replacement page format. Two additional Addenda to the 1998 Edition, in the form of replacement pages, will be issued on July 1, 1999 and July 1, 2000.

The Summary of Changes published with the 1998 Edition lists and describes the revisions that are part of the 1998 Addenda. These changes are identified with a margin note, **98**, denoting the affected area.

The Addenda for 1999 and 2000 will also have a Summary of Changes and identifiers printed on the replacement pages. The revisions, additions, or deletions will be incorporated directly into the affected pages. It is advisable to retain the title sheets and all replaced pages for reference.

The effective dates for Code Editions and Addenda are described in the Foreword.

ASME BOILER AND PRESSURE VESSEL CODE
AN INTERNATIONAL CODE

RULES FOR
CONSTRUCTION OF
NUCLEAR POWER
PLANT COMPONENTS

III

Division 1-
Subsection ND

Class 3
Components

1998 Edition
July 1, 1998

ASME BOILER AND
PRESSURE VESSEL
COMMITTEE
SUBCOMMITTEE ON
NUCLEAR POWER

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
NEW YORK, NEW YORK

Date of Issue - July 1, 1998
(Includes all Addenda dated December 1997 and earlier)

This code or standard was developed under procedures accredited as meeting the criteria for American National Standards.

This code or standard was developed under procedures accredited as meeting the criteria for American National Standards. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment which provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not "approve," "rate," or "endorse" any item, construction, proprietary device, or activity.

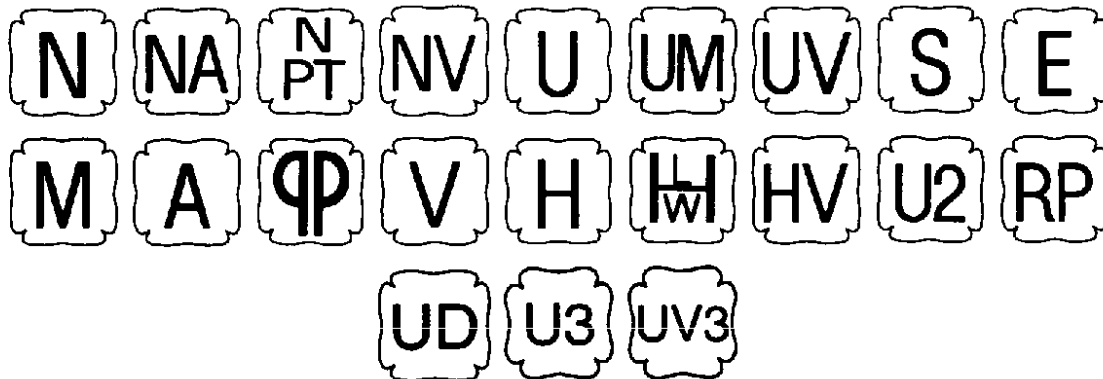
ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of any applicable Letters Patent, nor assume any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations issued in accordance with governing ASME procedures and policies which preclude the issuance of interpretations by individual volunteers.

The footnotes in this document are part of this American National Standard.

[ASME logo] ASME collective membership mark



LOGOS

The above ASME symbols are registered in the U.S. Patent Office.

"ASME" is the trademark of the American Society of Mechanical Engineers.

No part of this document may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Library of Congress Catalog Card Number: 56-3934

Printed in the United States of America

Adopted by the Council of the American Society of Mechanical Engineers, 1914.

Revised 1940, 1941, 1943, 1946, 1949, 1952, 1953, 1956, 1959, 1962, 1965, 1968, 1971, 1974, 1977, 1980, 1983, 1986, 1989, 1992, 1995, 1998

The American Society of Mechanical Engineers

Three Park Avenue, New York, NY 10016-5990

Copyright © 1998 by

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

All Rights Reserved

1998 ASME

BOILER AND PRESSURE VESSEL CODE

SECTIONS

I Rules for Construction of Power Boilers

II Materials

Part A - Ferrous Material Specifications

Part B - Nonferrous Material Specifications

Part C - Specifications for Welding Rods, Electrodes, and Filler Metals

Part D - Properties

III Subsection NCA - General Requirements for Division 1 and Division 2

III Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

III Division 2 - Code for Concrete Reactor Vessels and Containments

III Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

IV Rules for Construction of Heating Boilers

V Nondestructive Examination

VI Recommended Rules for the Care and Operation of Heating Boilers

VII Recommended Guidelines for the Care of Power Boilers

VIII Rules for Construction of Pressure Vessels

Division 1

Division 2 - Alternative Rules

Division 3 - Alternative Rules for Construction of High Pressure Vessels

IX Welding and Brazing Qualifications

X Fiber-Reinforced Plastic Pressure Vessels

ADDENDA

Colored-sheet Addenda, which include additions and revisions to individual Sections of the Code, are published annually and will be sent automatically to purchasers of the applicable Sections up to the publication of the 2001 Code. The 1998 Code is available only in the loose-leaf format; accordingly, the Addenda will be issued in the loose-leaf, replacement-page format.

INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code. The Interpretations for each individual Section will be published separately and will be included as part of the update service to that Section. They will be issued semiannually (July and December) up to the publication of the 2001 Code. Interpretations of Section III, Divisions 1 and 2, will be included with the update service to Subsection NCA.

CODE CASES

The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 1998 Code Cases book: (1) Boilers and Pressure Vessels and (2) Nuclear Components. Supplements will be sent automatically to the purchasers of the Code Cases books up to the publication of the 2001 Code.

Page v

FOREWORD

The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety governing the design, fabrication, and inspection during construction of boilers and pressure vessels, and to interpret these rules when questions arise regarding their intent. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property and to provide a margin for deterioration in service so as to give a reasonably long, safe period of usefulness. Advancements in design and material and the evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction,¹ and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

¹ Construction, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are responsible for the application of these programs to their design.

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal and allowable tolerances or local variances may be considered

acceptable when based on engineering judgment and standard practice as determined by the engineer.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Boiler and Pressure Vessel Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Mandatory Appendix covering preparation of technical inquiries). Proposed revisions to the Code resulting from inquiries will be presented to the Main Committee for appropriate action. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by ASME.

Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute and published in *Mechanical Engineering*

Page viii

to invite comments from all interested persons. After the allotted time for public review and final approval by ASME, revisions are published annually in Addenda to the Code.

Code Cases may be used in the construction of components to be stamped with the ASME Code symbol beginning with the date of their approval by ASME.

Code Editions may be used on or after the date of issue shown in the Edition. After Code revisions are approved by ASME, they may be used beginning with the date of issue shown on the Addenda. Revisions to material specifications are originated by the American Society for Testing and Materials (ASTM) and other recognized national or international organizations, and are usually adopted by ASME. However, those revisions may or may not have any effect on the suitability of material, produced to earlier editions of specifications, for use in ASME construction. ASME material specifications approved for use in each construction Code are listed in the Appendices of Section II, Parts A and B. These Appendices list, for each specification, the latest edition adopted by ASME, and earlier and later editions considered by ASME to be identical for ASME construction.

Owners of nuclear power plants are cautioned that Code Editions, Addenda, and Cases to be used in construction shall be acceptable to the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

Each state and municipality in the United States and each province in Canada that adopts or accepts one or more Sections of the Boiler and Pressure Vessel Code is invited to appoint a representative to act on the Conference Committee to the Boiler and Pressure Vessel Committee. Since the members of the Conference Committee are in active contact with the administration and enforcement of the rules, the requirements for inspection in this Code correspond with those in effect in their respective jurisdictions. The required qualifications for an Authorized Inspector under these rules may be obtained from the administrative authority of any state, municipality, or province which has adopted these rules.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, method of fabrication, inspection, and safety devices. Permission may be granted to regulatory bodies and organizations publishing safety standards to use a complete Section of the Code by reference. If usage of a Section, such as Section IX, involves exceptions, omissions, or changes in provisions, the intent of the Code might not be attained.

Where a state or other regulatory body, in the printing of any Section of the Boiler and Pressure Vessel Code, makes additions or omissions, it is recommended that such changes be clearly indicated.

The National Board of Boiler and Pressure Vessel Inspectors is composed of chief inspectors of states and municipalities in the United States and of provinces in Canada that have adopted the Boiler and Pressure Vessel Code. This Board, since its organization in 1919, has functioned to uniformly administer and enforce the rules of the Boiler and Pressure Vessel Code. The cooperation of that organization with the Boiler and Pressure Vessel Committee has been extremely helpful.

The Code Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The Scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Code for vessels or components not considered to be within its Scope or may establish additions or deletions in that Scope. Accordingly, inquiries regarding such laws or regulations are to be directed to the issuing enforcement or regulatory body.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the ASME Boiler and Pressure Vessel Committee. ASME is to be notified should questions arise concerning improper use of an ASME Code symbol.

The specifications for materials given in Section II are identical with or similar to those of specifications published by ASTM, AWS, and other recognized national or international organizations. When reference is made in an ASME material specification to a non-ASME specification for which a companion ASME specification exists, the reference shall be interpreted as applying to the ASME material specification. Not all materials included in the material specifications in Section II have been adopted for use in this Section. Usage is limited to those materials and grades listed in at least one of the tables of Section II, Part D, Subpart 1, identified as applicable to this Section. All materials allowed by this Section and used for construction within the scope of these rules shall be furnished in accordance with material specifications

Page ix

contained in Section II or referenced in Appendices A of Section II, Parts A and B except where otherwise provided in Code Cases or in this Section of the Code. Materials covered by these specifications are acceptable for use in items covered by the Code Sections only to the degree indicated in the applicable Section. Materials for Code use should preferably be ordered, produced, and documented on this basis. Material produced to an acceptable specification with requirements different from the requirements of the corresponding specification listed in Appendix A of Part A or Part B may also be used in accordance with the above, provided the material manufacturer or vessel manufacturer certifies with evidence acceptable to the Authorized Inspector that the corresponding ASME specification requirements of specifications listed in Appendix A of Part A or Part B have been met. Material produced to an acceptable material specification is not limited as to country of origin.

When required by context in this Section, the singular shall be interpreted as the plural, and vice-versa; and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

Publication of the SI (Metric) Edition of the ASME Boiler and Pressure Vessel Code was discontinued with the 1986 Edition. Effective October 1, 1986, the SI Edition was withdrawn as an ASME Boiler and Pressure Vessel Code document.

Page xi

STATEMENT OF POLICY ON THE USE OF CODE SYMBOLS AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use Code Symbols for marking items or constructions which have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the symbols, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications which might so indicate. An organization holding a Code Symbol and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME

Boiler and Pressure Vessel Code."

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified items will carry the symbol. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

The ASME logo, which is the cloverleaf with the letters ASME within, shall not be used by any organization other than ASME.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Code Symbol Stamp described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the various Code Symbols shall not be used on any item which is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME which tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

Page xiii

PERSONNEL ASME Boiler and Pressure Vessel Committee Subcommittees, Subgroups, and Working Groups

As of December 31, 1997

MAIN COMMITTEE

D. A. Canonico, *Chair*

G. G. Karcher, *Vice Chair*

J. S. Brzuszkiewicz, *Secretary*

R. W. Barnes

F. P. Barton

D. L. Berger

M. D. Bernstein

M. N. Bressler

W. J. Carter

T. M. Cullen

J. R. Farr

R. E. Feigel

J. G. Feldstein

M. Gold

O. F. Hedden

A. J. Justin

D. F. Landers

W. M. Lundy

J. R. MacKay

T. J. Mawson

T. G. McCarty

T. G. McCarty
G. C. Millman
R. A. Moen
C. C. Neely
C. J. Pieper
R. F. Reedy
B. W. Roberts
F. J. Schaaf, Jr.
A. Selz
K. K. Tam
D. E. Tanner

EXECUTIVE COMMITTEE (MAIN COMMITTEE)

G. G. Karcher, *Chair*
D. A. Canonico, *Vice Chair*
J. S. Brzuszkiewicz, *Secretary*
F. P. Barton
J. R. Farr
J. G. Feldstein
M. Gold
O. F. Hedden
A. J. Justin
J. R. MacKay
T. G. McCarty
T. P. Pastor
T. E. Quaka
R. F. Reedy
A. J. Spencer

HONORARY MEMBERS (MAIN COMMITTEE)

R. D. Bonner
R. J. Bosnak
H. M. Canavan
L. J. Chockie
J. S. Clarke
W. E. Cooper
W. D. Doty
R. C. Griffin
E. J. Hemzy
E. C. Kistner, Jr.
J. E. Lattan
J. LeCoff
F. N. Moschini
C. E. Rawlins
W. E. Somers
L. P. Zick, Jr.

HONORS AND AWARDS COMMITTEE

J. R. MacKay, *Chair*

A. J. Spencer, *Vice Chair*

F. R. Lyons, *Secretary*

F. P. Barton

W. J. Carter

J. G. Feldstein

M. Gold

F. E. Gregor

E. C. Kistner, Jr.

T. P. Pastor

R. F. Reedy

MARINE CONFERENCE GROUP

J. Tiratto, *Chair*

C. F. Banks

L. W. Douthwaite

J. L. Jones

G. F. Wright

CONFERENCE COMMITTEE

D. E. Tanner - Tennessee (*Chair*)

R. D. Reetz - North Dakota (*Vice Chair*)

A. J. Justin - National Board of Boiler and Pressure Vessel Inspectors (*Secretary*)

R. J. Aben, Jr. - Michigan

J. S. Aclaro - Los Angeles, California

E. A. Anderson - Chicago, Illinois

J. Anderson - South Dakota

R. Barkdoll - Washington

F. P. Barton - Virginia

C. Castle - Nova Scotia, Canada

R. R. Cate - Louisiana

L. Chase - Northwest Territories, Canada

R. A. Coomes - Kentucky

J. Corcoran - Connecticut

M. H. Diehl, Jr. - Maryland

D. A. Douin - Illinois

D. Eastman - Newfoundland and Labrador, Canada

G. L. Ebeyer - New Orleans, Louisiana

F. Ellis - New Hampshire

E. Everett - Georgia

P. C. Hackford - Utah

D. Hanrath - North Carolina

J. B. Harlan - Delaware

K. Hynes - Prince Edward Island, Canada

D. T. Jagger - Ohio

D. J. Jenkins - Kansas

M. Kotb - Quebec, Canada

J. P. Larson - Minnesota

K. T. Lau - Alberta, Canada
J. Lemire - California
G. A. Lundberg - Florida
W. C. Lundine - Oregon
M. A. Malek - Maine
I. W. Mault - Manitoba, Canada
H. T. McEwen - Mississippi
A. W. Meiring - Indiana
R. Mile - Ontario, Canada
T. J. Monroe - Oklahoma
Y. Nagpaul - Hawaii
J. D. Payton - Pennsylvania
D. K. Peetz - Missouri
D. C. Price - Yukon Territory, Canada
R. S. Pucek - Wisconsin
T. E. Rennie - Arizona
L. Roussinos - British Columbia, Canada
M. Shuff - West Virginia
R. Snyder - New Jersey
N. Surtees - Saskatchewan, Canada
M. J. Verhagen - Wisconsin
R. B. West - Iowa
M. J. Wheel - Vermont
K. A. White - Nevada
R. K. White - New York
T. F. Wickham - Rhode Island
C. S. Withers - Colorado

SUBCOMMITTEE ON POWER BOILERS (SC I)

J. R. MacKay, *Chair*
M. D. Bernstein, *Vice Chair*
P. D. Stumpf, *Secretary*
D. L. Berger
E. Everett
D. N. French
F. R. Gerety
J. Hainsworth
T. E. Hansen
J. S. Hunter
W. L. Lowry
T. C. McGough
P. A. Molvie
D. K. Parrish
J. T. Pillow
R. G. Presnak
B. W. Roberts
R. D. Schueler, Jr.

Subgroup on Design (SC I)

M. D. Bernstein, *Chair*
R. D. Schueler, Jr., *Vice Chair*
P. A. Molvie, *Secretary*
M. A. Farrugia
J. D. Fishburn
C. F. Jeerings
K. C. Morrison
A. Nassif
N. Surtees
R. V. Wielgoszinski

Subgroup on Fabrication and Examination (SC I)

D. L. Berger, *Chair*
R. E. McLaughlin, *Secretary*
R. W. Boyce
D. N. French
J. Hainsworth
T. E. Hansen
M. H. Iken
J. M. Lyons
J. T. Pillow
M. E. Reese
R. D. Schueler, Jr.
R. F. Slack, Sr.
R. V. Wielgoszinski

Subgroup on General Requirements (SC I)

T. C. McGough, *Chair*
M. D. Bernstein, *Vice Chair*
W. L. Lowry, *Secretary*
D. L. Berger
E. Everett
F. R. Gerety
J. Hainsworth
C. F. Jeerings
J. M. Lyons
R. E. McLaughlin
D. K. Parrish
J. T. Pillow
W. E. Somers
R. L. Williams

Subgroup on Materials (SC I)

B. W. Roberts, *Chair*

C. E. Spaeder, Jr., *Chair*
J. S. Hunter, *Secretary*
T. M. Cullen
D. N. French
J. F. Henry
J. P. Libbrecht
F. Masuyama
J. M. Tanzosh

Subgroup on Piping (SC I)

T. E. Hansen, *Chair*
D. L. Berger
M. D. Bernstein
P. D. Edwards
W. L. Lowry
T. C. McGough
R. G. Presnak
E. Whittle
P. L. Ziegler

SUBCOMMITTEE ON MATERIALS (SC II)

M. Gold, *Chair*
T. M. Cullen, *Vice Chair*
F. R. Lyons, *Secretary*
A. P. Ahrendt
M. N. Bressler
A. Cohen
R. Dirscherl
W. D. Doty
W. D. Edsall
D. Gandy
M. H. Gilkey
J. J. Heger
J. F. Henry
G. C. Hsu
F. Masuyama
E. Michalopoulos
R. A. Moen
R. K. Nanstad
E. G. Nisbett
J. T. Parsons
D. W. Rahoi
B. W. Roberts
E. Shapiro
C. E. Spaeder, Jr.
R. W. Swindeman
J. M. Tanzosh
B. E. Thurgood

A. W. Zeuthen

Subgroup on External Pressure (SC II)

R. W. Mikitka, *Chair*

D. J. Green

D. S. Griffin

E. Michalopoulos

B. R. Morelock

D. Nadel

C. E. Spaeder, Jr.

C. H. Sturgeon

Subgroup on Ferrous Specifications (SC II)

E. G. Nisbett, *Chair*

B. M. Dingman

W. D. Edsall

T. Graham

W. N. Holliday

E. A. Jonas

D. C. Krouse

J. F. Longenecker

W. C. Mack

A. S. Melilli

J. T. Parsons

E. J. Rozic, Jr.

E. Upitis

A. W. Zeuthen

R. H. Zong

Subgroup on International Material Specifications (SC II)

J. T. Parsons, *Chair*

D. C. Agarwal

J. Cameron

R. Dirscherl

W. D. Doty

D. M. Fryer

M. Gold

M. H. Iken

W. M. Lundy

H. Masahisa

T. F. Miskell

F. Osweiller

A. P. Povilonis

R. D. Schueler, Jr.

R. R. Seeley

E. A. Steen

E. Upitis

E. O. Woolridge

Subgroup on Nonferrous Alloys (SC II)

D. W. Rahoi, *Chair*
D. C. Agarwal, *Secretary*
W. R. Apblett
L. G. Coffee
A. Cohen
R. Dirscherl
M. H. Gilkey
G. C. Hsu
M. Katcher
E. Shapiro
L. E. Shoemaker
R. C. Sutherlin

Subgroup on Strength, Ferrous Alloys (SC II)

B. W. Roberts, *Chair*
J. M. Tanzosh, *Secretary*
A. P. Ahrendt
W. R. Apblett
T. M. Cullen
M. Gold
J. J. Heger
C. L. Hoffmann
A. Iseda
F. Masuyama
R. A. Moen
D. W. Rahoi
C. E. Spaeder, Jr.
R. W. Swindeman
B. E. Thurgood

Subgroup on Strength of Weldments (SC II & SC IX)

C. E. Spaeder, Jr., *Chair*
W. D. Doty
D. W. Rahoi
B. W. Roberts
C. Robino
W. J. Sperko
J. M. Tanzosh
B. E. Thurgood

Subgroup on Toughness (SC II)

J. M. Barsom
D. A. Hansen
A. Selz
R. S. Vecchio
S. Yukawa
R. Zawierucha

SUBCOMMITTEE ON NUCLEAR POWER (SC III)

C. J. Pieper, *Chair*
R. M. Jessee, *Vice Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
Y. Asada
R. W. Barnes
J. N. Baysden
W. H. Borter
E. B. Branch
M. N. Bressler
F. C. Cherny
G. D. Cooper
R. P. Deubler
W. D. Doty
F. R. Drahos
K. Ennis
B. A. Erler
D. Hanrath
C. L. Hoffmann
K.-H. Hsu
D. F. Landers
W. C. LaRochelle
T. J. Mawson
W. N. McLean
R. A. Moen
D. B. Nickerson
R. F. Perrin
R. F. Reedy
M. W. Smith
J. D. Stevenson
R. E. Tome
K. R. Wichman

Subgroup on Containment Systems for Spent Fuel and High-Level Waste Transport Packagings (SC III)

J. D. Stevenson, *Chair*
H. H. Chung
R. R. Doggart
E. L. Farrow
K. Goldmann
R. H. Jones
W. H. Lake
R. W. Lambert
H. W. Lee
P. McConnell

R. E. Nickell
D. J. Nolan
D. T. Raske
T. Saegusa
R. H. Smith
K. B. Sorenson
P. Turula
N. Urabe
C. R. Witt
S. Yukawa

Subgroup on Design (SC III)

R. W. Barnes, *Chair*
E. B. Branch, *Vice Chair*
R. S. Hill III, *Secretary*
Y. Asada
M. N. Bressler
C. W. Bruny
J. R. Cole
G. D. Cooper
R. P. Deubler
N. W. Edwards
R. E. Gimple
D. Hanrath
R. W. Haupt
T. Iida
B. Jarman
D. F. Landers
W. N. McLean
D. B. Nickerson
E. C. Rodabaugh
J. R. Santangelo
G. C. Slagis
J. D. Stevenson
J. H. Wawrzeniak
K. R. Wichman
R. Wray

Working Group on Administration (SG-D) (SC III)

E. B. Branch, *Chair*
R. W. Barnes, *Vice Chair*
R. S. Hill III, *Secretary*
C. W. Bruny
G. D. Cooper
R. P. Deubler
J. T. Land
D. F. Landers
W. N. McLean

D. B. Nickerson
J. R. Santangelo
R. Wray

Working Group on Core Support Structures (SG-D) (SC III)

J. T. Land, *Chair*
R. H. Hansen
K. B. Larsen
J. F. Mullooly
B. L. Silverblatt

Working Group on Dynamic and Extreme Load Conditions (SG-D) (SC III)

R. Wray, *Chair*
A. E. Meligi, *Secretary*
P. L. Anderson
M. K. Au-Yang
R. D. Blevins
G. J. Bohm
D. L. Caldwell
P.-Y. Chen
A. Hadjian
M. Hartzman
W. S. LaPay
H. Lockert
P. R. Olson
R. F. Perry
J. Wallach

Working Group on Piping (SG-D) (SC III)

D. F. Landers, *Chair*
R. S. Hill III, *Vice Chair*
P. Hirschberg, *Secretary*
T. M. Adams
G. A. Antaki
J. R. Cole
A. B. Glickstein
R. W. Haupt
J. C. Hennart
R. D. Hookway
R. B. Jenkins
K. A. Manoly
J. C. Minichiello
S. E. Moore
A. N. Nguyen
D. B. Nickerson
O. O. Oyamada
R. D. Patel
E. C. Rodabaugh

J. R. Santangelo
M. S. Sills
G. C. Slagis
E. A. Wais

Working Group on Pumps (SG-D) (SC III)

D. B. Nickerson, *Chair*
H. L. Brammer
P. Burchett
R. E. Cornman, Jr.
A. A. Fraser
M. Higuchi
G. R. Jones
J. W. Leavitt
J. E. Livingston
R. A. Schussler
H. Taffarodi
G. K. Vaghasia

Working Group on Supports (SG-D) (SC III)

R. P. Deubler, *Chair*
R. M. Dulin, Jr., *Secretary*
U. S. Bandyopadhyay
F. J. Birch
M. N. Bressler
J. R. Cole
J. C. Finneran, Jr.
R. W. Haupt
J. C. Hennart
A. S. Laurensen
A. Lee
R. J. Masterson
A. E. Meligi
A. N. Nguyen
J. R. Stinson

Working Group on Valves (SG-D) (SC III)

W. N. McLean, *Chair*
E. A. Bake
R. R. Brodin
W. G. Knecht
R. Koester
J. J. McGavin
S. N. Shields
H. R. Sonderegger
J. C. Tsacoyeanes
R. G. Visalli
J. R. Zahorsky

Working Group on Vessels (SG-D) (SC III)

C. W. Bruny, *Chair*

T. K. Burr, Sr.

G. D. Cooper

G. A. Deaver

N. W. Edwards

D. Hanrath

W. J. Heilker

B. Jarman

T. M. Khan

O. Maekawa

K. A. Manoly

A. Merend

G. K. Miller

W. Z. Novak

E. Pelling

H. S. Thornton

Page xvi

Special Working Group on Environmental Effects (SG-D) (SC III)

R. S. Hill III, *Chair*

Y. Asada

W. J. Heilker

C. L. Hoffmann

R. A. Moen

W. Z. Novak

S. Yukawa

Special Working Group on Seismic Piping Rules (SG-D) (SC III)

E. B. Branch, *Chair*

T. M. Adams

G. A. Antaki

R. D. Hookway

J. C. Minichiello

M. S. Sills

E. A. Wais

Subgroup on General Requirements (SC III & SC 3C)

W. C. LaRochelle, *Chair*

K. Ennis, *Secretary*

A. Appleton

J. R. Barbee

J. N. Baysden

L. M. Beason

B. H. Berg

R. E. Kelley

G. S. Korin

A. S. Laurenson

C. Lizotte
M. J. Meyer
M. R. Minick
L. C. Oakes
R. F. Perrin
U. Potapovs
B. B. Scott
D. E. Tanner
D. V. Walshe

Subgroup on Materials, Fabrication, and Examination (SC III)

C. L. Hoffmann, *Chair*
G. P. Milley, *Secretary*
C. W. Allison
D. Doyle
F. R. Drahos
G. M. Foster
G. B. Georgiev
J. E. Harris
R. W. Jackson
R. M. Jessee
C. C. Kim
R. A. Moen
C. J. Pieper
R. R. Seeley
N. M. Simpson
R. C. Soin
W. J. Sperko
K. B. Stuckey
S. Yukawa

Subgroup on Pressure Relief (SC III)

F. C. Cherny, *Chair*
S. F. Harrison, Jr.
E. M. Petrosky
M. W. Smith
A. L. Szeglin
B. S. York
J. R. Zahorsky

Special Working Group on Editing and Review (SC III)

R. F. Reedy, *Chair*
W. H. Borter
M. N. Bressler
R. P. Deubler
B. A. Erler
W. C. LaRochelle
M. W. Smith

J. D. Stevenson
E. O. Woolridge

JOINT ACI-ASME COMMITTEE ON CONCRETE COMPONENTS FOR NUCLEAR SERVICE (SC 3C)

B. A. Erler, *Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
R. M. Attar
A. C. Eberhardt
J. Gutierrez
D. J. Haavik
M. F. Hessheimer
T. E. Johnson
G. R. Murphy
S. F. Putman
B. B. Scott
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Design (SC 3C)

D. G. Adams
A. C. Eberhardt
T. E. Johnson
S. F. Putman
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Materials, Construction, and Examination (SC 3C)

D. J. Haavik, *Chair*
J. F. Artuso
R. M. Attar
B. A. Erler
J. Gutierrez

SUBCOMMITTEE ON HEATING BOILERS (SC IV)

F. P. Barton, *Chair*
P. A. Molvie, *Vice Chair*
B. P. Feder, *Secretary*
R. B. Duggan
W. L. Haag, Jr.
W. M. Hiddleston
J. D. Hoh
K. M. McTague
R. I. Mullican
E. A. Nordstrom
J. L. Seigle
D. E. Tanner

S. V. Voorhees
R. H. Weigel
R. V. Wielgoszinski
J. I. Woodworth
T. L. Bedeaux, Alternate

Subgroup on Care and Operation of Heating Boilers (SC IV)

J. I. Woodworth, *Chair*
B. P. Feder, *Secretary*
K. J. Hoey
J. D. Hoh
F. M. Lucas
K. M. McTague
P. A. Molvie
R. I. Mullican
R. H. Weigel
T. F. Wickham
T. L. Bedeaux, Alternate

Subgroup on Cast Iron Boilers (SC IV)

K. M. McTague, *Chair*
R. B. Duggan
R. H. Weigel
T. F. Wickham
J. I. Woodworth
T. L. Bedeaux, Alternate

Subgroup on Water Heaters (SC IV)

W. L. Haag, Jr., *Chair*
T. D. Gantt
W. M. Hiddleston
F. M. Lucas
K. M. McTague
R. I. Mullican
D. Smith
D. E. Tanner
M. A. Taylor

Subgroup on Welded Boilers (SC IV)

P. A. Molvie, *Chair*
T. L. Bedeaux
D. H. Mapes
E. A. Nordstrom
J. L. Seigle
R. F. Slack, Sr.
R. P. Sullivan
D. E. Tanner
R. V. Wielgoszinski

SUBCOMMITTEE ON NONDESTRUCTIVE EXAMINATION (SC V)

T. G. McCarty, *Chair*
J. E. Batey, *Vice Chair*
F. S. Fitzgerald, *Secretary*
A. S. Birks
B. H. Clark, Jr.
W. T. Clayton
R. A. Coomes
N. Y. Faransso
H. C. Graber
O. F. Hedden
G. W. Hembree
F. B. Kovacs
J. F. Manning
W. C. McGaughey
R. D. McGuire

Page xvii

Subgroup on General Requirements/Personnel Qualifications and Inquiries (SC V)

R. D. McGuire, *Chair*
J. E. Batey
W. T. Clayton
N. Y. Faransso
H. C. Graber
G. W. Hembree
J. R. MacKay
J. P. Swezy

Subgroup on Surface Examination Methods (SC V)

H. C. Graber, *Chair*
S. J. Akrin
T. Alexander
A. S. Birks
B. H. Clark
R. A. Coomes
G. W. Hembree

Subgroup on Volumetric Methods (SC V)

J. E. Batey, *Chair*
S. J. Akrin
W. T. Clayton
N. Y. Faransso
H. C. Graber
G. W. Hembree
B. Kellerhall
E. K. Kietzman
F. B. Kovacs
R. W. Kruzic
J. F. Manning

W. C. McGaughey

J. R. Mitchell

Working Group on Acoustic Emissions (SG-VM) (SC V)

B. H. Clark, Jr.

P. M. Horrigan

J. F. Manning

J. R. Mitchell

Working Group on Radiography (SG-VM) (SC V)

G. W. Hembree, *Chair*

S. J. Akrin

T. Alexander

J. E. Batey

N. Y. Faransso

H. C. Graber

F. B. Kovacs

Working Group on Ultrasonics (SG-VM) (SC V)

W. T. Clayton, *Chair*

O. F. Hedden

B. Kellerhall

E. K. Kietzman

J. F. Manning

W. C. McGaughey

R. Paillaman

F. J. Sattler

M. L. Shakinovsky

SUBCOMMITTEE ON PRESSURE VESSELS (SC VIII)

T. P. Pastor, *Chair*

K. Mokhtarian, *Vice Chair*

A. J. Roby, *Secretary*

A. P. Ahrendt

V. Bogosian

S. M. Caldwell

W. J. Carter

S. C. Cyr

R. Dirscherl

R. M. Elliott

J. R. Farr

R. E. Feigel

J. G. Feldstein

G. L. Hollinger

M. J. Houle

W. S. Jacobs

G. G. Karcher

G. B. Komora

K. T. Lau

R. W. Mikitka
U. R. Miller
C. C. Neely
K. J. Schneider
A. Selz
J. R. Sims, Jr.
A. J. Spencer
E. A. Steen
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Design (SC VIII)

U. R. Miller, *Chair*
R. E. Knoblock, *Secretary*
M. R. Bauman
M. R. Breach
S. M. Caldwell
N. W. Edwards
J. R. Farr
J. A. Hayward
G. L. Hollinger
W. S. Jacobs
G. G. Karcher
G. B. Komora
R. W. Mikitka
K. Mokhtarian
T. P. Pastor
M. D. Rana
A. Selz
S. C. Shah
J. W. Stokes
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Fabrication and Inspection (SC VIII)

E. A. Steen, *Chair*
K. Mokhtarian, *Vice Chair*
W. J. Bees
R. W. Boyce
S. C. Cyr
R. E. Feigel
H. E. Gordon
M. J. Houle
W. S. Jacobs
R. A. Johnson
A. S. Lester III
F. C. Ouyang

M. J. Rice
W. P. Webb

Subgroup on General Requirements (SC VIII)

R. M. Elliott, *Chair*
A. P. Ahrendt
V. Bogosian
W. J. Carter
W. P. Crow
J. P. Glaspie
C. R. Good
D. B. Kadakia
J. C. Keenan
W. E. Laveck, Jr.
A. S. Mann
C. C. Neely
A. S. Olivares
K. J. Schneider
A. J. Spencer

Subgroup on Materials (SC VIII)

R. Dirscherl, *Chair*
D. C. Agarwal
A. P. Ahrendt
J. Cameron
W. D. Doty
W. D. Edsall
M. Katcher
W. M. Lundy
E. E. Morgenegg
E. G. Nisbett
J. T. Parsons
D. W. Rahoi
K. K. Tam
B. K. Thakur

Special Working Group on Heat Transfer Equipment (SC VIII)

G. B. Komora, *Chair*
R. P. Zoldak, *Secretary*
C. F. Andreone
D. E. Bolt
S. M. Caldwell
T. K. Haldas
M. J. Holtz
W. G. Jandrasits
R. Mahadeen
U. R. Miller
F. Osweiller
J. E. Soehrens

Special Working Group on High-Pressure Vessels (SC VIII)

J. R. Sims, Jr., *Chair*
P. A. Reddington, *Secretary*
L. P. Antalffy
J. E. Baxter
R. C. Biel
T. B. Boyd
D. J. Burns
P. N. Chaku
E. L. Danfelt
R. E. Feigel
D. M. Fryer
J. L. Heck, Jr.
A. H. Honza
V. T. Hwang
M. M. James
P. Jansson
J. A. Kapp
D. P. Kendall
A. K. Khare
S. C. Mordre
G. J. Mraz
E. H. Perez
L. M. Picqueur
E. D. Roll
W. L. Stewart
J. F. Sullivan
F. W. Tatar

Special Working Group on Toughness (SC VIII)

W. S. Jacobs, *Chair*
J. Cameron
W. D. Doty
D. A. Hansen
G. G. Karcher
G. B. Komora
K. Mokhtarian
J. L. Mooney
C. C. Neely
M. D. Rana
J. W. Stokes

SUBCOMMITTEE ON WELDING (SC IX)

J. G. Feldstein, *Chair*
W. J. Sperko, *Vice Chair*
J. Labrador, *Secretary*
R. Barkdoll
D. A. Bowers
M. L. Carpenter
W. D. Doty
P. D. Flenner
M. J. Houle
R. A. Johnson
W. M. Lundy
R. D. McGuire
J. J. Meyer
A. H. Miller
B. R. Newmark
P. P. Norris
S. D. Reynolds, Jr.
W. K. Scattergood
G. W. Spohn III
M. J. Stanko
J. M. Tanzosh
R. R. Young

Subgroup on Brazing (SC IX)

M. J. Houle, *Chair*
A. S. Artayet
M. L. Carpenter
C. F. Jeerings
A. H. Miller
C. Robino

Subgroup on General Requirements (SC IX)

B. R. Newmark, *Chair*
R. Barkdoll
P. R. Evans
P. C. Filean
R. M. Jessee
D. W. Mann
A. S. Olivares
C. E. Wainwright
R. A. Weiss
K. R. Willens

Subgroup on Materials (SC IX)

M. L. Carpenter, *Chair*
L. P. Connor
P. D. Flenner
R. M. Jessee

A. H. Miller
H. A. Sadler
C. E. Sainz
C. E. Spaeder, Jr.
W. J. Sperko
M. J. Stanko
R. R. Young

Subgroup on Performance Qualification (SC IX)

J. J. Meyer, *Chair*
V. A. Bell
D. A. Bowers
L. P. Connor
R. A. Coomes
P. D. Flenner
G. Herrmann
M. J. Houle
W. M. Lundy
R. D. McGuire
S. R. Nordman
P. P. Norris
W. K. Scattergood
G. W. Spohn III

Subgroup on Procedure Qualification (SC IX)

J. J. Meyer, *Chair*
R. K. Brown, Jr.
R. A. Johnson
A. H. Miller
P. P. Norris
A. S. Olivares
F. C. Ouyang
S. D. Reynolds, Jr.
M. J. Rice
W. K. Scattergood
W. J. Sperko
T. C. Wiesner

SUBCOMMITTEE ON FIBER-REINFORCED PLASTIC PRESSURE VESSELS (SC X)

P. J. Conlisk, *Chair*
D. Eisberg, *Vice Chair*
A. J. Roby, *Secretary*
K. M. Agrawal
F. L. Brown
J. L. Bustillos
T. W. Cowley
T. J. Fowler
S. V. Hoa

L. E. Hunt
J. C. Murphy
A. L. Newberry
D. J. Painter
J. A. Rolston
B. F. Shelley
P. R. Wilt

SUBCOMMITTEE ON NUCLEAR INSERVICE INSPECTION (SC XI)

O. F. Hedden, *Chair*
T. J. Mawson, *Vice Chair*
G. L. Fechter, *Secretary*
C. W. Allison
W. H. Bamford, Jr.
R. L. Beverly
J. M. Bloom
R. W. Boyce
C. D. Cowfer
D. D. Davis
R. L. Dyle
T. N. Epps III
R. E. Gimple
F. E. Gregor
L. B. Gross
K. Iida
C. A. Ireland
R. D. Kerr
D. F. Landers
T. F. Lentz
J. T. Lindberg
G. C. Millman
C. R. Osman
P. C. Riccardella
L. Sage
F. J. Schaaf, Jr.
J. E. Staffiera
R. P. Sullivan
R. W. Swayne
R. J. Tamminga
J. C. Tobin
R. A. Yonekawa

Honorary Members (SC XI)

S. H. Bush
L. J. Chockie
J. P. Houstrup
L. R. Katz
R. R. MacCary

Subgroup on Evaluation Standards (SC XI)

W. H. Bamford, Jr., *Chair*
M. Kupinski, *Secretary*
J. M. Bloom
R. C. Cipolla
R. M. Gamble
T. J. Griesbach
P. J. Hijeck
K. Iida
Y. Imamura
J. G. Merkle
S. Ranganath
P. C. Riccardella
D. A. Scarth
W. L. Server
C. A. Tomes
W. A. Van Der Sluys
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa

Working Group on Flaw Evaluation (SG-ES) (SC XI)

R. C. Cipolla, *Chair*
W. H. Bamford, Jr.
M. Basol
J. M. Bloom
E. Friedman
T. J. Griesbach
F. D. Hayes
D. N. Hopkins
K. Iida
Y. Imamura
M. Kupinski
H. S. Mehta
J. G. Merkle
J. S. Panesar
R. K. Qashu
S. Ranganath
D. A. Scarth
T. S. Schurman
W. L. Server
F. A. Simonen
K. R. Wichman
G. M. Wilkowski

K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Working Group on Operating Plant Criteria (SG-ES) (SC XI)

T. J. Griesbach, *Chair*
W. H. Bamford, Jr.
H. Behnke
B. A. Bishop
W. F. Brady
E. Friedman
S. R. Gosselin
E. M. Hackett
P. J. Hijeck
S. D. Leshnoff
P. Manbeck
J. S. Panesar
W. E. Pennell
J. H. Phillips
S. Ranganath
S. T. Rosinski
W. L. Server
E. A. Siegel
F. A. Simonen
T. D. Spry
K. K. Yoon
S. Yukawa

Working Group on Pipe Flaw Evaluation (SG-ES) (SC XI)

D. A. Scarth, *Chair*
G. M. Wilkowski, *Secretary*
W. H. Bamford, Jr.
J. M. Bloom
R. C. Cipolla
N. G. Cofie
S. K. Daftuar
G. H. De Boo
E. Friedman
D. N. Hopkins
K. Iida
H. S. Mehta
J. G. Merkle
J. S. Panesar
D. Quinones
K. K. Yoon
S. Yukawa
A. Zahoor

V. A. Zilberstein

Subgroup on Liquid-Metal-Cooled Systems (SC XI)

C. G. McCargar, *Chair*

W. L. Chase

S. Hattori

R. Hundal

W. Kwant

J. C. Tobin

Working Group on Liquid-Metal Reactor Covers (SG-LMCS) (SC XI)

W. L. Chase, *Chair*

S. Hattori

R. Hundal

W. Kwant

Subgroup on Nondestructive Examination (SC XI)

R. L. Beverly, *Chair*

N. R. Bentley, *Secretary*

D. C. Adamonis

F. L. Becker

F. T. Carr

C. B. Cheezem

W. T. Clayton

C. D. Cowfer

F. J. Dodd

T. N. Epps III

D. O. Henry

M. R. Hum

S. N. Liu

R. D. McGuire

M. C. Modes

C. R. Osman

F. J. Schaaf, Jr.

J. C. Spanner, Jr.

C. J. Wirtz

Working Group on Personnel Qualification and Surface Visual and Eddy Current Examination (SG-NDE) (SC XI)

C. J. Wirtz, *Secretary*

B. L. Curtis

N. Economos

H. B. Garland

D. O. Henry

H. E. Houserman

J. J. McArdle III

R. D. McGuire

S. A. Redner

M. F. Sherwin

A. L. Smith

D. Spake
J. C. Spanner, Sr.
J. C. Spanner, Jr.
T. V. Tran

Working Group on Pressure Testing (SG-NDE) (SC XI)

G. P. Alexander
T. M. Anselmi
T. B. Basso
J. Boughman
T. R. Bugelholll
R. J. Cimocho
C. E. Jensen
W. N. Keisler
D. Lamond
F. J. Schaaf, Jr.
D. Terao

Working Group on Procedure Qualification and Volumetric Examination (SG-NDE) (SC XI)

C. D. Cowfer, *Chair*
C. E. Larsen, *Secretary*
D. C. Adamonis
F. L. Becker
N. R. Bentley
B. Bevins
F. T. Carr
C. B. Cheezem
W. T. Clayton
S. R. Doctor
F. J. Dodd
T. N. Epps III
B. Kellerhall
G. A. Lofthus
J. K. McClanahan
M. C. Modes
M. Saporito
T. T. Taylor
S. M. Walker

Subgroup on Repairs, Replacements, and Modifications (SC XI)

R. E. Gimple, *Chair*
W. C. Holston, *Secretary*
R. W. Boyce
M. N. Bressler
S. B. Brown
C. E. Hartz
R. A. Hermann
C. A. Ireland

R. D. Kerr
D. F. Landers
R. S. Lewis
T. J. Mawson
M. S. McDonald
R. R. Stevenson
R. P. Sullivan
R. W. Swayne
R. E. Tome
D. E. Waskey
R. A. Yonekawa

Page xx

Working Group on Design Reconciliation (SG-RR&M) (SC XI)

W. C. Holston, *Chair*
J. T. Conner, *Secretary*
R. W. Boyce
S. B. Brown
J. E. Chamley
T. E. Hiss
E. V. Imbro
D. N. Irvine, Jr.
D. F. Landers
R. W. Swayne
F. Tehranchi
H. J. Thailer
R. E. Tome

Working Group on Responsibilities and Program Requirements (SG-RR&M) (SC XI)

R. A. Yonekawa, *Chair*
R. R. Stevenson, *Secretary*
S. K. Fisher
G. M. Foster
C. E. Hartz
R. S. Lewis
M. S. McDonald
U. Potapovs
S. M. Swilley
A. J. Walcutt
J. Ghergurovich, *Alternate*

Working Group on Welding and Special Repair Processes (SG-RR&M) (SC XI)

D. E. Waskey, *Chair*
R. E. Cantrell, *Secretary*
D. A. Delsignore
A. L. Finney
P. D. Fisher
A. J. Giannuzzi

R. A. Hermann
R. P. Indap
R. D. Kerr
B. R. Newton
P. P. Norris
J. E. O'Sullivan
J. H. Sodergren
K. R. Willens

Subgroup on Water-Cooled Systems (SC XI)

T. F. Lentz, *Chair*
K. Christian, *Secretary*
C. W. Allison
W. J. Briggs
T. R. Bugelholl
D. D. Davis
A. F. Deardorff
R. L. Dyle
L. B. Gross
T. C. Hinkle
S. D. Kulat
M. P. Lintz
J. E. Staffiera
C. W. Tahnk
R. J. Tamminga
D. Terao
S. M. Walker
R. A. West

Working Group on Concrete Containment (SG-WCS) (SC XI)

W. J. Briggs, *Chair*
B. Talmadge, *Secretary*
H. G. Ashar
K. K. N. Chao
M. J. Ferlisi
H. T. Hill
R. D. Hough
C. N. Krishnaswamy
D. Naus
S. C. Petitgout
C. G. Ranganath

Working Group on Implementation of Risk-Based Examination (SG-WCS) (SC XI)

T. J. Mawson, *Chair*
A. McNeill III, *Secretary*
J. Agold
S. A. Ali
B. A. Bishop

J. W. Connor
A. F. Deardorff
H. Q. Do
R. Fougrousse
S. R. Gosselin
J. T. Lindberg
I. Mach
R. K. Mattu
P. J. O'Regan
J. H. Phillips
F. A. Simonen
T. V. Vo
R. A. West

Working Group on Inspection of Systems and Components (SG-WCS) (SC XI)

R. L. Dyle, *Chair*
G. C. Park, *Secretary*
G. L. Belew
T. W. Brombach
R. Fougrousse
T. C. Hinkle
M. R. Hum
S. D. Kulat
J. T. Lindberg
M. P. Lintz
T. K. McLellan
C. Pendleton
C. M. Ross
C. W. Tahnk
K. B. Thomas
E. Throckmorton
R. A. West
J. Whitman

Working Group on Metal Containment (SG-WCS) (SC XI)

J. E. Staffiera, *Chair*
W. E. Norris, *Secretary*
W. J. Briggs
K. K. N. Chao
M. J. Ferlisi
R. W. Hammelmann
M. P. Lintz
S. C. Petitgout
C. G. Ranganath
G. W. Robin
R. T. Zak

Special Working Group on Low-Temperature Heavy Water Reactors (SG-WCS) (SC XI)

C. D. Cowfer, *Chair*

J. M. Morrison, *Secretary*

B. Awadalla

K. F. Schmidt

P. R. Vormelker

S. H. Zaidi

Working Group on General Requirements (SC XI)

A. T. Roberts III, *Chair*

R. G. Edl, *Secretary*

D. A. Graham

L. B. Gross

C. A. Ireland

D. A. Jackson

R. K. Mattu

L. Sage

R. J. Scott

J. C. Shropshire

R. J. Tamminga

Special Working Group on Editing and Review (SC XI)

R. W. Swayne, *Chair*

R. L. Beverly

L. B. Gross

M. P. Lintz

J. E. Staffiera

C. J. Wirtz

Special Working Group on Plant Life Extension (SC XI)

F. E. Gregor, *Chair*

L. B. Gross, *Secretary*

D. D. Davis

D. A. Graham

D. L. Harrison

M. P. Lintz

P. Manbeck

H. W. Massie, Jr.

D. W. Peltola

D. A. Piccione

C. M. Regan

V. N. Shah

R. J. Tamminga

SUBCOMMITTEE ON TRANSPORT TANKS (SC XII)

A. Selz, *Chair*

P. D. Stumpf, *Secretary*

A. N. Antoniou

S. C. Cyr

K. Ennis

M. Hennemand

M. Hennemand
C. H. Hochman
G. G. Karcher
P. P. Laluc
G. McRae
M. R. Minick
T. P. Pastor
M. D. Rana
C. M. Serratella
G. R. Stoeckinger
N. Surtees
J. P. Swezy
A. P. Varghese
S. V. Voorhees
W. L. White

Page xxi

Subgroup on Design and Materials (SC XII)

M. D. Rana, *Chair*
D. A. Canonico
W. D. Doty
G. G. Karcher
P. P. Laluc
T. P. Pastor
T. A. Rogers
C. M. Serratella
A. P. Varghese
E. Whittle

Subgroup on Fabrication and Inspection (SC XII)

S. V. Voorhees, *Chair*
D. A. Canonico
M. L. Coats
M. Hennemand
D. J. Kreft
G. McRae
M. R. Minick
N. Surtees
J. P. Swezy

Subgroup on General Requirements (SC XII)

C. H. Hochman, *Chair*
T. Alexander
A. N. Antoniou
D. Carter
K. Ennis
M. A. Garrett
J. C. Keenan
F. A. Licari

G. R. Stoeckinger
W. L. White

SUBCOMMITTEE ON BOILER AND PRESSURE VESSEL ACCREDITATION (SC-BPVA)

A. J. Spencer, *Chair*
A. J. Justin, *Vice Chair*
K. I. Baron, *Secretary*
M. B. Doherty
D. A. Douin
P. D. Edwards
R. M. Elliott
C. E. Ford
J. J. Greene
R. C. Howard
B. B. MacDonald
M. L. Sisk
B. C. Turczynski
R. V. Wielgoszinski
R. L. Williams
V. A. Bell, Alternate
V. Bogosian, Alternate
M. A. De Vries, Alternate
J. R. Farr, Alternate
R. G. Friend, Alternate
W. C. LaRochelle, Alternate
A. S. Lester III, Alternate
K. M. McTague, Alternate
G. P. Milley, Alternate
R. E. Muise, Alternate
P. G. Scheckermann, Alternate
N. Surtees, Alternate

SUBCOMMITTEE ON NUCLEAR ACCREDITATION (SC-NA)

T. E. Quaka, *Chair*
R. R. Stevenson, *Vice Chair*
S. Griffin, *Secretary*
C. W. Allison
M. N. Bressler
G. Deily
F. R. Drahos
J. E. Harris
M. Kotb
W. C. LaRochelle
U. Potapovs
H. B. Prasse
A. J. Spencer
G. M. Tolson

L. M. Beason, Alternate
R. W. Boyce, Alternate
S. Dasgupta, Alternate
P. D. Edwards, Alternate
J. P. Ellenberger, Alternate
R. E. Feigel, Alternate
D. Hanrath, Alternate
K. A. Huber, Alternate
A. J. Justin, Alternate
N. C. Kist, Alternate
A. A. Lotfi, Alternate
R. P. McIntyre, Alternate
O. E. Trapp, Staff Representative

SUBCOMMITTEE ON DESIGN (SC-D)

W. J. Carter, *Chair*
F. S. Fitzgerald, *Secretary*
R. W. Barnes
C. Becht IV
O. F. Hedden
R. W. Mikitka
K. Mokhtarian
W. J. O'Donnell
R. D. Schueler, Jr.
M. P. Schwartz
A. Selz

Subgroup on Design Analysis (SC-D)

T. P. Pastor, *Secretary*
P. J. Conlisk
A. G. Eggers
J. L. Hechmer
G. L. Hollinger
D. P. Jones
A. Kalnins
W. J. Koves
T. H. Liu
O. Maekawa
A. Merend
T. V. Narayanan
E. L. Thomas, Jr.

Subgroup on Elevated Temperature Design (SC-D)

C. Becht IV, *Chair*
J. M. Corum, *Secretary*
C. R. Brinkman
R. D. Campbell
D. S. Griffin
R. I. Jetter

R. I. Jetter
C. Lawton
W. J. O'Donnell
D. A. Osage
C. C. Schultz, Jr.
L. K. Severud
D. F. Shaw
A. L. Snow
B. E. Thurgood

Subgroup on Fatigue Strength (SC-D)

C. R. Brinkman
P. R. Donavin
J. A. Hayward
J. L. Hechmer
D. P. Jones
G. Kharshafdjian
C. Lawton
A. Merend
H. H. Ziada

Subgroup on Openings (SC-D)

M. P. Schwartz, *Chair*
R. W. Mikitka, *Secretary*
M. R. Breach
V. T. Hwang
S. C. Lou
R. B. Luney
J. P. Madden
K. C. Morrison
D. R. Palmer
M. D. Rana
E. C. Rodabaugh

Special Working Group on Bolted Flanged Joints (SC-D)

R. W. Mikitka, *Chair*
G. D. Bibel
G. Kharshafdjian
D. L. Kurle
E. Michalopoulos
S. N. Pagay
J. R. Payne
R. W. Schneider
R. D. Schueler, Jr.
A. Selz

SUBCOMMITTEE ON SAFETY VALVE REQUIREMENTS (SC-SVR)

E. C. Kistner, Jr., *Chair*
M. D. Bernstein, *Vice Chair*

U. D'Urso, *Secretary*
J. F. Ball
J. A. Cox
R. D. Danzy
R. J. Doelling
D. A. Douin
R. G. Friend
H. I. Gregg
S. F. Harrison, Jr.
C. F. Laitner
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson
D. J. Scallan
C. M. Schroepfer
A. J. Spencer
J. C. Standfast
E. A. Steen
L. L. Thompson
J. A. West
T. J. Ferrigan, *Alternate*

Page xxii

Subgroup on Design (SC-SVR)

R. G. Friend, *Chair*
J. Cahoon, Jr.
R. D. Danzy
D. B. DeMichael
R. J. Doelling
H. I. Gregg
S. R. Irvin
C. F. Laitner
P. R. Sievert
A. J. Spencer
E. A. Steen
T. R. Tarbay
J. A. West

Subgroup on General Requirements (SC-SVR)

M. D. Bernstein, *Chair*
J. F. Ball
V. M. Deluca
D. A. Douin
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson

J. C. Standfast
L. L. Thompson

Subgroup on Testing (SC-SVR)

S. F. Harrison, Jr., *Chair*
S. Cammeresi
J. A. Cox
W. F. Hart
D. M. Papa
D. J. Scallan
C. M. Schroepfer
D. E. Snyder

Page xxiii

ORGANIZATION OF SECTION III

1. GENERAL

Section III consists of Division 1, Division 2, and Division 3. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter "N" for Division 1, by the letter "C" for Division 2, and by the letter "W" for Division 3. The following eleven books make up the three Divisions.

Subsection NCA - General Requirements for Division 1 and Division 2

Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

Division 2 - Code for Concrete Reactor Vessels and Containments

Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

The Division 2 book includes Subsection CC - Concrete Containments and Division 2 Appendices.

The Division 3 book includes Subsections WA and WB for General Requirements and Class TP (Type B) Containment, respectively.

2. SUBSECTIONS

Subsections are divided into Articles, Subarticles, paragraphs, and, where necessary, subparagraphs and subsubparagraphs.

3. ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections followed by Arabic numbers, such as NB-1000. Where possible, Articles dealing with the same topics are given the same number in each Subsection in accordance with the following general scheme:

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination
6000	Testing
7000	Overpressure Protection
8000	Nameplates, Stamping, and Reports

The numbering of Articles and the material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the rules have been prepared with some gaps in the numbering.

4. SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

5. SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as NB-2130, and generally have no text. When a number such as NB-1110 is followed by text, it is considered a paragraph.

6. PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

7. SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as B-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

8. SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

Page xxiv

9. REFERENCES

References used within Section III generally fall into one of the following four categories.

A. References to Other Portions of Section III

When a reference is made to another Article, Subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to NB-3000 includes all material in Article NB-3000; reference to NB-3200 includes all material in Subarticle NB-3200; reference to NB-3230 includes all paragraphs NB-3231 through NB-3236.

B. References to Other Sections

Other Sections referred to in Section III are:

Section II, Materials. When a requirement for a material, or for the examination or testing of a material, is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II.

These references begin with the letter "S."

Section V, Nondestructive Examination. Section V references begin with the letter "T" and relate to the nondestructive examination of material or welds.

Section IX, Welding and Brazing Qualifications. Section IX references begin with the letter "Q" and relate to welding and brazing requirements.

Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components. When a reference is made to inservice inspection, the rules of Section XI shall apply.

C. Reference to Specifications and Standards Other Than Published in Code Sections

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials. At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E 71-64 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

² The American National Standards Institute (ANSI) was formerly known as the American Standards Association. Standards approved by the Association were designated by the prefix "ASA" followed by the number of the standard and the year of publication. More recently, the American National Standards Institute was known as the United States of America Standards Institute. Standards were designated by the prefix "USAS" followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the numbers of the standards have remained unchanged.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by the American Society of Mechanical Engineers and approved by the American National Standards Institute.² When a product is to conform to such a standard, for example ANSI B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NB-3132-1, for example ANSI B16.5-1977. Standards published by the American Society of Mechanical Engineers are available from ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-6, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, 127 Park Street, N.E., Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NB-3132-1, for example MSS SP-6-1963.

(4) Specifications for welding and brazing materials are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33135. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix "SF," for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-620 and API-2000. When documents so designated are referred to in Section III, they are standards published by the American Petroleum Institute.

D. References to Appendices

Two types of Appendices are used in Section III and are designated Mandatory and Nonmandatory.

(1) Mandatory Appendices contain requirements which must be followed in construction; such references are designated by a Roman numeral followed by Arabic numerals. References to II-1100 or XI-3212, for example, relate to the Mandatory Appendices.

(2) Nonmandatory Appendices provide information or guidance for the use of Section III; such references are designated by a capital letter followed by Arabic numerals. A reference to D-1100, for example, relates to a Nonmandatory Appendix.

July 1, 1998

American Society Of Mechanical Engineers
SEC III D1 ND-1000

ARTICLE ND-1000 INTRODUCTION

Page 1

ND-1100 SCOPE

(a) Subsection ND contains rules for the materials, design, fabrication, examination, testing, overpressure relief, marking, stamping, and preparation of reports by the Certificate Holder of items which are intended to conform to the requirements for Class 3 construction.

(b) The rules of Subsection ND cover the requirements for the strength and pressure integrity of items the failure of which would violate the pressure retaining boundary. The rules cover load stresses, but do not cover deterioration which may occur in service as a result of corrosion, radiation effects, or instability of material. NCA-1130 gives further limits to the rules of this Subsection.

(c) Subsection ND does not contain rules to cover all details of construction of Class 3 vessels and storage tanks. Where complete details are not provided in this Subsection, it is intended that the Certificate Holder, subject to the approval of the Owner or his designee and acceptance by the Inspector, shall provide details of construction which will be consistent with those provided by the rules of this Subsection.

ND-1130 BOUNDARIES OF JURISDICTION APPLICABLE TO THIS SUBSECTION

ND-1131 Boundary of Components

The Design Specification shall define the boundary of a component to which piping or another component is attached. The boundary shall not be closer to a vessel, tank, pump, or valve than:

- (a) the first circumferential joint in welded connections (the connecting weld shall be considered part of the piping);
- (b) the face of the first flange in bolted connections (the bolts shall be considered part of the piping);
- (c) the first threaded joint in screwed connections.

ND-1132 Boundary Between Components and Attachments

ND-1132.1 Attachments

(a) An *attachment* is an element in contact with or connected to the inside or outside of the pressure retaining portion of a component which may have either a pressure retaining or nonpressure-retaining function and either a structural or nonstructural function.

(b) Attachments with a pressure retaining function include items such as stiffeners and branch or vessel opening reinforcement.

(c) Attachments with a nonpressure-retaining function include items such as valve guides, thermal sleeves, turning vanes, and component support load path items such as vessel saddles, support and shear lugs, brackets, pipe clamps, trunnions, and skirts.

(d) Attachments with a structural function (structural attachments) perform a pressure retaining function or are in the component support load path.

(e) Attachments with a nonstructural function (non structural attachments) do not perform a pressure retaining function nor are they in the component support load path. Nonstructural attachments include items such as nameplates, insulation supports, and locating and lifting lugs.

ND-1132.2 Jurisdictional Boundary.

The jurisdictional boundary between a pressure retaining component and an attachment defined in the Design Specification shall not be any closer to the pressure retaining portion of the component than as defined in (a) through (g)

below. Figures ND-1132.2-1 through ND-1132.2-3 are provided as an aid in defining the boundary and construction requirements of this Subsection.

(a) Attachments cast or forged with the component and weld buildup on the component surface shall be considered part of the component.

(b) Attachments, welds, and fasteners having a pressure retaining function shall be considered part of the component.

Page 4

(c) Except as provided in (d) and (e) below, the boundary between a pressure retaining component and an attachment not having a pressure retaining function shall be at the surface of the component.

(d) The first connecting weld of a nonpressure-retaining structural attachment to a component shall be considered part of the component unless the weld is more than $2t$ from the pressure retaining portion of the component, where t is the nominal thickness of the pressure retaining material. Beyond $2t$ from the pressure retaining portion of the component, the first weld shall be considered part of the attachment.

(e) The first connecting weld of a welded nonstructural attachment to a component shall be considered part of the attachment. At or within $2t$ from the pressure retaining portion of the component the first connecting weld shall conform to ND-4430.

(f) Mechanical fasteners used to connect a nonpressure-retaining attachment to the component shall be considered part of the attachment.

(g) The boundary may be located further from the pressure retaining portion of the component than as defined in (a) through (f) above when specified in the Design Specification.

Page 5

Page 6

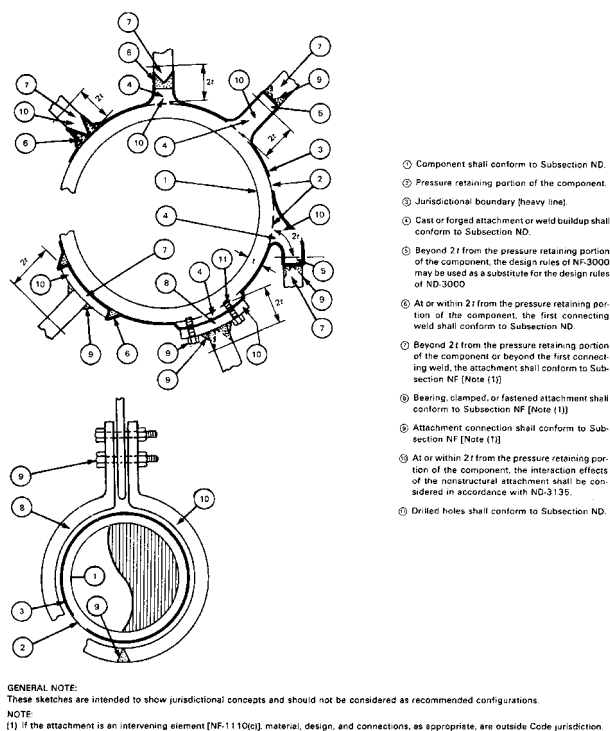
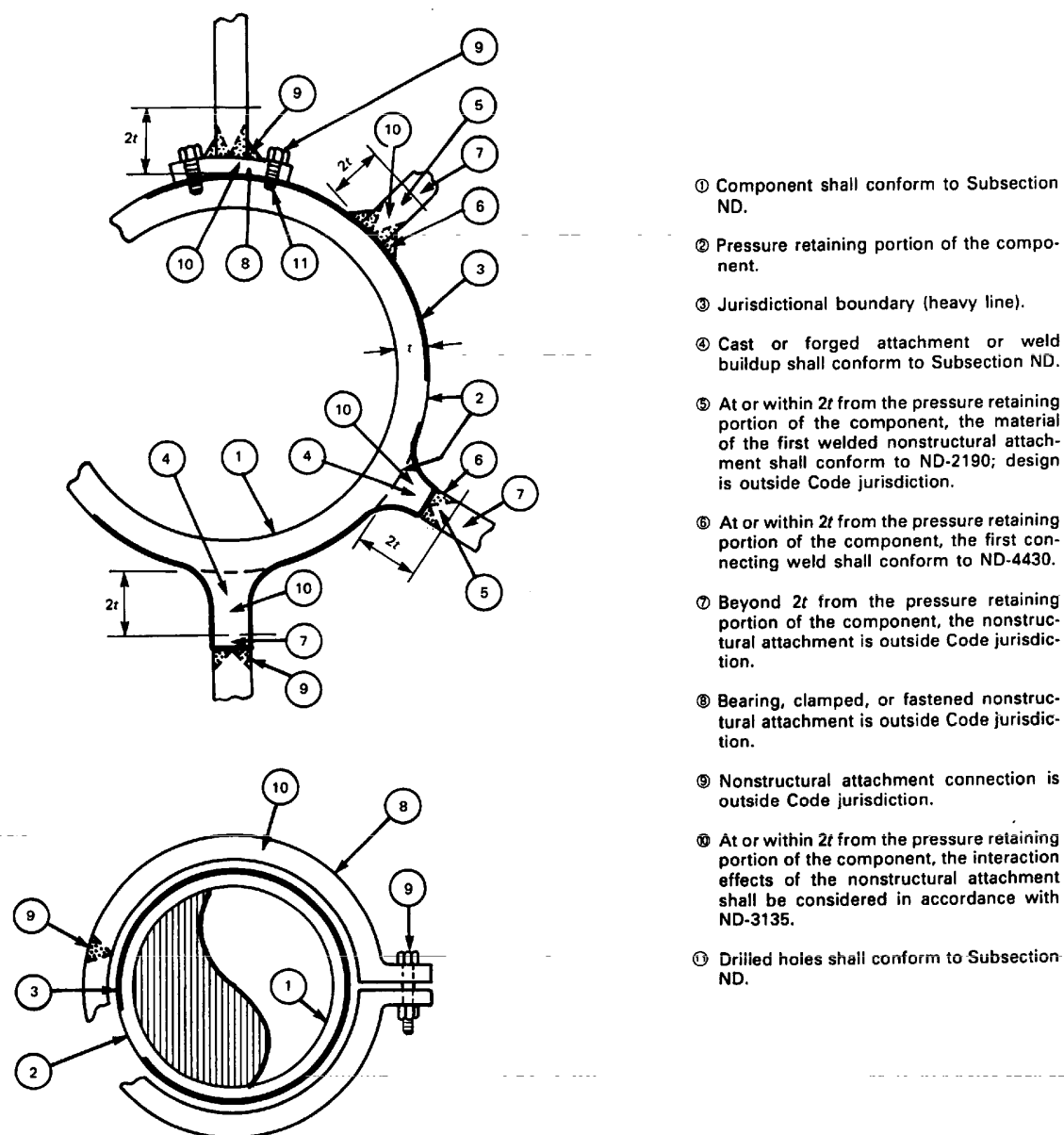


FIG. ND-1132.2-1 ATTACHMENTS IN THE COMPONENT SUPPORT LOAD PATH WHICH DO NOT PERFORM A PRESSURE RETAINING FUNCTION



GENERAL NOTE:
These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

FIG. ND-1132.2-2 ATTACHMENTS WHICH DO NOT PERFORM A PRESSURE RETAINING FUNCTION AND ARE NOT IN THE COMPONENT SUPPORT LOAD PATH (NONSTRUCTURAL ATTACHMENTS)

FIG. ND-1132.2-2 ATTACHMENTS WHICH DO NOT PERFORM A PRESSURE RETAINING FUNCTION AND ARE NOT IN THE COMPONENT SUPPORT LOAD PATH (NONSTRUCTURAL ATTACHMENTS)

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 ND-2000

ARTICLE ND-2000 MATERIAL

Page 9

ND-2100 GENERAL REQUIREMENTS FOR MATERIAL

ND-2110 SCOPE OF PRINCIPAL TERMS EMPLOYED

(a) The term *material* as used in this Subsection is defined in NCA-1220. The term *Material Organization* is defined in NCA-9000.

(b) The term *pressure retaining material* as used in this Subsection applies to items such as vessel shells, heads, and nozzles; pipes, tubes, and fittings; valve bodies, bonnets, and disks; pump casings and covers; and bolting which joins pressure retaining items.

(c) The requirements of this Article make reference to the term *thickness*. For the purpose intended, the following definitions of nominal thickness apply:

(1) *plate* - the thickness is the dimension of the short transverse direction;

(2) *forgings* - the thickness is the dimension defined as follows:

(a) *hollow forgings* - the nominal thickness is measured between the inside and outside surfaces (radial thickness);

(b) *disk forgings* (axial length less than the outside diameter) - the nominal thickness is the axial length;

(c) *flat ring forgings* (axial length less than the radial thickness) - for axial length ≤ 2 in. (51 mm), the axial length is the nominal thickness; for axial length > 2 in. (51 mm), the radial thickness is the nominal thickness;

(d) *rectangular solid forgings* - the least rectangular dimension is the nominal thickness;

(3) *castings*:

(a) thickness t for fracture toughness testing is defined as the nominal pipe wall thickness of the connecting piping;

(b) thickness t for heat treatment purposes is defined as the thickness of the pressure retaining wall of the casting, excluding flanges and sections designated by the designer as nonpressure retaining.

ND-2120 PRESSURE RETAINING MATERIAL

ND-2121 Permitted Material Specifications

(a) Pressure retaining material shall conform to the requirements of one of the specifications for materials listed in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1 and to all of the requirements of this Article which apply to the product form in which the material is used. Attachments which perform a pressure retaining function shall be pressure retaining material.

(b) The requirements of this Article do not apply to material for items not associated with the pressure retaining function of a component, such as shafts, stems, trim, spray nozzles, bearings, bushings, springs, and wear plates, nor to seals, packing, gaskets, valve seats, and ceramic insulating material and special alloys used as seal material in electrical penetration assemblies.

(c) Material made to specifications other than those specified in Tables 1A and 1B, Section II, Part D, Subpart 1 may be used for the following applications:

(1) *Safety valve disks and nozzles* - when the nozzles are internally contained by the external body structure

(2) *Control valve disks and cages* - when valves function for flow control only

(3) *Line valve disks in valves* - whose inlet connections are NPS 2 (DN 50) and smaller.

(d) Material for line fittings, NPS 1 (DN 25) and less, may be of material made to specifications other than those listed in Section II, Part D, provided that the fittings are in conformance with the requirements of ND-3671.4 and the material is determined to be adequate for the service conditions by the piping system designer.

(e) Welding and brazing materials used in manufacture of items shall comply with an SFA specification in Section II, Part C, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article. The requirements of this

Page 14

Article do not apply to materials used as backing rings or backing strips in welded joints.

(f) The requirements of this Article do not apply to hard surfacing or corrosion resistant weld metal overlay which is 10% or less of the thickness of the base material (ND-3122).

ND-2122 Special Requirements Conflicting With Permitted Material Specifications

Special requirements stipulated in this Article shall apply in lieu of the requirements of the material specifications wherever the special requirements conflict with the material specification requirements [NCA-3856]. Where the special requirements include an examination, test, or treatment which is also required by the material specification, the examination test or treatment need be performed only once. Required nondestructive examinations shall be performed as specified for each product form in ND-2500. Any examination, repair, test, or treatment required by the material specification or by this Article may be performed by the Material Organization or the Certificate Holder as provided in ND-4121.1. Any hydrostatic or pneumatic pressure test required by a material specification need not be performed, provided the material is identified as not having been pressure tested and it is subsequently pressure tested in accordance with ND-6114, except where the location of the material in the component or the installation would prevent performing any nondestructive examination required by the material specification to be performed subsequent to the hydrostatic or pneumatic test.

ND-2124 Material Size Ranges and Tolerances

(a) Material outside the limits of size or thickness given in any specification in Section II may be used if the material is in compliance with the other requirements of the specification and no size limitation is given in this Subsection. In those specifications in which chemical composition or mechanical properties are indicated to vary with size or thickness, any material outside the specification range shall be required to conform to the composition and mechanical properties shown for the nearest specified range [NCA-3856].

(b) Plate material shall be ordered not thinner than the design thickness. Components, except for piping, made of plate furnished with an undertolerance of not more than the smaller value of 0.01 in. (0.3 mm), or 6% of the ordered thickness may be used at the full Design Pressure for the thickness ordered. If the specification to which the plate is ordered allows a greater undertolerance, the ordered thickness of the material shall be sufficiently greater than the design thickness so that the thickness of the material furnished is not more than the smaller of 0.01 in. (0.3 mm) or 6% under the design thickness.

(c) If pipe or tube is ordered by its nominal wall thickness, the manufacturing undertolerance on wall thickness shall be taken into account. The manufacturing undertolerances are given in the several pipe and tube specifications listed in the applicable Tables in Section II, Part D. After the minimum wall thickness is determined (ND-3641.1), it shall be increased by an amount sufficient to provide for the manufacturing undertolerance allowed in the pipe or tube specification.

ND-2125 Materials in Combination¹

A component may be constructed of any combination of materials permitted in ND-2000, provided the applicable rules are followed and the requirements of Section IX for welding dissimilar metals are met.

ND-2126

Integrally finned tubes may be made from tubes that conform to one of the specifications for tubes listed in Tables 1A and 1B, Section II, Part D, Subpart 1 and to all of the special requirements of this Article which apply to that product form. In addition, the following requirements shall apply.

(a) The requirements of ND-2550 shall be met by the tube before finning.

(b) The tubes, after finning, shall conform to the applicable heat treatment requirements of the basic material specification.

(c) The allowable stress values shall be those given in Tables 1A and 1B, Section II, Part D, for the tube material from which the finned tube is made.

(d) After finning, each tube shall be subjected to one of the following tests:

(1) an internal pneumatic pressure test at not less than 250 psi (1720 kPa) without evidence of leakage. The test method, such as immersion of the tube under water during the test, shall permit visual detection of any leakage.

1 Because of the different thermal coefficients of expansion of dissimilar materials, caution shall be exercised in construction under the provisions of this paragraph in order to avoid difficulties inservice under extreme temperature conditions, or with unusual restraint such as may occur at points of stress concentration and also because of metallurgical changes occurring at high temperatures.

Page 15

(2) an individual tube hydrostatic test at 1.25 times the Design Pressure which permits complete examination of the tube for leakage.

(e) A visual examination shall be performed after finning. Material having discontinuities, such as laps, seams, or cracks, is unacceptable.

ND-2128 Bolting Material

(a) Material for bolts and studs shall conform to the requirements of one of the specifications listed in Table 3, Section II, Part D, . Material for nuts shall conform to SA-194 or to the requirements of one of the specifications for nuts or bolting listed in Table 3, Section II, Part D, .

(b) The use of washers is optional. When used, they shall be made of wrought material, with mechanical properties compatible with the nuts with which they are to be employed.

ND-2130 CERTIFICATION OF MATERIAL

All materials used in construction of components shall be certified as required in NCA-3862 and NCA-3861. Certified Material Test Reports are required for pressure retaining material, except as provided by NCA-3861, and for small products as defined in ND-2610(c). A Certificate of Compliance may be provided in lieu of a Certified Material Test Report for all other material. Copies of all Certified Material Test Reports and Certificates of Compliance applicable to material used in a component shall be furnished with the material.

ND-2140 WELDING MATERIAL

For the requirements governing the material to be used for welding, see ND-2400.

ND-2150 MATERIAL IDENTIFICATION

All material shall be marked in accordance with the marking requirements of the material specification. Material for small items shall be controlled during manufacture and installation of the component so that they are identifiable as acceptable material at all times. Welding and brazing material shall be controlled during the repair of material and the manufacture and installation so that they are identifiable as acceptable until the material is actually consumed in the process (ND-4122).

ND-2160 DETERIORATION OF MATERIAL IN SERVICE

Consideration of deterioration of material caused by service is generally outside the scope of this Subsection. It is the responsibility of the Owner to select material suitable for the conditions stated in the Design Specifications (NCA-3250),

with specific attention being given to the effects of service conditions upon the properties of the material.

ND-2170 HEAT TREATMENT TO ENHANCE IMPACT PROPERTIES

Carbon steels, low alloy steels, and high alloy chromium (Series 4XX) steels may be heat treated by quenching and tempering to enhance their impact properties. Postweld heat treatment of the component at a temperature of not less than 1100°F (593°C) may be considered to be the tempering phase of the heat treatment.

ND-2180 PROCEDURES FOR HEAT TREATMENT OF MATERIAL

When heat treating temperature or time is required by the material specification and the rules of this Subsection, the heat treating shall be performed in temperature-surveyed and -calibrated furnaces or the heat treating shall be controlled by measurement of material temperature by thermocouples in contact with the material or attached to blocks in contact with the material or by calibrated pyrometric instruments. Heat treating shall be performed under furnace loading conditions such that the heat treatment is in accordance with the material specification and the rules of this Subsection.

ND-2190 NONPRESSURE-RETAINING MATERIAL

(a) Material in the component support load path and not performing a pressure retaining function (see ND-1130) welded to pressure retaining material shall meet the requirements of NF-2000.

(b) Material not performing a pressure retaining function and not in the component support load path (non structural attachments) welded at or within $2t$ of the pressure retaining portion of the component need not comply with ND-2000 or NF-2000 provided the requirements of ND-4430 are met.

Page 16

(c) Structural steel rolled shapes, which are permitted by this Subsection to be furnished with a Certificate of Compliance, may be repaired by welding using the welders, documentation, and examination requirements specified in SA-6.

ND-2200 MATERIAL TEST COUPONS AND SPECIMENS FOR FERRITIC STEEL MATERIAL

ND-2210 HEAT TREATMENT REQUIREMENTS

ND-2211 Test Coupon Heat Treatment for Ferritic Material²

Where ferritic steel material is subjected to heat treatment during fabrication or installation of a component, the material used for the tensile and impact test specimens shall be heat treated in the same manner as the component, except that test coupons and specimens for P-No. 1 material with a nominal thickness of 2 in. (51 mm) or less are not required to be so heat treated where nominal thickness for flanges refers to the wall thickness at the weld joint to the pipe or component. The Certificate Holder shall provide the Material Organization with the temperature and heating and cooling rate to be used. In the case of postweld heat treatment, the total time at temperature or temperatures for the test material shall be at least 80% of the total time at temperature or temperatures during actual postweld heat treatment of the material, and the total time at temperature or temperatures for the test material, coupon, or specimen may be performed in a single cycle.

ND-2212 Test Coupon Heat Treatment for Quenched and Tempered Material

ND-2212.1 Cooling Rates.

2 Any postweld heat treatment time which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

Where ferritic steel material is subjected to quenching from the austenitizing temperature, the test coupons representing those materials shall be cooled at a rate similar to and no faster than the main body of the material except in the case of certain forgings and castings (ND-2223.3 and ND-2226.4). This rule shall apply for coupons taken directly from the material as well as for separate test coupons representing the material, and one of the general procedures described in ND-2212.2 or one of the specific procedures described in ND-2220 shall be used for each product form.

ND-2212.2 General Procedures.

One of the general procedures in (a), (b), and (c) below may be applied to quenched and tempered material or test coupons representing the material, provided the specimens are taken relative to the surface of the product in accordance with ND-2220. Further specific details of the methods to be used shall be the obligation of the Material Organization and the Certificate Holder.

(a) Any procedure may be used which can be demonstrated to produce a cooling rate in the test material that matches the cooling rate of the main body of the product at the region midway between midthickness and the surface ($\frac{1}{4}t$) and no nearer any heat treated edge than a distance equal to the nominal thickness t being quenched within 25°F (14°C) and 20 sec at all temperatures after cooling begins from the austenitizing temperature.

(b) If cooling rate data for the material and cooling rate control devices for the test specimens are available, the test specimens may be heat treated in the device to represent the material provided that the provisions of (a) above are met.

(c) When any of the specific procedures described in ND-2220 are used, faster cooling rates at the edges may be compensated for by:

- (1) taking the test specimens at least t from a quenched edge, where t equals the material thickness;
- (2) attaching a steel pad at least t wide by a partial penetration weld (which completely seals the buffered surface) to the edge where specimens are to be removed; or
- (3) using thermal barriers or insulation at the edge where specimens are to be removed.

It shall be demonstrated (and this information shall be included in the Certified Material Test Report) that the cooling rates are equivalent to (a) or (b) above.

ND-2220 PROCEDURE FOR OBTAINING TEST COUPONS AND SPECIMENS FOR QUENCHED AND TEMPERED MATERIAL

ND-2221 General Requirements

The procedure for obtaining test specimens for quenched and tempered material is related to the product form. Coupon and specimen location shall be as required by the material specification, except as stated in the following paragraphs of this Subarticle. References to dimensions signify nominal values.

Page 17

ND-2222 Plates

ND-2222.1 Orientation and Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from a rolled surface and with the midlength of the specimen at least t from any heat treated edge, where t is the nominal thickness of the material.

ND-2222.2 Requirements for Separate Test Coupons.

Where a separate test coupon is used to represent the component material, it shall be of sufficient size to ensure that the cooling rate of the region from which the test coupons are removed represents the cooling rate of the material at least $\frac{1}{4}t$ deep and t from any edge of the product. Unless cooling rates applicable to the bulk pieces or product are simulated in accordance with ND-2212.2, the dimensions of the coupon shall be not less than $3t \times 3t \times t$, where t is the nominal material thickness.

ND-2223 Forgings and Forged Bars

ND-2223.1 Location of Test Coupons.

The longitudinal axis of the test specimens shall be located at least $\frac{1}{4}t$ from the nearest surface. The gage length of

4

tension test specimens and the area under the notch of Charpy specimens shall be located at a distance of at least t from any second surface to compensate for faster cooling rates at the edges. t is the maximum nominal heat treated thickness or cross section of the forging. Either of the following methods may be used to obtain the required distance from any second surface.

(a) *Method A.* A thermal buffer ring, at least $t \times t$ in cross section, or sections of such a ring at least $3t$ in length, shall be welded to the test end of a forging prior to heat treatment for mechanical properties. The buffer material may be any weldable carbon or low alloy steel and shall be joined to the forging with a partial penetration-type weld that completely seals the buffered surface. The test coupons shall be removed from the forging in the region buffered by the ring or ring segments. If ring segments are used, the test coupons shall be removed from the forging in the area under the center one-third of the buffer ring segment length. In either case, the longitudinal axis of the test specimens shall be located at a minimum distance of $\frac{1}{2}$ in. (13 mm) from the buffered surface of the forging, and at least $\frac{1}{4}t$ from a quenched surface of the forging.

(b) *Method B.* Thermal insulation or other thermal barriers shall be used during the heat treatment adjacent to the product surface where specimens are to be removed. It shall be demonstrated that the cooling rate of the test specimen location is no faster than that attained by the method described in ND-2223.1, or Method A. Test specimen locations shall be the same as stated for Method A. Details of thermal insulation, including substantiation data, shall be available from the agency performing the heat treatment.

ND-2223.2 Very Thick and Complex Forgings.

For forgings that are very thick and complex (for example, thick tubesheets, flanges, nozzles, pump and valve bodies, and other complex forgings that are contour-shaped or machined essentially to the inservice configuration prior to heat treatment), the purchaser shall specify the surfaces of the finished product subjected to significant tension loading in service. The test specimens shall be removed from a prolongation or other stock from the forging or from a test forging in accordance with ND-2223.4. They shall be taken so that the longitudinal center line is at a distance below the nearest heat treated surface equivalent to at least the greatest distance that the significantly stressed location is from the nearest heat treated surface. The gage length of tension test specimens and the area under the notch of Charpy specimens, shall be located at least twice this distance from any second heat treated surface. These respective locations, however, shall not be closer than $\frac{3}{4}$ in. (19 mm) from the nearest surface and $1\frac{1}{2}$ in. (38 mm) from any second surface.

ND-2223.3 Multiple Forgings

(a) *Multiple Forgings Separated Into Identical Individual Forgings Prior to Quenching and Tempering Treatment.* At least one individual forging from each multiple forging in each heat treating lot shall be tested using the test specimen locations of ND-2223.1 or ND-2223.2 as specified on the purchase order, except that test specimens located at midlength may be closer to the ends of the production forging than the specified distance to the second surfaces. All forgings shall be quenched simultaneously and tempered in the same furnace charge. All forgings from the multiple shall be Brinell hardness tested after heat treatment and forgings not tested for mechanical properties shall have a BHN within 20 points of the BHN of the forging that has been tested for mechanical properties.

(b) *Multiple Forgings Separated After Quench and Temper Treatment.* The multiple forging shall have an integral prolongation and when the heat treated length of the multiple (excluding test metal) exceeds 80 in. (2030 mm), each end shall have an integral prolongation. Test specimen locations shall meet the requirements of ND-2223.1 or ND-2223.2 as specified on the purchase order.

Page 18

ND-2223.4 Forgings Tested With Representative, Separately Forged Test Pieces.

Separately forged test pieces shall be used. Test specimens shall be taken from a representative separate test forging made from the same heat of steel as the production forgings. Separate test forgings shall receive substantially the same reduction and type of hot working as the production forgings, except that a longitudinal forged bar with dimensions not less than $3t \times t$ may be used to represent a ring forging. Test forgings shall be of the same nominal thickness as the as-quenched production forgings, and shall be heat treated in the same furnace charge and under the same conditions as the production forgings. For forgings requiring impact testing, the use of representative separate test pieces shall be

limited to forgings with machined weights of 1,000 lb (454 kg) or less, except in the case of forgings covered by ND-2223.1. Test specimen locations shall meet the requirements of ND-2223.1 or ND-2223.2 as applicable. When destructively tested production forgings are not of sufficient length to obtain the t distance from a second surface, the location from the second surface may be at midlength of the forging.

ND-2223.5 Quenched and Tempered Bars

(a) For bars (other than those used for bolting materials) the coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside or rolled surface. The gage length of tension test specimens and the area under the notch of Charpy specimens shall be indented at least one diameter or thickness from a heat treated end.

(b) *Bars With Thicknesses Exceeding $1\frac{1}{2}$ in. (38 mm).* For bars (other than those used for bolting materials) with diameters or thickness over $1\frac{1}{2}$ in. (38 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside or rolled surface. The gage length of tension test specimens and the area under the notch of Charpy specimens shall be located at least one diameter or thickness from a heat treated end.

ND-2224 Bars and Bolting Material

ND-2224.1 Bars With 2 in. (51 mm) Maximum Thickness.

For bars with diameters or thicknesses 2 in. (51 mm) or less, the coupons shall be taken so that specimens shall have their longitudinal axes on a line representing the center of the thickness and with the midlength of the specimens at least one diameter or thickness from a heat treated end.

ND-2224.2 Bars With Thicknesses Exceeding 2 in. (51 mm).

For bars with diameters or thicknesses over 2 in. (51 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside or rolled surface and with the midlength of the specimens at least t from a heat treated end, where t is either the bar diameter or thickness.

ND-2224.3 Bolting Material.

For bolting material, the coupons shall be taken in conformance with the applicable material specification and with the midlength of the specimen at least one diameter or thickness from a heat treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

ND-2225 Tubular Products

ND-2225.1 Tubular Products With 2 in. (51 mm) Maximum Thickness.

For tubular products with 2 in. (51 mm) maximum wall thickness, the coupons shall be taken so that specimens shall have their longitudinal axes on a surface midway between the outside and inside surfaces and with the midlength of the specimens at least one wall thickness from a heat treated end.

ND-2225.2 Tubular Products Exceeding 2 in. (51 mm) Nominal Thickness.

For tubular products with nominal wall thicknesses exceeding 2 in. (51 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside surface and with the midlength of the specimens at least one wall thickness from a heat treated end.

ND-2225.3 Separately Produced Coupons Representing Fittings.

Separately produced test coupons representing fittings may be used. When separately produced coupons are used, the requirements of ND-2223.4 shall be met.

ND-2226 Tensile Test Specimen Location (for Quenched and Tempered Ferritic Steel Castings)

NOTE: Users of this requirement should note that the hardenability of some grades may limit the usable section size.

(a) This section applies only to quenched and tempered ferritic steel castings with a thickness t exceeding 2 in. (51 mm), where t is the thickness of the pressure retaining wall of the casting, excluding flanges and sections designated by the designer as nonpressure-retaining. The order, inquiry, and drawing shall designate what the thickness t is for the casting.

(b) One of the following shall apply.

(1) The longitudinal centering of the thickness of the tension test specimen, shall be taken at least $\frac{1}{4}t$ from the t dimension surface. For cylindrical castings, the longitudinal center line of the specimens shall be taken at least $\frac{1}{4}t$ from the outside or inside surface and the gage length at least t from the as-heat-treated end.

(2) Where separately cast test coupons are used, their dimensions shall be not less than $3t \times 3t \times t$ and each specimen cut from it shall meet the requirements of (b). The test coupon shall be of the same heat of steel and shall receive substantially the same casting practices as the production casting it represents. (Centrifugal castings may be represented by statically cast coupons.) The test coupon shall be heat treated under the same conditions as the production casting(s). The t dimension of the test coupon shall be the same maximum thickness t as defined in (a) above. Where separate test blocks require reheat treatment, thermal buffers in accordance with (b) may be used.

(3) Where specimens are to be removed from the body of the casting, a steel thermal buffer pad $1t \times 1t \times$ at least $3t$ shall be joined to the casting surface by a partial penetration weld completely sealing the buffered surface prior to the heat treatment process. The test specimens shall be removed from the casting in a location adjacent to the center third of the buffer pad. They shall be located at a minimum distance of $\frac{1}{2}$ in. (13 mm) from the buffered surface and $\frac{1}{4}t$ from the other heat treated surfaces.

(4) Where specimens are to be removed from the body of the casting, thermal insulation or other thermal barriers shall be used during the heat treatment process adjacent to the casting edge where specimens are to be removed. It shall be demonstrated that the cooling rate of the test specimen is no faster than that of specimens taken by the method described in (b)(1) above. This information shall be included in the test reports.

(5) Where castings are cast or machined to essentially the finished product configuration prior to heat treatment, the test specimens shall be removed from a casting prolongation or other stock on the product at a location below the nearest heat treated surface indicated on the order. The specimens shall be located with their longitudinal axes a distance below the nearest heat treated surface equivalent to at least the greatest distance that the indicated high tensile stress surface will be from the nearest heat treated surface and with their midlength a minimum of twice this distance from a second heat treated surface. In any case, the longitudinal axes of the test specimens shall be no nearer than $\frac{1}{4}$ in. (6 mm) to a heat treated surface and the midlength shall be at least $1\frac{1}{2}$ in. (38 mm) from a second heat treated surface. The component manufacturer shall specify the surfaces of the finished product subjected to high tensile stress in service.

ND-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL

ND-2310 MATERIAL TO BE IMPACT TESTED

ND-2311 Material for Which Impact Testing Is Required

(a) Pressure retaining material shall be impact tested in accordance with the requirements of ND-2330, except that impact testing of the material described in (1) through (9) below is not a requirement of this Sub-section:

(1) material with a nominal section thickness of $\frac{5}{8}$ in. (16 mm) and less where the thickness shall be taken as defined in (a) through (d) below:

(a) for pumps, valves, and fittings, use the largest nominal pipe wall thickness of the connecting pipes;

(b) for vessels and tanks, use the nominal thickness of the shell or head, as applicable;

(c) for nozzles or parts welded to vessels, use the lesser of the vessel shell thickness to which the item is welded or the maximum radial thickness of the item exclusive of integral shell butt welding projections;

- (d) for flat heads, tubesheets, or flanges, use the maximum shell thickness associated with the butt welding hub;
- (2) bolting, including studs, nuts, and bolts, with a nominal size of 1 in. (25 mm) and less;
- (3) bars with a nominal cross-sectional area of 1 sq in. (645 mm²) and less;

**TABLE ND-2311-1
EXEMPTIONS FROM IMPACT TESTING UNDER ND-2311(a)(8)**

Material	Material Condition [Note (1)]	Lowest Service Temperature for the Thickness Shown			
		Over $\frac{5}{8}$ in. to $\frac{3}{4}$ in., Incl.	Over $\frac{3}{4}$ in. to 1 in., Incl.	Over 1 in. to $1\frac{1}{2}$ in., Incl.	Over $1\frac{1}{2}$ in. to $2\frac{1}{2}$ in., Incl.
SA-516 Grade 70	N	−30°F	−20°F	0°F	0°F
SA-537 Class 1	N	−40°F	−30°F	−30°F	−30°F
SA-516 Grade 70	Q & T	[Note (2)]	[Note (2)]	[Note (2)]	−10°F
SA-508 Class 1	Q & T	[Note (2)]	[Note (2)]	[Note (2)]	10°F
SA-508 Class 2	Q & T	[Note (2)]	[Note (2)]	[Note (2)]	40°F
SA-533 Grade B	Q & T	[Note (2)]	[Note (2)]	[Note (2)]	10°F
Class 1 [Note (3)]					
SA-216 Grades WCB, WCC	Q & T	[Note (2)]	[Note (2)]	[Note (2)]	30°F
SA-299 [Note (3)]	N	[Note (2)]	[Note (2)]	[Note (2)]	20°F

NOTES:

(1) Material Condition letters refer to:

N — Normalize

Q & T — Quench and Temper

(2) The lowest service temperature shown in the column Over $1\frac{1}{2}$ in. to $2\frac{1}{2}$ in. may be used for these thicknesses.

(3) Material made to a fine grain melting practice.

TABLE ND-2311-1 EXEMPTIONS FROM IMPACT TESTING UNDER ND-2311(a)(8)

- (4) all thicknesses of material for pipe, tube, fittings, pumps, and valves with a NPS 6 diameter (DN 150) and smaller;
- (5) material for pumps, valves, and fittings with all pipe connections of $\frac{5}{8}$ in. (16 mm) nominal wall thickness and less;
- (6) austenitic stainless steel;
- (7) nonferrous material;
- (8) materials listed in Table ND-2311-1 in the thicknesses shown and for Lowest Service Temperatures³ equal to or more than the tabulated temperatures. This exemption does not exempt either the weld metal (ND-2430) or the welding procedure qualification (ND-4335) from impact testing.
- (9) materials for components for which the Lowest Service Temperature exceeds 100°F (38°C).
- (b) The Design Specification shall state the Lowest Service Temperature for the component.

ND-2320 IMPACT TEST PROCEDURES

ND-2321 Charpy V-Notch Tests

³ Lowest Service Temperature (LST) is the minimum temperature of the fluid retained by the component, or, alternatively, the calculated minimum metal temperature whenever the pressure within the component exceeds 20% of the preoperational system hydrostatic test pressure.

The Charpy V-notch test C_v , when required, shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Fig. 11, Type A. A test shall consist of a set of three full-size 10 mm × 10 mm specimens. The lateral expansion and absorbed energy, as applicable, and the test temperature, as well as the orientation and location of all tests performed to meet the requirements of ND-2330 shall be reported in the Certified Material Test Report.

ND-2322 Test Specimens

ND-2322.1 Location of Test Specimens.

Impact test specimens shall be removed from the locations specified for tensile test specimens in the material specification. For bolting, the C_v impact test specimens shall be taken with the longitudinal axis of the specimen located at least one-half radius or 1 in. (25 mm) below the surface plus the machining allowance per side, whichever is less. The fracture plane of the specimen shall be at least one diameter or thickness from the heat treated end, except when the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size, except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

ND-2322.2 Orientation of Impact Test Specimens.

Specimens for C_v impact tests shall be oriented as

Page 21

required in ND-2200 for the tensile test specimen, or, alternatively, the orientation may be in the direction of maximum stress. The notch of the C_v specimen shall be normal to the surface of the material.

ND-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS

ND-2331 Pressure Retaining Material Other Than Bolting

Pressure retaining material other than bolting for vessels, tanks, piping (pipe and tubes), pumps, valves, and fittings shall be tested as required by (a) and (b) below.

(a) A Charpy V-notch test shall be performed at a temperature lower than or equal to the Lowest Service Temperature. All three specimens shall meet one of the acceptance standards applicable to the specific test method.

(1) *Charpy V-Notch Testing for the Lateral Expansion Values.* The test results of the three specimens, collectively and singly, shall meet the respective requirements of Table ND-2331(a)-1.

(2) *Charpy V-Notch Testing for Absorbed Energy Values.* The test results of the three specimens, collectively and singly, shall meet the respective requirements of Table ND-2331(a)-2.

(b) Apply the procedures of (a) above to:

(1) the base material;

(2) the base material, the heat affected zone, and weld metal from the weld procedure qualification tests in accordance with ND-4330; and

(3) the weld metal of ND-2431.

ND-2333 Bolting Material

For bolting material, including studs, nuts, and bolts, a Charpy V-notch test shall be performed at a temperature equal to or less than the preload temperature or the Lowest Service Temperature, whichever is less. All three specimens shall meet the requirements of Table ND-2333-1.

ND-2340 NUMBER OF IMPACT TESTS REQUIRED

ND-2341 Plates

TABLE ND-2331(a)-1
REQUIRED C_v LATERAL EXPANSION VALUES^{1,2}
FOR PRESSURE RETAINING MATERIAL
(EXCEPT BOLTING)

Nominal Wall Thickness, in. [Note (3)]	Lateral Expansion, mils	
	Average of 3	Lowest 1 of 3
$\frac{5}{8}$ in. or less [Note (4)]	...	...
Over $\frac{5}{8}$ in. to $\frac{3}{4}$ in., incl.	13	10
Over $\frac{3}{4}$ in. to 1 in., incl.	15	10
Over 1 in. to $1\frac{1}{2}$ in., incl.	20	15
Over $1\frac{1}{2}$ in. to $2\frac{1}{2}$ in., incl.	25	20
Over $2\frac{1}{2}$ in.	30	25

NOTES:

- (1) When two base materials having different specified minimum lateral expansion values are joined, the weld impact lateral expansion requirements of the welding procedure qualification (ND-4330) shall conform to the requirements of either of the base materials.
- (2) When the weld metal tests of ND-2400 are performed to these requirements, the impact lateral expansion shall conform to the requirements of either of the base materials being joined.
- (3)(a) For pumps, valves, and fittings, use the largest nominal wall thickness of the connecting pipes.
- (b) For vessels and tanks, use the nominal thickness of the shell or head, as applicable.
- (c) For nozzles or other items welded to vessels, use the lesser of the vessel shell thickness to which the item is welded or the maximum radial thickness of the item exclusive of integral shell butt welding projections.
- (d) For flat heads, tubesheets, or flanges, use the maximum shell thickness associated with the butt welding hub.
- (4) No test required.

TABLE ND-2331(a)-1 REQUIRED C_V LATERAL EXPANSION VALUES^{1,2} FOR PRESSURE RETAINING MATERIAL (EXCEPT BOLTING)

A Charpy V-notch test shall be performed for each plate as heat treated. Where plates are furnished in the unheat-treated condition and qualified by heat treated test specimens, one test shall be made for each plate as-rolled. The term *as-rolled* refers to the plate rolled from a slab or directly from an ingot, not to its heat treated condition.

ND-2342 Forgings and Castings

(a) Where the weight of an individual forging or casting is less than 1000 lb (454 kg), one test shall be made to represent each heat in each heat treatment charge.

(b) When heat treatment is performed in a continuous-type furnace with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a heat treatment charge shall be considered as the lesser of a continuous run not exceeding 8 hr duration or a total weight, so treated, not exceeding 2000 lb (907 kg).

(c) One test shall be made for each forging or casting of 1000 lb to 10,000 lb (454 kg to 4540 kg) in weight.

(d) As an alternative to ND-2342(c), a separate test forging or casting may be used to represent forgings

Page 22

or castings of different sizes in one heat and heat treat lot, provided the test piece is a representation of the greatest thickness in the heat treat lot. In addition, test forgings shall have been subjected to substantially the same reduction and working as the forgings represented.

TABLE ND-2331(a)-2
REQUIRED C_V ENERGY VALUES^{1,2} FOR PRESSURE
RETAINING MATERIAL (EXCEPT BOLTING)

Nominal Wall Thickness [Note (3)]	Energy, ft-lb, for Materials of Specified Minimum Yield Strength, ksi					
	40 ksi or Below		Over 40 ksi to 55 ksi		Over 55 ksi to 105 ksi	
	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3
$\frac{5}{8}$ in. or less [Note (4)]	...	...	...	...	...	...
Over $\frac{5}{8}$ in. to $\frac{3}{4}$ in., incl.	13	10	15	10	20	15
Over $\frac{3}{4}$ in. to 1 in., incl.	15	10	20	15	25	20
Over 1 in. to $1\frac{1}{2}$ in., incl.	20	15	25	20	30	25
Over $1\frac{1}{2}$ in. to $2\frac{1}{2}$ in., incl.	25	20	35	30	40	35
Over $2\frac{1}{2}$ in.	30	25	40	35	45	40

NOTES:

- (1) When two base materials having different specified minimum energy values are joined, the weld impact energy requirements of the welding procedure qualification (ND-4330) shall conform to the requirements of either of the base materials.
- (2) When the weld metal tests of ND-2400 are performed to these requirements, the impact energy shall conform to the requirements of either of the base materials being joined.
- (3)(a) For pumps, valves, and fittings, use the largest nominal wall thickness of the connecting pipes.
(b) For vessels and tanks, use the nominal thickness of the shell or head, as applicable.
(c) For nozzles or other items welded to vessels, use the lesser of the vessel shell thickness to which the item is welded or the maximum radial thickness of the item exclusive of integral shell butt welding projections.
(d) For flat heads, tubesheets, or flanges, use the maximum shell thickness associated with the butt welding hub.
- (4) No test required.

TABLE ND-2331(a)-2 REQUIRED C_V ENERGY VALUES^{1,2} FOR PRESSURE RETAINING MATERIAL (EXCEPT BOLTING)

**TABLE ND-2333-1
REQUIRED C_v VALUES FOR
BOLTING MATERIAL**

Nominal Diameter, in.	Lateral Expansion, mils	Absorbed Energy, ft-lb
1 or less	No test required	No test required
Over 1 through 4	15	30
Over 4	20	35

TABLE ND-2333-1 REQUIRED C_v VALUES FOR BOLTING MATERIAL

(e) Forgings or castings larger than 10,000 lb (4540 kg) shall have two tests per part for Charpy V-notch. The location of C_v impact test specimens shall be selected so that an equal number of specimens is obtained from positions in the forging or casting 180 deg apart.

(f) As an alternative to ND-2342(e) for static castings, a separately cast coupon [ND-2226(b)(2)] may be used; one test shall be made for Charpy V-notch.

ND-2343 Bars

One test shall be made for each lot of bars with cross-sectional area greater than 1 sq in. (645 mm²) where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed 6000 lb (2720 kg).

ND-2344 Tubular Products and Fittings

On products which are seamless or welded without filler metal, one test shall be made from each lot. On products which are welded with filler metal, one additional test with the specimens taken from the weld area shall also be made on each lot. A lot shall be defined as stated in the applicable material specification, but in no case shall a lot consist of products from more than one heat of material and of more than one diameter, with the nominal thickness of any product included not exceeding that to be impact tested by more than $\frac{1}{4}$ in. (6 mm); such a lot shall be in a single heat treatment load or in the same continuous run in a continuous furnace controlled within a 50°F (28°C) range and equipped with recording pyrometers.

Page 23

ND-2345 Bolting Material

One test shall be made for each lot of material where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed in weight the following:

$1\frac{3}{4}$ in. diameter and less	1,500 lb
$1\frac{3}{4}$ in. to $2\frac{1}{2}$ in. diameter	3,000 lb

Over 5 in. diameter

6,000 lb

10,000 lb

ND-2350 RETESTS

ND-2351 Retests for Material Other Than Bolting

(a) For Charpy V-notch tests required by ND-2330, one retest at the same temperature may be conducted, provided:

(1) the average value of the test results meets the average of three requirements specified in Table ND-2331(a)-1 or Table ND-2331(a)-2, as applicable;

(2) not more than one specimen per test is below the lowest one of three requirements specified in Table ND-2331(a)-1 or Table ND-2331(a)-2, as applicable;

(3) the specimen not meeting the requirements is not lower than 5 ft-lb (6.8 J) or 5 mils (0.13 mm) below the lowest one of three requirements specified in Table ND-2331(a)-1 or Table ND-2331(a)-2, as applicable.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall be equal to or greater than the average of three requirements specified in Table ND-2331(a)-1 or Table ND-2331(a)-2, as applicable.

ND-2352 Retests for Bolting Material

(a) For Charpy V-notch tests required by ND-2330, one retest at the same temperature may be conducted, provided:

(1) not more than one specimen per test is below the acceptance requirements;

(2) the specimen not meeting the acceptance requirements is not lower than 5 ft-lb (6.8 J) or 5 mils (0.13 mm) below the acceptance requirements.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall meet the specified acceptance requirements.

ND-2360 CALIBRATION OF INSTRUMENTS AND EQUIPMENT

Calibration of temperature instruments and C_v impact test machines used in impact testing shall be performed at the frequency specified in (a) and (b) below.

(a) Temperature instruments used to control test temperature of specimens shall be calibrated and the results recorded to meet the requirements of NCA-3868 at least once in each 3 month interval.

(b) C_v impact test machines shall be calibrated and the results recorded to meet the requirements of NCA-3868. The calibrations shall be performed at least once per year using methods outlined in ASTM E 23-72 and employing standard specimens obtained from the National Institute of Standards and Technology.

ND-2400 WELDING MATERIAL

ND-2410 GENERAL REQUIREMENTS

(a) All welding material used in the construction and repair of components or material, except welding material used for cladding or hard surfacing, shall conform to the requirements of the welding material specification or to the requirements for other welding material as permitted in Section IX. In addition, welding material shall conform to the requirements stated in this Subarticle and to the rules covering identification in ND-2150.

(b) The Certificate Holder shall provide the organization performing the testing with the information listed below, as applicable:

(1) welding process;

- (2) SFA specification and classification;
 - (3) other identification if no SFA specification applies;
 - (4) minimum tensile strength [ND-2431.1(e)] in the as-welded or heat treated condition, or both [ND-2431.1(c)];
 - (5) Charpy V-notch test for material as welded, or heat treated, or both (ND-2331); the test temperature and the lateral expansion or the absorbed energy shall be provided;
 - (6) the preheat and interpass temperature to be used during welding of the test coupon [ND-2431.1(c)];
 - (7) postweld heat treatment time, temperature range, and maximum cooling rate, if the production weld will be heat treated [ND-2431.1(c)];
-

Page 24

- (8) elements for which chemical analysis is required per the SFA specification or WPS, and ND-2432;
- (9) minimum delta ferrite (ND-2433).

ND-2420 REQUIRED TESTS

The required tests shall be conducted for each lot of covered, flux cored, or fabricated electrodes; for each heat of bare electrodes, rod, or wire for use with the OFW, GMAW, GTAW, PAW, and EGW (electrogas welding) processes (Section IX, QW-492); for each heat of consumable inserts; for each combination of heat of bare electrodes and lot of submerged arc flux; for each combination of lot of fabricated electrodes and lot of submerged arc flux; for each combination of heat of bare electrodes or lot of fabricated electrodes and dry blend of supplementary powdered filler metal and lot of submerged arc flux; or for each combination of heat of bare electrodes and lot of electroslag flux. Tests performed on welding material in the qualification of weld procedures will satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used, provided the tests required by ND-4000 and this Subarticle are made and the results conform to the requirements of this Article. The definitions in (a) through (h) below apply.

(a) A *dry batch of covering mixture* is defined as the quantity of dry covering ingredients mixed at one time in one mixing vessel; a dry batch may be used singly or may be subsequently subdivided into quantities to which the liquid binders may be added to produce a number of wet mixes.

(b) A *dry blend* is defined as one or more dry batches mixed in a mixing vessel and combined proportionately to produce a uniformity of mixed ingredients equal to that obtained by mixing the same total amount of dry ingredients at one time in one mixing vessel.

(c) A *wet mix* is defined as the combination of a dry batch or dry blend [(a) and (b) above, respectively] and liquid binder ingredients at one time in one mixing vessel.

(d) A *lot of covered, flux cored, or fabricated electrodes* is defined as the quantity of electrodes produced from the same combination of heat of metal and dry batch, dry blend, or chemically controlled mixes of flux or core materials. Alternatively, a lot of covered, flux cored, or fabricated electrodes may be considered one type and size of electrode, produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45,360 kg), from chemically controlled tube, wire, or strip and a dry batch, a dry blend, or chemically controlled mixes of flux, provided each container of welding materials is coded for identification and trace able to the production period, the shift, line, and the analysis range of both the mix and the rod, tube, or strip used to make the electrode.

(1) *Chemically controlled tube, wire, or strip* is defined as consumable tube, wire, or strip material supplied on coils with maximum of one splice per coil that has been chemically analyzed to assure that the material conforms to the electrode manufacturer's chemical control limits for the specific type of electrode. Both ends of each coil shall be chemically analyzed except that those coils which are splice free need only be analyzed on one end of the coil.

(2) *Chemically controlled mixes of flux* are defined as flux material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the electrode manufacturer's standard for each chemical element for that type electrode. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending.

(e) A *heat of bare electrode, rod, wire, or consumable insert* is defined as the material produced from the same melt of

metal.

(f) Alternatively, for carbon and low alloy steel bare electrode, rod, wire, or consumable inserts for use with SAW, OFW, GMAW, GTAW, PAW, and EGW processes, a heat may be defined as either the material produced from the same melt of metal or the material produced from one type and size of wire when produced in a continuous period [not to exceed 24 hr and not to exceed 100,000 lb (45,360 kg)] from chemically controlled wire, subject to requirements of (1), (2), and (3) below.

(1) For the chemical control of the product of the rod mill, coils shall be limited to a maximum of one splice prior to processing the wire. Chemical analysis shall be made from a sample taken from both ends of each coil of mill coiled rod furnished by mills permitting spliced coil practice of one splice maximum per coil. A chemical analysis need be taken from only one end of rod coils furnished by mills prohibiting spliced coil practice.

(2) Carbon, manganese, silicon, and other intentionally added elements shall be identified to ensure that the material conforms to the SFA or user's material specification.

(3) Each container of wire shall be coded for identification and traceability to the lot, production period, shift, line, and analysis of rod used to make the wire.

(g) A lot of submerged arc or electroslag flux is defined as the quantity of flux produced from the same

Page 25

combination of raw materials under one production schedule.

(h) A dry blend of supplementary powdered filler metal is defined as one or more mixes of material produced in a continuous period, not to exceed 24 hr and not to exceed 20,000 lb (9070 kg) from chemically controlled mixes of powdered filler metal, provided each container of powdered metal is coded for identification and traceable to the production period, the shift, and the mixing vessel. A chemically controlled mix of powdered filler metal is defined as powdered filler metal material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the powdered filler metal manufacturer's standard, for each chemical element, for that type of powdered filler metal. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending. The chemical analysis range of the supplemental powdered filler shall be the same as that of the welding electrode, and the ratio of powder to electrode used to make the test coupon shall be the maximum permitted for production welding.

ND-2430 WELD METAL TESTS

ND-2431 Mechanical Properties Test

Tensile and impact tests shall be made in accordance with this paragraph, of welding materials which are used to join P-Nos. 1, 3, 4, 5, 6, 7, 9, and 11 base materials in any combination, with the exceptions listed in (a) through (d) below:

(a) austenitic stainless steel and nonferrous welding materials;

(b) consumable inserts (backing filler material);

(c) welding material used for GTAW root deposits with a maximum of two layers;

(d) welding material to be used for the welding of base materials exempted from impact testing by ND-2311(a)(1) through (a)(7) or ND-2311(a)(9) shall also be exempted from the impact testing required by this paragraph.

ND-2431.1 General Test Requirements.

The welding test coupon shall be made in accordance with (a) through (f) below using each process with which the weld material will be used in production welding.

(a) Test coupons shall be of sufficient size and thickness such that the test specimens required herein can be removed.

(b) The weld metal to be tested for all processes except electroslag welding shall be deposited in such a manner as to eliminate substantially the influence of the base material on the results of the tests. Weld metal to be used with the electroslag process shall be deposited in such a manner as to conform to one of the applicable Welding Procedure

Specifications (WPS) for production welding, Section IX, QW-201.1. The base material shall conform to the requirements of Section IX, QW-403.1 or QW-403.4, as applicable.

(c) The welding of the test coupon shall be performed within the range of preheat and interpass temperatures that will be used in production welding. Coupons shall be tested in the as-welded condition, or they shall be tested in the applicable postweld heat treated condition when the production welds are to be postweld heat treated. The postweld heat treatment holding time² shall be at least 80% of the maximum time to be applied to the weld metal in production application. The total time for postweld heat treatment of the test coupon may be applied in one heating cycle. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the component. In addition, weld coupons for weld metal to be used with the electroslag process, which are tested in the as-welded condition or following a postweld heat treatment within the holding temperature ranges of Table ND-4622.1-1 or ND-4622.4(c)-1, shall have a thickness within the range of 0.5 to 1.1 times the thickness of the welds to be made in production. Electroslag weld coupons to be tested following a postweld heat treatment, which will include heating the coupon to a temperature above the Holding Temperature Range of Table ND-4622.1-1 for the type of material being tested, shall have a thickness within the range of 0.9 to 1.1 times the thickness of the welds to be made in production.

(d) Regardless of the welding process or welding material being tested, the tensile specimens and the C_v impact specimens, when required, shall be located and prepared in accordance with the requirements of SFA-5.1, Specification for Mild Steel Covered Electrodes. Drop weight impact test specimens, when required, shall be oriented so that the longitudinal axis is transverse to the weld with the notch in the weld face, or in a plane parallel to the weld face. For impact specimen preparation and testing, the applicable requirements of ND-2321.1 and ND-2321.2 shall apply. The longitudinal axis of the specimen shall be at a minimum depth of $1/4t$ from a surface, where t is the thickness of the test weld.

(e) One all-weld-metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the base material specification. Where base materials of different specifications are to

Page 26

be welded, the tensile strength results shall conform to either of the base material specifications.

(f) Impact specimens of the weld metal shall be tested when impact tests are required for either of the base materials of the production weld. The weld metal shall conform to the requirements of ND-2330 applicable to the base material. When different requirements exist for the two base materials, the weld metal may conform to either of the two requirements.

[98]

ND-2431.2 Standard Test Requirements.

In lieu of the use of the General Test Requirements specified in ND-2431.1, tensile and impact tests may be made in accordance with this subparagraph when they are required for mild and low alloy steel covered electrodes. The material combinations to require weld material testing as listed in ND-2431 shall apply for this Standard Test Requirements option. The limitations and testing under this Standard Test option shall be in accordance with (a) through (f) below.

(a) Testing to the requirements of this subparagraph shall be limited to electrode classifications included in specifications SFA-5.1 or SFA-5.5.

(b) The test assembly required by SFA-5.1 or SFA-5.5, as applicable, shall be used for test coupon preparation, except that it shall be increased in size to obtain the number of C_v specimens required by ND-2331 when applicable.

(c) The welding of the test coupon shall conform to the requirements of the SFA specification for the classification of electrode being tested. Coupons shall be tested in the as-welded condition and also in the postweld heat treated condition. The PWHT temperatures shall be in accordance with Table ND-4622.1-1 for the applicable P-Number equivalent. The time at PWHT temperature shall be 8 hr (this qualifies PWHT of 10 hr or less). When the PWHT of the production weld exceeds 10 hr, or the PWHT temperature is other than that required above, the general test of ND-2431.1 shall be used.

(d) The tensile and C_v specimens shall be located and prepared in accordance with the requirements of SFA-5.1 or SFA-5.5 as applicable.

(e) One all-weld-metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the SFA specification for the applicable electrode classification.

(f) The requirements of ND-2431.1(f) shall be applicable to the impact testing of this option.

[98]

ND-2432 Chemical Analysis Test

Chemical analysis of filler metal or weld deposits shall be made in accordance with ND-2420 and as required by the following subparagraphs.

**TABLE ND-2432.1-1
SAMPLING OF WELDING MATERIALS FOR
CHEMICAL ANALYSIS**

	GTAW/PAW	GMAW	All Other Processes
A-No. 8 filler metal	Filler metal or weld deposit	Weld deposit	Weld deposit
All other filler metal	Filler metal or weld deposit	Filler metal or weld deposit	Weld deposit

TABLE ND-2432.1-1 SAMPLING OF WELDING MATERIALS FOR CHEMICAL ANALYSIS

ND-2432.1 Test Method.

The chemical analysis test shall be performed in accordance with this subparagraph and Table ND-2432.1-1, and the results shall conform to ND-2432.2.

(a) A-No. 8 welding material to be used with GTAW and PAW processes and any other welding material to be used with any GTAW, PAW, or GMAW process shall have chemical analysis performed either on the filler metal or on a weld deposit made with the filler metal in accordance with (c) or (d) below.

(b) A-No. 8 welding material to be used with other than the GTAW and PAW processes and other welding material to be used with other than the GTAW, PAW, or GMAW process shall have chemical analysis performed on a weld deposit of the material or combination of materials being certified in accordance with (c) or (d) below. The removal of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c) below. As an

alternative, the deposit shall be made in accordance with (d) below for material that will be used for corrosion resistant overlay cladding. Where the Welding Procedure Specification or the welding material specification specifies percentage composition limits for analysis, it shall state that the specified limits apply for the filler metal analysis, the undiluted weld deposit analysis, or *in situ* cladding deposit analysis in conformance with the above required certification testing.

(c) The preparation of samples for chemical analysis of undiluted weld deposits shall comply with the method given in the applicable SFA specification. Where a weld deposit method is not provided by the SFA specification, the sample shall be removed from a weld

Page 27

pad, groove, or other test weld⁴ made using the welding process that will be followed when the welding material or combination of welding materials being certified is consumed. The weld for A-No. 8 material to be used with the GMAW or EGW process shall be made using the shielding gas composition specified in the Welding Procedure Specifications that will be followed when the material is consumed. The test sample for ESW shall be removed from the weld metal of the mechanical properties test coupon. Where a chemical analysis is required for a welding material which does not have a mechanical properties test requirement, a chemical analysis test coupon shall be prepared as required by ND-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of ND-2431.1(c) do not apply.

(d) The alternate method provided in (b) above for the preparation of samples for chemical analysis of welding material to be used for corrosion resistant overlay cladding shall require a test weld made in accordance with the essential variables of the Welding Procedure Specification that will be followed when the welding material is consumed. The test weld shall be made in conformance with the requirements of Section IX, QW-214.1. The removal of chemical analysis samples shall conform with QW-214.3 for the minimum thickness for which the Welding Procedure Specification is qualified.

ND-2432.2 Requirements for Chemical Analysis.

The chemical elements to be determined, the composition requirements of the weld metal, and the recording of results of the chemical analysis shall be in accordance with (a), (b), and (c) below.

(a) Welding material of ferrous alloy A-No. 8 (Section IX, QW-442) shall be analyzed for the elements listed in Table ND-2432.2-1 and any other elements specified in the welding material specification referenced by the Welding Procedure Specification.

⁴ The methods given in the Appendix of SFA 5.9, Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Rods and Bare Electrodes, shall be used to establish a welding and sampling method for the pad, groove, or other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution.

(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition limits. Where the Welding Procedure Specification contains a modification of the composition limits of SFA or other referenced welding material specifications, or provides limits for additional elements,

these composition limits of the Welding Procedure Specification shall apply for acceptability.

TABLE ND-2432.2-1 WELDING MATERIAL CHEMICAL ANALYSIS

Cr–Ni stainless materials	C, Cr, Mo, Ni, Mn, Si, Cb
---------------------------	------------------------------

TABLE ND-2432.2-1 WELDING MATERIAL CHEMICAL ANALYSIS

(c) The results of the chemical analysis shall be reported in accordance with NCA-3867. Elements listed in Table ND-2432.2-1 but not specified in the welding material specification or Welding Procedure Specification shall be reported for information only.

ND-2433 Delta Ferrite Determination

A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, QW-442) backing filler metal (consumable inserts); bare electrode, rod, or wire filler metal; or weld metal, except that delta ferrite determinations are not required for SFA-5.4 Type 16-8-2, or A-No. 8 weld filler metal to be used for weld metal cladding.

ND-2433.1 Method.

Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of chemical analysis of ND-2432 in conjunction with Fig. ND-2433.1-1.

(a) Calibration of magnetic instruments shall conform to AWS-A4.2-91.

(b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with ND-2432.1(c).

(c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number (FN).

ND-2433.2 Acceptance Standards.

The minimum acceptable delta ferrite shall be 5FN. The results of the delta ferrite determination shall be included in the Certified Material Test Report of ND-2130 or ND-4120.

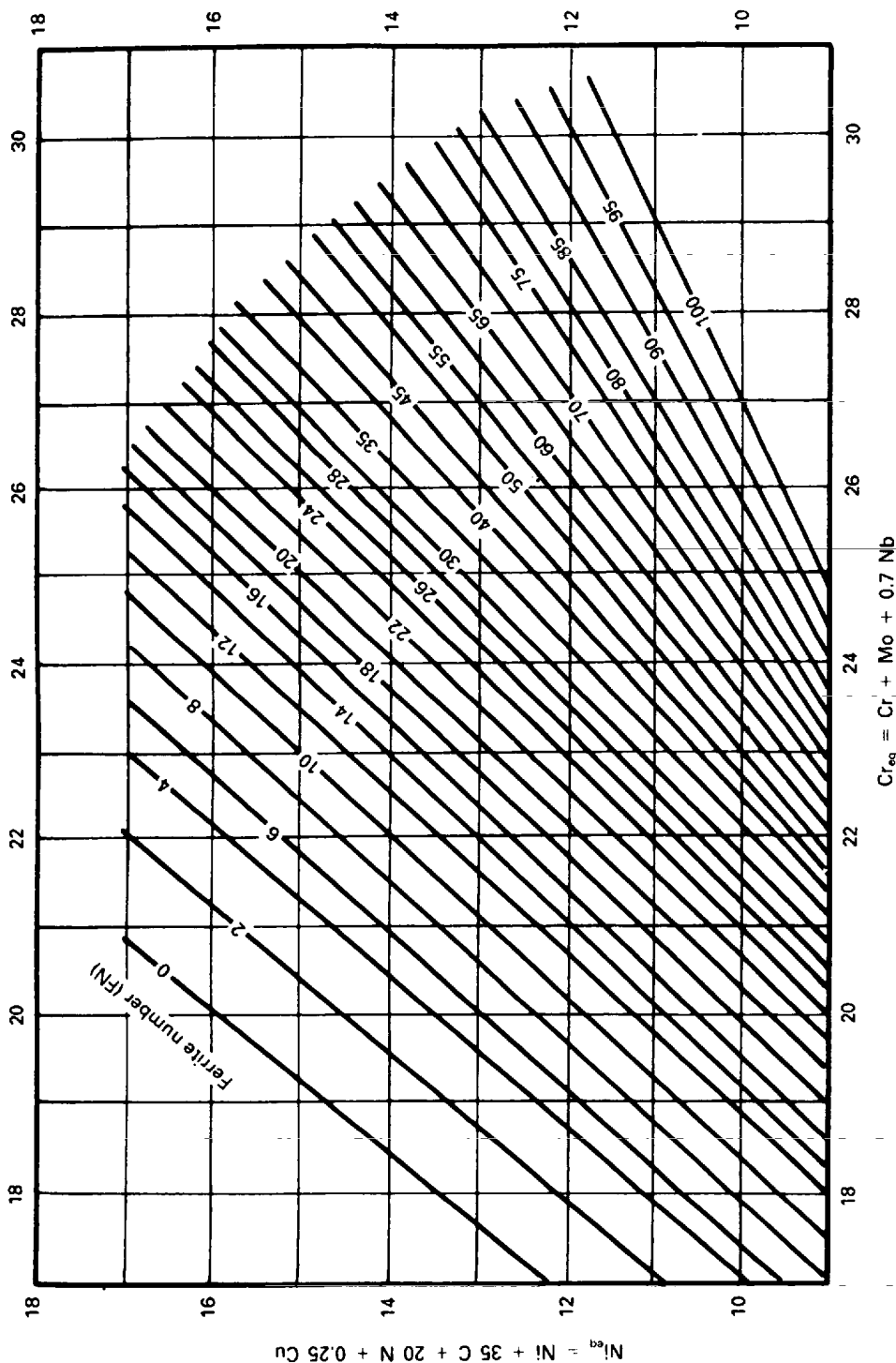
ND-2440 STORAGE AND HANDLING OF WELDING MATERIAL

Suitable storage and handling of electrodes, flux, and other welding material shall be maintained. Precautions

Page 28

Page 29

shall be taken to minimize absorption of moisture by fluxes and cored, fabricated, and coated electrodes.



GENERAL NOTES:

- (a) The actual nitrogen content is preferred. If this is not available, the following applicable nitrogen value shall be used:
 - (1) GMAW welds-0.08%, except that when self shielding flux cored electrodes are used-0.12%.
 - (2) Welds made using other processes-0.06%.
- (b) This diagram is identical to the WRC-1992 Diagram, except that the solidification mode lines have been removed for ease of use.

FIG. ND-2433.1-1 DELTA FERRITE CONTENT

FIG. ND-2433.1-1 DELTA FERRITE CONTENT

ND-2500

ND-2510 PRESSURE RETAINING MATERIAL

Pressure retaining material shall be examined and repaired in accordance with the material specification and as otherwise required by this Subarticle. Pressure retaining material for ASME B16.34 Special Class category valves (NC-3513) shall be examined and repaired in accordance with the requirements therein and as otherwise required by this Subarticle. If the examination and repair requirements of this Subarticle either duplicate or exceed the ASME B16.34 requirements, then only the requirements of this Subarticle need to be met. Size exclusions of this Subarticle shall not be applied so as to reduce the examination requirements of ASME B16.34 for Special Class category valves.

ND-2530 EXAMINATION AND REPAIR OF PLATE

ND-2531 Required Examination

Plates shall be examined in accordance with the requirements of the material specification.

ND-2537 Time of Examination

Acceptance examinations shall be performed at the time of manufacture as required in (a) through (c) below.

(a) Examinations required by the material specification shall be performed at the time of manufacture as specified in the material specification.

(b) Radiographic examination of repair welds, when required, may be performed prior to any required postweld heat treatment.

(c) Magnetic particle or liquid penetrant examination of repair welds shall be performed after any required heat treatment, except for P-No. 1 material which may be examined before or after any required postweld heat treatment.

ND-2538 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) and (b) below are met.

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) If the elimination of the defect reduces the thickness of the section below the minimum required by the design, the material shall be repaired in accordance with ND-2539.

ND-2539 Repair by Welding

The Material Organization may repair by welding material from which defects have been removed, provided the depth of the repair cavity does not exceed one-third of the nominal thickness and the requirements of the following subparagraphs are met. Prior approval of the Certificate Holder shall be obtained for the repair of plates to be used in the manufacture of vessels.

ND-2539.1 Defect Removal.

The defect shall be removed or reduced to an imperfection of acceptable limit by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair (ND-4211.1).

ND-2539.2 Qualification of Welding Procedures and Welders.

The welding procedure and welders or welding operators shall be qualified in accordance with the ND-4000 and Section IX.

ND-2539.3 Blending of Repaired Areas.

After repair, the surface shall be blended uniformly into the surrounding surface.

[98]

ND-2539.4 Examination of Repair Welds.

Each repair weld shall be examined by the magnetic particle method (ND-2545) or by the liquid penetrant method (ND-2546). In addition, when the depth of repair cavities exceeds the lesser of $\frac{3}{8}$ in. (10 mm), or 10% of the section thickness, the repair weld shall be radiographed in accordance with and to the applicable acceptance standards of ND-5320. The penetrameter shall be based upon the section thickness of the repaired area.

[98]

ND-2539.5 Heat Treatment After Repair.

The product shall be heat treated after repair in accordance with the heat treatment requirements of ND-4620.

ND-2539.6 Material Report Describing Defects and Repair.

Each defect repair that is required to be radiographed shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart which shows the

Page 30

location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and a report of the results of the examinations, including radiographic film.

ND-2540 EXAMINATION AND REPAIR OF FORGINGS AND BARS

ND-2541 Required Examination

Forgings and bars shall be examined in accordance with the requirements of the material specification except when magnetic particle or liquid penetrant examination is specifically required by the rules of this Subsection, in which case the examination shall conform to the requirements of ND-2545 or ND-2546, as applicable.

ND-2545 Magnetic Particle Examination

ND-2545.1 Examination Procedure.

The procedure for magnetic particle examination shall be in accordance with the methods of Section V, Article 7.

ND-2545.2 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication in excess of the ND-2545.3 acceptance standards, which is believed to be nonrelevant, shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width. Indications resulting from nonmetallic inclusions are not considered relevant indications.

ND-2545.3 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for material less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for material 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 sq in. (3871 mm²) of area whose major dimension is no more than 6 in. (152 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

ND-2546 Liquid Penetrant Examination

ND-2546.1 Examination Procedure.

The procedure for liquid penetrant examination shall be in accordance with the methods of Section V, Article 6.

ND-2546.2 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities such as may occur from machining marks or surface conditions may produce similar indications which are not relevant.

(b) Any indication in excess of the ND-2546.3 acceptance standards which is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

ND-2546.3 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for materials less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for material 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 sq in. (3871 mm²) of area whose major dimension is no more than 6 in. (152 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

ND-2547 Time of Examination

Acceptance examinations shall be performed as follows.

(a) Magnetic particle or liquid penetrant examination shall be performed in the finished condition.

(b) Forged and rolled bars which are to be bored or turned to form tubular products or fittings shall be examined after boring or turning, except for threaded or drilled holes.

ND-2548 Elimination of Surface Defects

(a) Unacceptable surface defects shall be removed by grinding or machining, provided the requirements of (1) through (4) below are met.

(1) The remaining thickness of the section is not reduced below that required by ND-3000.

(2) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(3) After defect elimination, the area is reexamined by the magnetic particle method in accordance with ND-2545 or the liquid penetrant method in accordance with ND-2546 to ensure that the defect has been removed or the indication reduced to an acceptable size.

(4) Areas ground to remove oxide scale or other mechanically caused impressions for appearance or to facilitate proper ultrasonic testing need not be examined by the magnetic particle or liquid penetrant method.

(b) When the elimination of the defect reduces the thickness of the section below the minimum required to satisfy ND-3000, the product shall be repaired in accordance with ND-2549.

ND-2549 Repair by Welding

The Material Organization may repair by welding material from which defects have been removed, provided the requirements of the following subparagraphs are met.

ND-2549.1 Defect Removal.

The defect shall be removed or indication reduced to an acceptable size by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair (ND-4211.1).

ND-2549.2 Qualification of Welding Procedures and Welders.

The welding procedure and welders or welding operators shall be qualified in accordance with ND-4000 and Section IX.

ND-2549.3 Blending of Repaired Areas.

After repair, the surface shall be blended uniformly into the surrounding surface.

ND-2549.4 Examination of Repair Welds.

Each repair weld shall be examined by the magnetic particle method (ND-2545) or by the liquid penetrant method (ND-2546). In addition, when the depth of the repair cavity exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness, the repair weld shall be radio graphed after repair in accordance with ND-5000. The penetrameter and the acceptance standards for radio graphic examination of repair welds shall be based on the section thickness at the repaired area.

ND-2549.5 Heat Treatment After Repairs.

The product shall be heat treated after repair in accordance with the heat treatment requirements of ND-4620.

ND-2549.6 Material Report Describing Defects and Repairs.

Each defect repair exceeding in depth the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart which shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographic film.

ND-2550 EXAMINATION AND REPAIR OF SEAMLESS AND WELDED (WITHOUT FILLER METAL) TUBULAR PRODUCTS AND FITTINGS

ND-2551 Required Examination

Wrought seamless and welded (without filler metal) tubular products and fittings shall comply with the requirements of ND-2557, ND-2558, and ND-2559 in addition to the basic material specification.

Page 32

ND-2557 Time of Examination

(a) Products that are quenched and tempered shall be examined, as required, after the quenching and tempering heat treatment.

(b) Products that are not quenched and tempered shall receive the required examinations as follows.

(1) Magnetic particle or liquid penetrant examination of welds, including repair welds, shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment for P-No. 1 (Section IX of the Code) materials of 2 in. (51 mm) and less nominal thickness.

(2) Forgings and rolled bars which are to be bored and/or turned to form tubular parts or fittings shall be examined after boring and/or turning, except for threading. Fittings shall be examined after final forming.

(3) When surface examination is required all external surfaces and all accessible internal surfaces shall be examined except for bolt holes and threads.

ND-2558 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (c) below are met:

(a) the depression, after defect elimination, is blended uniformly into the surrounding surface;

(b) after defect elimination, the area is examined by the method which originally disclosed the defect to ensure that the defect has been removed or reduced to an imperfection of acceptable size.

(c) If the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of ND-3000, the product shall be repaired in accordance with ND-2559.

ND-2559 Repair by Welding

Repair of defects shall be in accordance with ND-2539, except repair by welding is not permitted on copper alloy and nickel alloy heat exchanger tubes.

ND-2560 EXAMINATION AND REPAIR OF TUBULAR PRODUCTS AND FITTINGS WELDED WITH FILLER METAL

ND-2561 Required Examinations

(a) Welded (with filler metal) tubular products such as pipe made in accordance with SA-134, SA-358, SA-409, SA-671, SA-672, and SA-691 and fittings made in accordance with the WPW grades of SA-234, SA-403, and SA-420 which are made by welding with filler metal shall be treated as materials; however, inspection by an Inspector and stamping with the NPT symbol shall be in accordance with Section III requirements. In addition to the NPT symbol, the numeral 3 shall be stamped below and outside the official Code symbol.

(b) In addition to the requirements of the material specification, tubular products shall comply with this Article.

(c) Weld joint efficiency factors listed in Tables 1A and 1B, Section II, Part D, shall apply.

(d) Tubular products and fittings which have been radiographed shall be marked to indicate that radiography has been performed. The radiographic film and a radiographic report showing film locations shall be provided with the Certified Material Test Report.

(e) The Authorized Inspector shall certify by signing the Partial Data Report Form NM-1 in accordance with NCA-5290.

ND-2567 Time of Examination

The time of examination shall be in accordance with the requirements of ND-2557.

ND-2568 Elimination of Surface Defects

Unacceptable surface defects shall be removed in accordance with the requirements of ND-2558.

ND-2569 Repair by Welding

When permitted by the basic material specification, base material defects shall be repair welded in accordance with the requirements of ND-2559. Repair welding of weld seam defects shall be in accordance with ND-4450.

ND-2570 EXAMINATION AND REPAIR OF STATICALLY AND CENTRIFUGALLY CAST PRODUCTS

In addition to the requirements of the material specification and of this Article, statically and centrifugally cast products shall comply with the following subparagraphs.

Page 33

ND-2571 Required Examinations

(a) Cast products shall be examined by volumetric and/or surface methods, including repairs, as required for the product form by Table ND-2571-1 Class 3 castings.

(b) For cast valves furnished to ASME B16.34 special class category, examination of castings, including procedure and acceptance requirements, shall be as required by ASME B16.34.

ND-2572 Time of Nondestructive Examination

ND-2572.1 Acceptance Examinations.

Acceptance examinations shall be performed at the time of manufacture as stipulated in the following and Table ND-2571-1.

(a) *Ultrasonic Examination.* Ultrasonic examination, if required, shall be performed at the same stage of manufacture as required for radiography.

(b) *Radiographic Examination.* Radiography may be performed prior to heat treatment and may be performed prior to or after finish machining at the following limiting thicknesses.

(1) For finished thicknesses under $2\frac{1}{2}$ in. (64 mm), castings shall be radiographed within 20% of the finished thickness when Type 2 radiographic film is used or within $\frac{1}{2}$ in. (13 mm) of the finished thickness when Type 1 radiographic film is used. The penetrometer and the acceptance reference radiographs shall be based on the finished thickness.

(2) For finished thickness from $2\frac{1}{2}$ in. (64 mm) up to 6 in. (152 mm), castings shall be radiographed within 20% of the finished thickness. The penetrometer and the acceptance reference radiographs shall be based on the finished thickness.

(3) For finished thicknesses over 6 in. (152 mm), castings shall be radiographed with $\frac{1}{2}$ in. (13 mm) or 15% of the finished thickness, whichever is greater. The penetrometer and the acceptance reference radiographs shall be based on the finished thickness.

(c) Radiography of castings for pumps and valves may be performed in as-cast or rough machined thickness exceeding the limits of (b)(1), (b)(2), or (b)(3) above, subject to the following conditions.

(1) When the thickness of the as-cast or rough machined section exceeds 2 in. (51 mm), acceptance shall be based on

reference radiographs for the next lesser thickness; e.g., if the section being radiographed exceeds $4\frac{1}{2}$ in. (114 mm), use reference radiographs of ASTM E 186-75 (reapproved 1979). The penetrameter shall be based on the thickness of the section being radiographed.

(2) When the thickness of the as-cast or rough machined section is 2 in. (51 mm) or less, the reference radiographs of ASTM E 446-78 shall be used and the penetrameter shall be based on the final section thickness.

(3) Weld ends for a minimum distance of t or $\frac{1}{2}$ in. (13 mm), whichever is less (where t is the design section thickness of the weld) from the final welding end shall be radiographed at a thickness within the limits given in (b)(1), (b)(2), or (b)(3) above as applicable. As an alternative, the weld ends may be radiographed in the as-cast or rough machined thickness in accordance with (c)(1) and (c)(2) above and the penetrameter shall be based on the final section thickness.

(d) *Magnetic Particle or Liquid Penetrant Examination.* Magnetic particle or liquid penetrant examination shall be performed after the final heat treatment required by the material specification. Repair weld areas shall be examined after postweld heat treatment when a postweld heat treatment is performed, except that repair welds in P-No. 1 (see Section IX of the Code) material 2 in. nominal thickness and less may be examined prior to postweld heat treatment. For cast products with machined surfaces, all finished machine surfaces, except threaded surfaces and small deep holes, shall also be examined by magnetic particle or liquid penetrant methods.

ND-2573 Provisions for Repair of Base Material by Welding

The Material Organization may repair, by welding, products from which defects have been removed, provided the requirements of this Article are met.

ND-2573.1 Defect Removal.

The defects shall be removed or reduced to an imperfection of acceptable size by suitable mechanical or thermal cutting or gouging methods, and the cavity prepared for repair. When thermal cutting is performed, consideration shall be given to preheating the material.

ND-2573.2 Repair by Welding.

The Material Organization may repair castings by welding after removing the material containing unacceptable defects. The depth of the repair is not limited. A cored hole or access hole may be closed by the Material Organization by welding in accordance with the requirements of this paragraph provided the hole is closed by filler metal only. If the hole is closed by welding in a metal insert, the welding shall be performed by a holder of a Certificate of Authorization in accordance with the requirements of the Code.

Page 34

Page 35

TABLE ND-2571-1 REQUIRED EXAMINATIONS

Nominal Pipe Size	Item	Applicable Special Requirements for Class 3 Castings
Inlet piping connections of 2 in. and less	Cast Pipe fittings, pump, and valves	None, except for ASME B16.34 special class category valves, which shall be in accordance with ND-2571(b).
	Cast pressure retaining material with a Quality Factor of 0.80, excluding pipe fittings, pumps, and valves	Visual examination required
	Cast pressure retaining material with a Quality Factor of 0.85, excluding pipe fittings, pumps, and valves	Magnetic particle or liquid penetrant examination shall be performed on all external surfaces and on all accessible internal surfaces.
	Cast pressure retaining material with a Quality Factor of 1.00, excluding pipe fittings, pumps, and valves	Radiographic or ultrasonic examination required; magnetic particle or liquid penetrant examination optional
	Repair welds	(a) When magnetic particle or liquid penetrant examination of the casting is required, each repair shall be examined by the magnetic particle method or by the liquid penetrant method. (b) When radiography of the casting is required, repair welds in cavities, the depth of which exceeds the lesser of $\frac{3}{8}$ in. or 10% of the section thickness, shall be radiographed in accordance with ND-2575. (c) When partial radiography of a casting is required, repairs located in an area of the casting which is not covered by radiography need only be examined by the magnetic particle method or by the liquid penetrant method.
Inlet piping connections over 2 in.	Cast valves	None, except for ASME B16.34 special class category valves, which shall be in accordance with ND-2571(b).
	Cast pressure retaining material with a Quality Factor of 0.80, excluding valves	Visual examination required
	Cast pressure retaining material with a Quality Factor of 0.85, excluding valves	Magnetic particle or liquid penetrant examination shall be performed on all external surfaces and on all accessible internal surfaces.
	Cast pressure retaining material with a Quality Factor of 1.00, excluding valves	Radiographic or ultrasonic examination required, magnetic particle or liquid penetrant examination optional
	Repair welds	(a) When magnetic particle or liquid penetrant examination of the casting is required, each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. (b) When radiography of the casting is required, repair welds in cavities, the depth of which exceeds the lesser of $\frac{3}{8}$ in. or 10% of the section thickness, shall be radiographed in accordance with ND-2575. (c) When partial radiography of a casting is required, repairs located in an area of the casting which is not covered by radiography need only be examined by the magnetic particle method or by the liquid penetrant method.

TABLE ND-2571-1 REQUIRED EXAMINATIONS

ND-2573.3 Qualification of Welding Procedures and Welders.

Each manufacturer is responsible for the welding done by his organization and shall establish the procedures and conduct the tests required by ND-4000 and by Section IX of the Code in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures. He is also responsible for the welding performed by his subcontractors and shall assure himself that the subcontractors conduct the tests required by ND-4000 and by Section IX of the Code in order to qualify their welding procedures and the performance of their welders and welding operators.

ND-2573.4 Blending of Repaired Areas.

After repair, the surface shall be blended uniformly into the surrounding surface.

ND-2573.5 Examination of Repair Welds

(a) Each repair weld shall be examined by the magnetic particle method in accordance with the requirements of ND-2577 or by the liquid penetrant method in accordance with the requirements of ND-2576. In addition, when radiography is specified in the order for the original casting, repair cavities, the depth of which exceeds the lesser or $\frac{3}{8}$ in. or 10% of the nominal wall thickness, shall be radiographed after repair, except that weld slag, including elongated slag, shall be considered as inclusions under Category B of the applicable reference radiographs. The total area of all inclusions, including slag inclusions, shall not exceed the limits of the applicable severity level of Category B of the reference radiographs. The penetrometer and the acceptance standards for radiographic examination of repair welds shall be based on the actual section thickness at the repaired area.

(b) Examination of repair welds in P-No. 1 and P-No. 8 material is not required for pumps and valves with inlet piping connections NPS 2 and less.

ND-2573.6 Heat Treatment After Repairs.

The material shall be heat treated after repair in accordance with the heat treatment requirements of ND-4620, except that the heating and cooling rate limitations of ND-4623 do not apply.

ND-2573.7 Elimination of Surface Defects.

Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (c) below are met:

(a) the depression, after defect elimination, is blended uniformly into the surrounding surface;

(b) after defect elimination, the area is reexamined by the magnetic particle method in accordance with ND-2577 or the liquid penetrant method in accordance with ND-2576 to ensure that the defect has been removed or reduced to an imperfection of acceptable size;

(c) if the elimination of the defect reduces the section thickness below the minimum required by the specification or drawing, the casting shall be repaired in accordance with ND-2539.

ND-2573.8 Material Report Describing Defects and Repairs.

Each defect repair exceeding in depth the lesser of $\frac{3}{8}$ in. or 10% of the nominal wall thickness shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart that shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographic film, when radiography is specified in the order for the original casting.

ND-2574 Ultrasonic Examination of Ferritic Steel Castings

Ultrasonic examination shall be performed in accordance with T-541.4 of Article 5 of Section V. Each manufacturer shall certify that the procedure is in accordance with the requirements of ND-2574 and shall make the procedure available for approval upon request.

ND-2574.1 Acceptance Standards

(a) The Quality Levels of SA-609 as shown in Section V shall apply for the casting thicknesses indicated:

- (1) Quality Level 1 for thicknesses up to 2 in.;
- (2) Quality Level 3 for thicknesses 2 to 4 in.;
- (3) Quality Level 4 for thicknesses greater than 4 in.

(b) In addition to the Quality Level requirements stated in (a) above, the requirements in (1) through (5) below shall apply for both straight beam and angle beam examination.

(1) Areas giving indications exceeding the Amplitude Reference Line with any dimension longer than those specified in the following tabulation are unacceptable:

Page 36

UT Quality Level	Longest Dimension of Area ⁵⁶⁷
1	1.5 in.
2	2.0 in.
3	2.5 in.
4	3.0 in.

(2) Quality Level 1 shall apply for the volume of castings within 1 in. of the surface regardless of the overall thickness.

(3) Discontinuities indicated to have a change in depth equal to or greater than one-half the wall thickness or 1 in. (whichever is less) are unacceptable.

(4) Two or more imperfections producing indications in the same plane with amplitudes exceeding the Amplitude Reference Line and separated by a distance less than the longest dimension of the larger of the adjacent indications are unacceptable if they cannot be encompassed within an area less than that of the Quality Level specified in (b)(1) above.

(5) Two or more imperfections producing indications greater than permitted for Quality Level 1 for castings less than 2 in. in thickness, greater than permitted for Quality Level 2 for thicknesses 2 in. through 4 in., and greater than permitted for Quality Level 3 for thicknesses greater than 4 in., separated by a distance less than the longest dimension of the larger of the adjacent indications are unacceptable, if they can not be encompassed in an area less than that of the Quality Level requirements stated in (a) above.

ND-2575 Radiographic Examination

ND-2575.1 Examination.

Cast pressure retaining materials shall be examined by the radiographic method when specified in the order for the original castings, except that cast ferritic steels may be examined by either radiographic or ultrasonic methods, or a combination of both methods. Castings or sections of castings that have coarse grains or configurations that do not yield meaningful examination results by ultrasonic methods shall be examined by the radiographic method.

⁵ The areas for the Ultrasonic Quality Levels in SA-609 refer to the surface area on the casting over which a continuous indication exceeding the transfer corrected distance amplitude curve is maintained.

⁶ Areas are to be measured from dimensions of the movement of the search unit, using the center of the search unit as the reference point.

⁷ In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or

smaller than the actual area of the discontinuity in the casting; in such cases, other criteria which incorporate a consideration of beam angles or beam spread must be used for realistic evaluation of the discontinuity.

ND-2575.2 Extent.

Radiographic examination shall be performed on pressure retaining castings such as vessel heads and flanges, valve bodies, bonnets and disks, pump casings and covers, and piping and fittings. The extent of radiographic coverage shall be of the maximum feasible volume and, when the shape of the casting precludes complete coverage, the coverage shall be at least as exemplified in the typical sketches as shown in Fig. ND-2575.2-1.

ND-2575.3 Examination Procedure.

The radiographic examination shall be performed in accordance with Article 2 of Section V, with the following modifications.

(a) *Film Selection.* Only Types 1, 2, and 3 are permitted.

(b) *Radiographic Density.* The transmitted film density through the radiographic image of the body of the appropriate penetrameter and the area of interest shall be 1.3 minimum for single film viewing. For composite viewing of multiple film exposures, each film of the composite set shall have a minimum density of 1.0. The maximum density shall be 4.0 for either single or composite viewing. A tolerance of 0.05 in density is allowed for variations between densitometer readings.

(c) The requirements of T-274 and T-285 of Article 2 of Section V need not be met.

(d) *Image Quality Indicator (IQI) Design.* Penetrameters shall be manufactured and identified in accordance with the requirements or alternatives allowed in SE-142 and Appendices.

(e) *Image Quality Indicator (IQI) Selection.* The radio graphic quality level shall be 2-4 T for section thicknesses up to and including $\frac{3}{4}$ in. and 2-2 T for section thicknesses greater than $\frac{3}{4}$ in. Radiographic quality is defined in Note 2 of SE-94.

(f) When radiographing weld ends of cast valves, NPS 4 and less, double-wall radiography may be used subject to the conditions of (1) and (2) below.

(1) The penetrameter thickness shall be based on the design section thickness of the double wall, excluding the weld preparation lip.

(2) Acceptance standards shall be based on nominal single-wall thickness.

ND-2575.4 Procedure Requirements.

Radiographic examination shall be performed in accordance with a written procedure. Each manufacturer shall certify that the procedure is in accordance with the requirements of NB-2575. The procedure shall be available for the interpretation of the films and shall be submitted together with the radiographs. Each procedure shall include at least the following information:

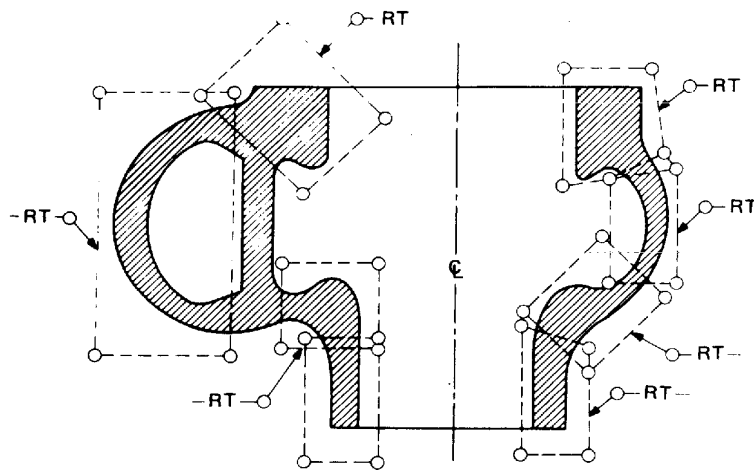
(a) the type of material to be radiographed;

Page 37

(b)

Page 39

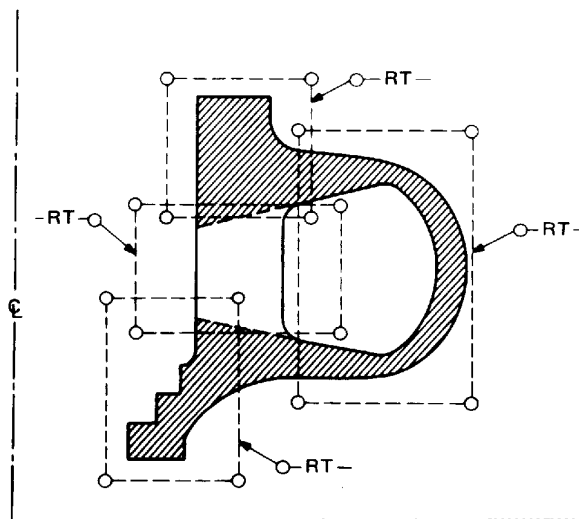
Pages 38-38



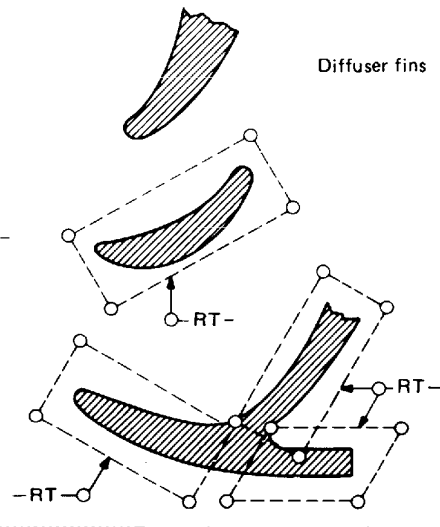
(a) Typical Volute-Type Pump Case

GENERAL NOTES:

- (a) Radiographic examination areas shall be indicated by a circle at each change of direction. The examination symbol for radiography shall be indicated as RT.
- (b) For nondestructive examination areas of revolution, the area shall be indicated by the examine-all-around symbol: — RT — ⌀
- (c) The sketches are typical and are to be used as a guide for minimum required coverage. Even though a sketch may be titled, "pump" or "valve," the coverage shown by the configurations may be applied interchangeably.



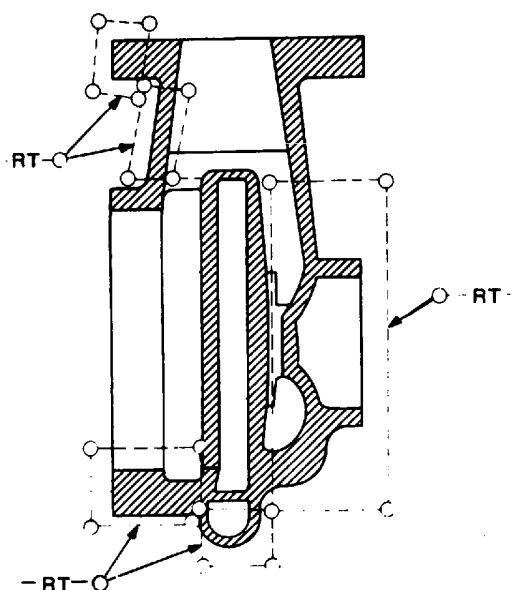
(b) Typical Diffuser-Type Pump Case



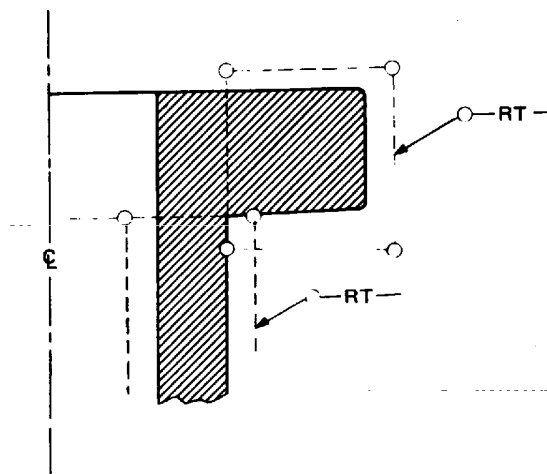
(c) Typical Diffuser-Type Pump Case Detail

FIG. ND-2575.2-1 TYPICAL PRESSURE RETAINING PARTS OF PUMPS AND VALVES

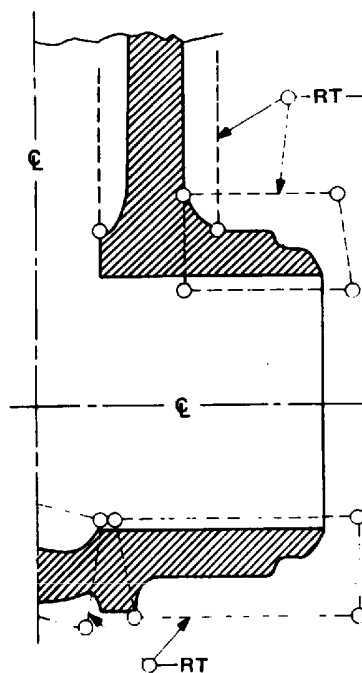
FIG. ND-2575.2-1 TYPICAL PRESSURE RETAINING PARTS OF PUMPS AND VALVES



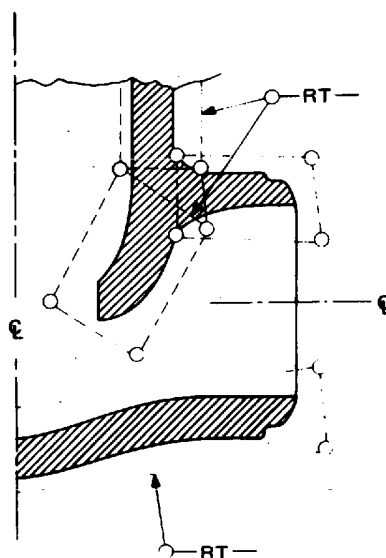
(d) Typical Single Stage Pump Case



(e) Typical Flange



(f) Typical Gate Valve



(g) Typical Globe Valve

FIG. ND-2575.2-1 TYPICAL PRESSURE RETAINING PARTS OF PUMPS AND VALVES (CONT'D)

FIG. ND-2575.2-1 TYPICAL PRESSURE RETAINING PARTS OF PUMPS AND VALVES (CONT'D)

(b) the material thickness ranges to be radiographed;

(c) the type of radiation source, actual or maximum source size or focal spot, and X-ray equipment voltage rating and manufacturer. The equipment manufacturer's or supplier's publications, such as technical manuals, decay curves, or written statements documenting the actual or maximum source size or focal spot, shall be acceptable as source size verification. For X-ray machines 320 KV and less, the focal spot size may be determined by the pinhole method⁸

(d) type and thickness of intensifying screens and filters;

(e) minimum source-to-film distance.

ND-2575.5 Radiographic Setup Information.

To aid in proper interpretation of radiographs, details of the radiographic examination setup used shall accompany each group of radiographs. As a minimum, the information shall include:

(a) film brand and the type and number of films in the cassette;

(b) for multiple film technique, state whether viewing is to be single or superimposed;

(c) blocking or masking technique, if used;

(d) isotope or X-ray voltage used;

(e) source to film distance used;

(f) distance between film and object when film/cassette is not in contact with object;

(g) geometric arrangement for the radiograph(s) (sketch);

(h) orientation of location markers;

(i) description of how internal markers, when used, locate area of interest;

(j) Location markers, such as lead numbers or letters, which shall appear as radiographic images on the film, shall be permanently stamped on the surface of the casting being radiographed in a manner permitting the area of interest on a radiograph to be accurately located on the casting and providing evidence on the radiograph that the extent of coverage required by ND-2575.2 has been obtained. On castings or sections of castings where stamping is not feasible, the radiographic procedure shall so state, in which case a radiographic film location map shall be provided.

⁸ Nondestructive Testing Handbook, Volume I, First Edition, pp. 14.32, 14.33, "Measuring Focal-Spot Size." Also, pp. 20, 21 of Radiography in Modern Industry, Fourth Edition.

ND-2575.6 Acceptance Criteria.

Castings shall meet the acceptance requirements of Severity Level 2 of ASTM E 446-72, E 446-75, or E 446-78, Reference Radiographs for Steel Castings up to 2 in. in Thickness, ASTM E 186-67, E 186-73, or E 186-75, Reference Radiographs for Heavy-Walled (2 to 4½ in.) Steel Castings, or ASTM E 280-68, E 280-72, or E 280-75, Reference Radiographs for Heavy Walled (4½ to 12 in.) Steel Castings, as applicable for the thickness being radiographed, except Category D, E, F, or G defects are not acceptable. The requirements of ASTM E 280-68, E 280-72, or E 280-75 shall apply for castings over 12 in. in thickness.

ND-2576 Liquid Penetrant Examination

(a) Castings shall be examined, if required, on all accessible surfaces by the liquid penetrant method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by bleeding out of the penetrant; however, localized surface discontinuities as may occur from machining marks, scale, or dents may produce indications which are not relevant. Any indication in excess of the acceptance standards believed to be nonrelevant shall be reexamined to verify whether actual

defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation that would mask indications of defects are unacceptable. Relevant indications are those which result from imperfections and have a major dimension greater than $\frac{1}{16}$ in. Linear indications are those whose length is more than three times the width. Rounded indications are those which are circular or elliptical with the length less than three times the width.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for materials less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for materials from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for materials 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

Page 40

ND-2577 Magnetic Particle Examination (for Ferritic Steel Products Only)

(a) Castings of magnetic material shall be examined, if required, on all accessible surfaces by a magnetic particle method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by retention of the examination medium. All indications are not necessarily defects since certain metallurgical discontinuities and magnetic permeability variations may produce indications that are not relevant. Any indication in excess of the acceptance standards believed to be nonrelevant shall be reexamined to verify whether actual defects are present. Nonrelevant indications which would mask indications of defects are unacceptable. Surface conditioning may precede the reexamination. Relevant indications are those which result from imperfections and have a major dimension greater than $\frac{1}{16}$ in. (1.6 mm). Linear indications are those whose length is more than three times the width. Rounded indications are those which are circular or elliptical with the length less than three times the width.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for materials less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for materials from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for materials 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

ND-2580 EXAMINATION OF BOLTS, STUDS, AND NUTS

ND-2581 Requirements

All bolting materials shall be visually examined in accordance with ND-2582.

ND-2582 Visual Examination

Visual examination shall be applied to the areas of threads, shanks, and heads of final machined parts. Harmful

discontinuities such as laps, seams, or cracks that would be detrimental to the intended service are unacceptable.

ND-2600 MATERIAL ORGANIZATIONS' QUALITY SYSTEM PROGRAMS

ND-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS

(a) Except as provided in (b) below, Material Organizations shall have a Quality System Program or an Identification and Verification Program, as applicable, which meets the requirements of NCA-3800.

(b) The requirements of NCA-3862 shall be met as required by ND-2130. The other requirements of NCA-3800 need not be used by Material Organizations for small products, as defined in (c) below, for brazing material, and for material which is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Control System (NCA-8120) shall include measures to provide assurance that the material is furnished in accordance with the material specification and with the applicable requirements of this Subsection.

(c) For the purpose of this paragraph, small products are defined as given in (1) through (5) below:

- (1) pipe, tube (except heat exchanger tube), pipe fittings, and flanges NPS 2 (DN 50) and less;
- (2) bolting material, including studs, nuts, and bolts of 1 in. (25 mm) nominal diameter and less;
- (3) bars with a nominal cross-sectional area of 1 sq in. (645 mm²) and less;
- (4) material for pumps and valves with inlet pipe connections of NPS 2 (DN 50) and less;
- (5) material exempted by ND-2121(c).

ND-2700 DIMENSIONAL STANDARDS

Dimensions of standard items shall comply with the standards and specifications of Table ND-3132-1.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 ND-3000

ARTICLE ND-3000 DESIGN

Page 41

Page 42

ND-3100 GENERAL DESIGN

ND-3110 LOADING CRITERIA

ND-3111 Loading Conditions

The loadings that shall be taken into account in designing a component shall include, but are not limited to, those in (a) through (h) below:

- (a) internal and external pressure;
- (b) impact forces caused by either external or internal conditions;
- (c) impact loads, including rapidly fluctuating pressures;
- (d) weight of the component and normal contents under operating or test conditions, including additional pressure due to static and dynamic head of liquids;
- (e) superimposed loads such as other components, operating equipment, insulation, corrosion resistant or erosion

resistant linings, and piping;

(f) wind loads, snow loads, vibrations, and earth quake loads where specified;

(g) reactions of supporting lugs, rings, saddles, or other types of supports;

(h) temperature effects.

ND-3112 Design Loadings

The Design Loadings shall be established in accordance with NCA-2142.1 and the following subparagraphs.

ND-3112.1 Design Pressure.

The specified internal and external Design Pressures to be used in this Subsection shall be established in accordance with NCA-2142.1(a).

ND-3112.2 Design Temperature.

The specified Design Temperature shall be established in accordance with NCA-2142.1(b). It shall be used in conjunction with Design Pressure. If necessary, the metal temperature shall be determined by computation using accepted heat transfer procedures or by measurement from equipment in service under equivalent operating conditions.

In no case shall the temperature at the surface of the metal exceed the maximum temperature listed in Tables 1A and 1B, Section II, Part D, Subpart 1 nor exceed the temperature limitations specified elsewhere in this Subsection.

ND-3112.3 Design Mechanical Loads.

The specified Design Mechanical Loads shall be established in accordance with NCA-2142.1(c). They shall be used in conjunction with the Design Pressure.

ND-3112.4 Design Allowable Stress Values

(a) Allowable stresses for design for material are listed in Tables 1A and 1B, Section II, Part D, Subpart 1. The material shall not be used at metal and design temperatures above those for which stress values are given. The values in the Tables may be interpolated for intermediate temperatures.

(b) The maximum allowable compressive stress to be used in the design of cylindrical shells subjected to loadings that produce longitudinal compressive stress in the shell shall be the smaller of the following values:

(1) the maximum allowable tensile stress value permitted in (a) above;

(2) the value of the factor B determined from ND-3133.6(b).

(c) The wall thickness of a component computed by the rules of this Subsection shall be determined so that the general membrane stress, due to any combination of mechanical loadings listed in ND-3111 which are expected to occur simultaneously during a condition of loading for which Service Level A is designated for the component, does not exceed¹ the maximum allowable stress value permitted at the Design Temperature unless specifically permitted in other paragraphs of this Subsection. These allowable stress values may be interpolated for intermediate Design Temperatures.

¹ It is recognized that high localized and secondary stresses may exist in components designed and fabricated in accordance with the rules of this Subsection; however, insofar as practical, design rules for details have been written to hold such stresses at a safe level consistent with experience.

(d) When welding or brazing is performed on nonferrous material having increased tensile strength produced by hot or cold working, the allowable stress value for the material in the annealed condition shall be used for the joint design. One piece heads and seamless shells may be designed on the basis of the actual temper of the material.

(e) When welding or brazing is done on nonferrous material having increased tensile strength produced by heat treatment, the allowable stress value for the material in the annealed condition shall be used for the joint design unless the stress values for welded construction are given in the Tables 1A and 2B, Section II, Part D, Subpart 1 or unless the

finished construction is subjected to the same heat treatment as that which produced the temper in the *as-received* material, provided the welded joint and the base metal are similarly affected by the heat treatment.

ND-3113 Service Conditions

(a) Each condition to which the components may be subjected shall be classified in accordance with NCA-2142(b) designated in the Design Specifications in such detail as will provide a complete basis for design in accordance with this Article.

(b) When any Level B, Level C, or Level D Conditions are specified in the Design Specifications, they shall be evaluated in accordance with NCA-2140 and in compliance with the applicable design rules and stress limits of this Article.

ND-3115 Casting Quality Factors

A casting quality factor shall be applied to the allowable stress values for cast material given in Tables 1A, 1B, 2B, and 3, Section II, Part D, Subpart 1.

ND-3120 SPECIAL CONSIDERATIONS

ND-3121 Corrosion

(a) Materials subject to thinning by corrosion, erosion, mechanical, or other environmental effects shall have provision made for these effects in the Design Specifications by indicating the increase in the thickness of the material over that determined by the design equations. Other suitable methods of protection may be used. Material added for these purposes need not be of the same thickness for all areas of the component if different rates of attack are expected for the various areas.

(b) Except as required in (c) below, no additional thickness need be provided when previous experience in like service has shown that corrosion does not occur or is of only a superficial nature.

(c) Vessels constructed of materials listed in Tables 1A and 2B, Section II, Part D, Subpart 1 with a required minimum thickness of less than $\frac{1}{4}$ in. (6 mm) that are to be used in compressed air service, steam service, or water service shall be provided with a corrosion allowance on the metal surface in contact with such substance of not less than one-sixth of the calculated plate thickness.

(d) Telltale holes may be used to provide some positive indication when the thickness has been reduced to a minimum. When telltale holes are provided, they shall be at least $\frac{3}{16}$ in. (4.8 mm) in diameter and have a depth not less than 80% of the thickness required for a section of like dimensions. These holes shall be provided in the surface opposite to that where deterioration is expected.

ND-3122 Cladding

The rules of this paragraph apply to the design of clad components constructed of material permitted in Tables 1A and 2B, Section II, Part D, Subpart 1.

ND-3122.1 Stresses.

No structural strength shall be attributed to the cladding.

ND-3122.2 Design Dimensions.

The dimensions given in (a) and (b) below shall be used in the design of the component.

(a) For components subjected to internal pressure, the inside diameter shall be taken at the nominal inner face of the cladding.

(b) For components subjected to external pressure, the outside diameter shall be taken at the outer face of the base metal.

ND-3123 Welds Between Dissimilar Metals

In satisfying the requirements of this Article, caution shall be exercised in construction involving dissimilar metals having different chemical compositions, mechanical properties, and coefficients of thermal expansion in order to avoid difficulties in service.

ND-3125 Configuration

Accessibility to permit the examinations required by the Edition and Addenda of Section XI as specified in the Design Specification for the component shall be provided in the design of the component.

Page 55

ND-3130 GENERAL DESIGN RULES

ND-3131 General Requirements

The design shall be such that the design rules of this Article are satisfied for all configurations and loadings using the maximum allowable stress values S of Tables 1A, 1B, and 3, Section II, Part D, Subpart 1 in the various equations and including the use of the standard products listed in Table ND-3132-1.

ND-3131.1 Design Reports.

The N Certificate Holder is required to provide a Design Report as part of the responsibility for achieving structural integrity of the component. The Design Report shall be certified when required by NCA-3550.

ND-3131.2 Proof Tests to Establish Maximum Allowable Pressure.

When the configuration of a component is such that the stresses resulting from internal or external pressure cannot be determined with adequate accuracy by the rules of this Article, the maximum allowable pressure shall be determined by proof testing in accordance with the rules of ND-6900, except for piping as otherwise provided in this Article.

ND-3132 Dimensional Standards for Standard Products

Dimensions of standard products shall comply with the standards and specifications listed in Table ND-3132-1 when the standard or specification is referenced in the specific design Subarticle. However, compliance with these standards does not replace or eliminate the requirements for stress analysis when called for by the design Subarticle for a specific component.

ND-3133 Components Under External Pressure

ND-3133.1 General.

Rules are given in this paragraph for determining the thickness under external pressure loading in spherical shells, conical sections, cylindrical shells with or without stiffening rings, formed heads, and tubular products consisting of pipes, tubes, and fittings. Charts for determining the stresses in shells and hemispherical heads are given in Section II, Part D, Subpart 3.

ND-3133.2 Nomenclature.

The symbols used in this paragraph are defined as follows:

A	= factor determined from Fig. G, Section II, Part D, Subpart 3 and used to enter the applicable material chart in Section II, Part D, Subpart 3. For the case of cylinders having D_o/T values less than 10, see ND-3133.3(b). Also, factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a stiffening ring, corresponding to the factor B
-----	---

and the design metal temperature for the shell under consideration.

A_s	= cross-sectional area of a stiffening ring, sq in.
B	= factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a shell or stiffening ring at the design metal temperature, psi
D_o	= outside diameter of the cylindrical shell course, head skirt, or tube under consideration, in.
D_s	= outside diameter at small end of conical section under consideration, in.
D_L	= outside diameter at large end of conical section under consideration, in.
$D_o/2h_o$	= ratio of the major to the minor axis of ellipsoidal heads, which equals the outside diameter of the head skirt divided by twice the outside height of the head (see Table ND-3332.2-1)
E	= modulus of elasticity of material at Design Temperature, psi. For external pressure and axial compression design in accordance with this Section the modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 3. (Interpolation may be made between lines for intermediate temperatures.) The modulus of elasticity values shown in Section II, Part D, Subpart 3 for material groups may differ from those values listed in Table TM, Section II, Part D, Subpart 2 for specific materials. Section II, Part D, Subpart 3 values shall be applied only to external pressure and axial compression design.
h_o	= one-half of the length of the outside minor axis of the ellipsoidal head, or the outside height of the ellipsoidal head measured from the tangent line (head-bend line), in.
I	= available moment of inertia of the stiffening ring about its neutral axis, parallel to the axis of the shell, in. ⁴
I'	= available moment of inertia of the combined ring-shell cross section about its neutral axis, parallel to the shell, in. ⁴ The width of the shell which is taken as contributing to the combined moment of inertia shall not be greater than $1.10\sqrt{D_o \bar{T}_n}$ and shall be taken as lying one-half on each side of the centroid of the ring. Portions of shell plates shall not be considered as contributing to more than one stiffening ring.

I'_s	= required moment of inertia of the combined ring-shell section about its neutral axis parallel to the axis of the shell, in. ⁴
I_s	= required moment of inertia of the stiffening ring about its neutral axis parallel to the axis of the shell, in. ⁴

K_1	= factor depending on the ellipsoidal head proportions $D_o/2h_o$ (see Table ND-3332.2-1)
L	= total length of a tube between tubesheets, or the design length of a vessel section, taken as the largest of the following: (1) the distance between head tangent lines plus one-third of the depth of each head if there are no stiffening rings (excluding conical heads and sections); (2) the distance between cone-to-cylinder junctions for vessels with a cone or conical head if there are no stiffening rings; (3) the greatest center-to-center distance between any two adjacent stiffening rings; (4) the distance from the center of the first stiffening ring to the head tangent line plus one-third of the depth of the head
	Page 57
	(excluding conical heads and sections), all measured parallel to the axis of the vessel;
	(5) the distance from the first stiffening ring in the cylinder to the cone-to-cylinder junction; or
	(6) the axial length of the conical heads and sections as given in ND-3133.4(e), and Appendix XXII.
L_e	= equivalent length of conical section, in. $= (L/2)(1 + D_s/D_L)$
L_s	= one-half of the distance, in., from the center line of the stiffening ring to the next line of support on one side, plus one-half of the center line distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the component. A line of support is: (1) a stiffening ring that meets the requirements of this paragraph; (2) a circumferential line on a head at one-third the depth of the head from the head tangent line; (3) a circumferential connection to a jacket for a jacketed section of a cylindrical shell; or (4) a cone-to-cylinder junction.
P	= external Design Pressure, psi (gage or absolute, as required)
P_a	= allowable external pressure, psi (gage or absolute, as required)
R	= inside radius of cylindrical shell or tubular product in the corroded condition, in.
R_o	= for hemispherical heads, the outside radius in the corroded condition, in. = for ellipsoidal heads, the equivalent outside spherical radius taken as $K_1 D_o$ in the corroded condition, in. = for torispherical heads, the outside radius of the crown portion of the head in the corroded condition, in.

S	= the lesser of twice the allowable stress at design metal temperature from Tables 1A and 1B, Section II, Part D, Subpart 1, or 0.9 times the tabulated yield strength at design metal temperature from Tables Y-1, Section II, Part D, Subpart 2, psi
T	= minimum required thickness of cylindrical shell or tube, spherical shell, or formed head after forming, in the corroded condition, in.
T_e	= effective thickness of conical section, in. = $T \cos \alpha$
T_n	= nominal thickness used, less corrosion allowance, of a cylindrical shell or tube, in.
α	= one-half the apex angle in conical heads and sections, deg

**TABLE ND-3132-1
DIMENSIONAL STANDARDS**

Standard	Designation
Pipe and Tubes	
Welded and Seamless Wrought Steel Pipe	ANSI B36.10M-1985
Stainless Steel Pipe	ANSI B36.19M-1985
Fittings, Flanges, and Gaskets	
Steel Pipe Flanges and Flanged Fittings	ANSI B16.5-1988
Factory Made Wrought Steel Butt welding Fittings	ANSI B16.9-1986 [Note (1)]
Forged Steel Fittings, Socket-Welding and Threaded	ANSI B16.11-1980
Cast Copper Alloy Solder-Joint Pressure Fittings	ANSI B16.18-1984
Ring-Joint Gaskets and Grooves for Steel Pipe Flanges	ANSI B16.20-1973
Nonmetallic Gaskets for Pipe Flanges	ANSI B16.21-1978
Wrought Copper and Bronze Solder-Joint Pressure Fittings	ANSI B16.22-1980
Butt welding Ends	ANSI B16.25-1986
Wrought Steel Butt welding Short Radius Elbows and Returns	ANSI B16.28-1986 [Note (2)]
Refrigeration Tube Fittings	SAE J513f-1981
Stainless Steel Butt welding Fittings	MSS SP-43-1982 (R 1986)
Steel Pipeline Flanges	MSS SP-44-1985
Large Diameter Carbon Steel Flanges	API 605-1980
Standard for Steel Pipe Flanges	AWWA C207-1978
Bolting	
Square and Hex Bolts and Screws, Including Askew Heads Bolts, Hex Cap Screws and Lag Screws	ANSI B18.2.1-1981
Square and Hex Nuts	ANSI B18.2.2-1987
Socket Cap, Shoulder, and Set Screws	ANSI B18.3-1986
Threads	
Unified Inch Screw Threads (UN and UNR Thread Form)	ANSI B1.1-1982
Pipe Threads (Except Dryseal)	ANSI B1.20.1-1983
Dryseal Pipe Threads	ANSI B1.20.3-1976 (R 1982)
Gaging for Dryseal Piping Threads	ANSI B1.20.5-1978
Valves	
Valves — Flanges and Butt welding End	ANSI B16.34-1988
Qualification Requirements for Elastomer Diaphragms for Nuclear Service Diaphragm Type Valves	MSS SP 100-1988

NOTES:

- (1) Analysis per ANSI B16.9, paragraph 2.2, is acceptable only for caps and reducers.
(2) Analysis per ANSI B16.28, paragraph 2.2, is not acceptable.

TABLE ND-3132-1 DIMENSIONAL STANDARDS

ND-3133.3 Cylindrical Shells and Tubular Products.

The thickness of cylinders under external pressure shall be as determined by the procedure given in (a) or (b) below.

(a) Cylinders having D_o/T values ≥ 10 :

Step 1: Assume a value for T and determine the ratios L/D_o and D_o/T .

Step 2: Enter Fig. G, Section II, Part D, Subpart 3 at the value of L/D_o determined in Step 1. For values of L/D_o greater than 50, enter the chart at a value of $L/D_o = 50$. For values of $L/D_o < 0.05$, enter the chart at a value of L/D_o of 0.05.

Step 3: Move horizontally to the line for the value of D_o/T determined in Step 1. Interpolation may be made for intermediate values of D_o/T . From this point of intersection move vertically downward to determine the value of factor A .

Step 4: Using the value of A calculated in Step 3, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 7.

Step 5: From the intersection obtained in Step 4, move horizontally to the right and read the value of B .

Step 6: Using this value of B , calculate the value of the maximum allowable external pressure P_a using the following equation:

$$P_a = \frac{4B}{3(D_o/T)}$$

Step 7: For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following equation:

$$P_a = \frac{2AE}{3(D_o/T)}$$

Step 8: Compare P_a with P . If P_a is smaller than P , select a larger value for T and repeat the design procedure until a value of P_a is obtained that is equal to or greater than P .

(b) Cylinders having D_o/T values < 10:

Step 1: Using the same procedure as given in (a) above, obtain the value of B . For values of D_o/T less than 4, the value of factor A can be calculated using the following equation:

$$A = \frac{1.1}{(D_o/T)^2}$$

For values of A greater than 0.10, use a value of 0.10.

Step 2: Using the value of B obtained in Step 1, calculate a value P_{a1} using the following equation:

$$P_{a1} = \left[\frac{2.167}{(D_o/T)} - 0.0833 \right] B$$

Step 3: Calculate a value P_{a2} using the following equation:

$$P_{a2} = \frac{2S'}{(D_o/T)} \left[1 - \frac{1}{(D_o/T)} \right]$$

Step 4: The smaller of the values of P_{a1} calculated in Step 2 or P_{a2} calculated in Step 3 shall be used for the maximum allowable external pressure P_a . Compare P_a with P . If P_a is smaller than P , select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P .

ND-3133.4 Spherical Shells and Formed Heads

(a) *Spherical Shells*. The minimum required thickness of a spherical shell under external pressure, either seamless or of built-up construction with butt joints, shall be determined by the procedure given in Steps 1 through 6.

Step 1: Assume a value for T and calculate the value of factor A using the following equation:

$$A = \frac{0.125}{(R_o/T)}$$

Step 2: Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values at A falling to the left of the material/temperature line, see Step 5.

Step 3: From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B .

Step 4: Using the value of B obtained in Step 3, calculate the value of the maximum allowable external pressure P_a using the following equation:

$$P_a = \frac{B}{(R_o/T)}$$

Step 5: For values of A falling to the left of the applicable material/temperature line for the Design Temperature, the value of P_a can be calculated using the following equation:

$$P_a = \frac{0.0625E}{(R_o/T)^2}$$

Step 6: Compare P_a obtained in Steps 4 or 5 with P . If P_a is smaller than P , select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P .

(b) *Hemispherical Heads*. The required thickness of a hemispherical head having pressure on the convex side shall be determined in the same manner as outlined in (a) above for determining the thickness for a spherical shell.

(c) *Ellipsoidal Heads*. The required thickness of an ellipsoidal head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the following procedure.

Step 1: Assume a value for T and calculate the value of factor A using the following equation:

Page 59

$$A = \frac{0.125}{(R_o/T)}$$

Step 2: Using the value of A calculated in Step 1, follow the same procedure as that given for spherical shells in (a) above, Steps 2 through 6.

(d) *Torispherical Heads*. The required thickness of a torispherical head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the same design procedure as is used for ellipsoidal heads given in (d) above, using the appropriate value for R_o .

(e) *Conical Heads and Sections*. The required thickness of a conical head or section under pressure on the convex side, either seamless or of built-up construction with butt joints, shall be determined in accordance with the following subparagraphs.

(1) When α is equal to or less than 60 deg

(a) Cones having D_L/T_e values ≥ 10 :

Step 1: Assume a value for T_e and determine the ratios L/D_L and D_L/T_e .

Step 2: Enter Fig. G, Section II, Part D, Subpart 3 at a value of L/D_o equivalent to the value of L/D_L determined in Step 1. For values of L/D_L greater than 50, enter the chart at a value of $L/D_L = 50$.

Step 3: Move horizontally to the line for the value of D_o/T equivalent to the value of D_L/T_e determined in Step 1. Interpolation may be made for intermediate values of D_L/T_e . From this point of intersection move vertically downward to determine the value of factor A .

Step 4: Using the value of A calculated in Step 3, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature (see ND-3112.2). Interpolation may be made between lines for intermediate temperatures. In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 7.

Step 5: From the intersection obtained in Step 4, move horizontally to the right and read the value of factor B .

Step 6: Using this value of B , calculate the value of the maximum allowable external pressure P_a using the following formula:

$$P_a = \frac{4B}{3(D_L / T_e)}$$

Step 7: For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following formula:

$$P_a = \frac{2AE}{3(D_L / T_e)}$$

Step 8: Compare the calculated value of P_a obtained in Steps 6 or 7 with P . If P_a is smaller than P , select a larger value for T and repeat the design procedure until a value of P_a is obtained that is equal to or greater than P .

Step 9: Provide adequate reinforcement of the cone-to-cylinder juncture according to Appendix XXII.

(b) Cones having D_L/T_e values < 10:

Step 1: Using the same procedure as given in (e)(1)(a) above, obtain the value of B . For values of D_L/T_e less than 4, the value of factor A can be calculated using the following formula:

$$A = \frac{1.1}{(D_L / T_e)^2}$$

For values of A greater than 0.10, use a value of 0.10.

Step 2: Using the value of B obtained in Step 1, calculate a value P_{a1} using the following formula:

$$P_{a1} = \left[\frac{2.167}{(D_L/T_e)} - 0.0833 \right] B$$

Step 3: Calculate a value P_{a1} using the following formula:

$$P_{a2} = \frac{2S'}{D_L/T_e} - \frac{1}{D_L/T_e}$$

Step 4: The smaller of the values of P_{a1} calculated in Step 2, or P_{a2} calculated in Step 3 shall be used for the maximum allowable external pressure P_a . Compare P_a with P . If P_a is

Page 60

smaller than P , select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P .

Step 5: Provide adequate reinforcement of the cone-to-cylinder juncture according to Appendix XXII.

(2) When α of the cone is greater than 60 deg, the thickness of the cone shall be the same as the required thickness for a flat head under external pressure, the diameter of which equals the largest diameter of the cone (see ND-3325).

(3) The thickness of an eccentric cone shall be taken as the greater of the two thicknesses obtained using both the smallest and largest α in the calculations.

(f) The required thickness of a toriconical head having pressure on the convex side, either seamless or of built-up construction with butt joints within the head, shall not be less than that determined from (e) above with the exception that L_e shall be determined as follows.

(1) For sketch (c) in Fig. ND-3133.4-1:

$$L_e = r_1 \sin \theta_1 + \frac{L}{2} \left(\frac{D_L + D_s}{D_{Ls}} \right)$$

(2) For sketch (d) in Fig. ND-3133.4-1:

$$L_e = r_2 \frac{D_{ss}}{D_L} \sin \theta_2 + \frac{L}{2} \left(\frac{D_L + D_s}{D_L} \right)$$

(3) For sketch (e) in Fig. ND-3133.4-1:

$$L_e = r_1 \sin \theta_1 + r_2 \frac{D_{ss}}{D_{Ls}} \sin \theta_2 + \frac{L}{2} \frac{(D_L + D_s)}{D_{Ls}}$$

(g) When lap joints are used in formed head construction or for longitudinal joints in a conical head under external pressure, the thickness shall be determined by the rules in this paragraph, except that $2P$ shall be used instead of P in the calculations for the required thickness.

(h) The required length of skirt on heads convex to pressure shall comply with the provisions of ND-3324.5(c) and (i) for heads concave to pressure.

(i) Openings in heads convex to pressure shall comply with the requirements of ND-3330.

(j) When necessary, provisions shall be made to vessels and heads to prevent overstressing and excessive distortion due to external loads other than pressure and temperature (see ND-3111).

ND-3133.5 Stiffening Rings for Cylindrical Shells

(a) The required moment of inertia of a circumferential stiffening ring shall be not less than that determined by one of the following two equations:

$$I_s = \frac{D_o^2 L_s (T + A_s / L_s) A}{14}$$

$$I_s' = \frac{D_o^2 L_s (T + A_s / L_s) A}{10.9}$$

If the stiffeners should be so located that the maximum permissible effective shell sections overlap on either or both sides of a stiffener, the effective shell section for that stiffener shall be shortened by one-half of each overlap. Stiffening rings shall be designed to preclude lateral buckling.

(b) The available moment of inertia I or I' for a stiffening ring shall be determined by the following procedure.

Step 1: Assuming that the shell has been designed and D_o , L_s , and T_n are known, select a member to be used for the stiffening ring and determine its cross-sectional area A_s . Then calculate factor B , psi, using the following equation:

$$B = 3/4 \left(\frac{PD_o}{T_n + A_s/L_s} \right)$$

Step 2: Enter the right-hand side of the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening ring, use the material chart resulting in the larger value of A in Step 4 or 5 below.

Step 3: Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5.

Step 4: Move vertically to the bottom of the chart and read the value of A .

Step 5: For values of B falling below the left end of the material/temperature line for the Design Temperature, the value of A can be calculated using the equation:

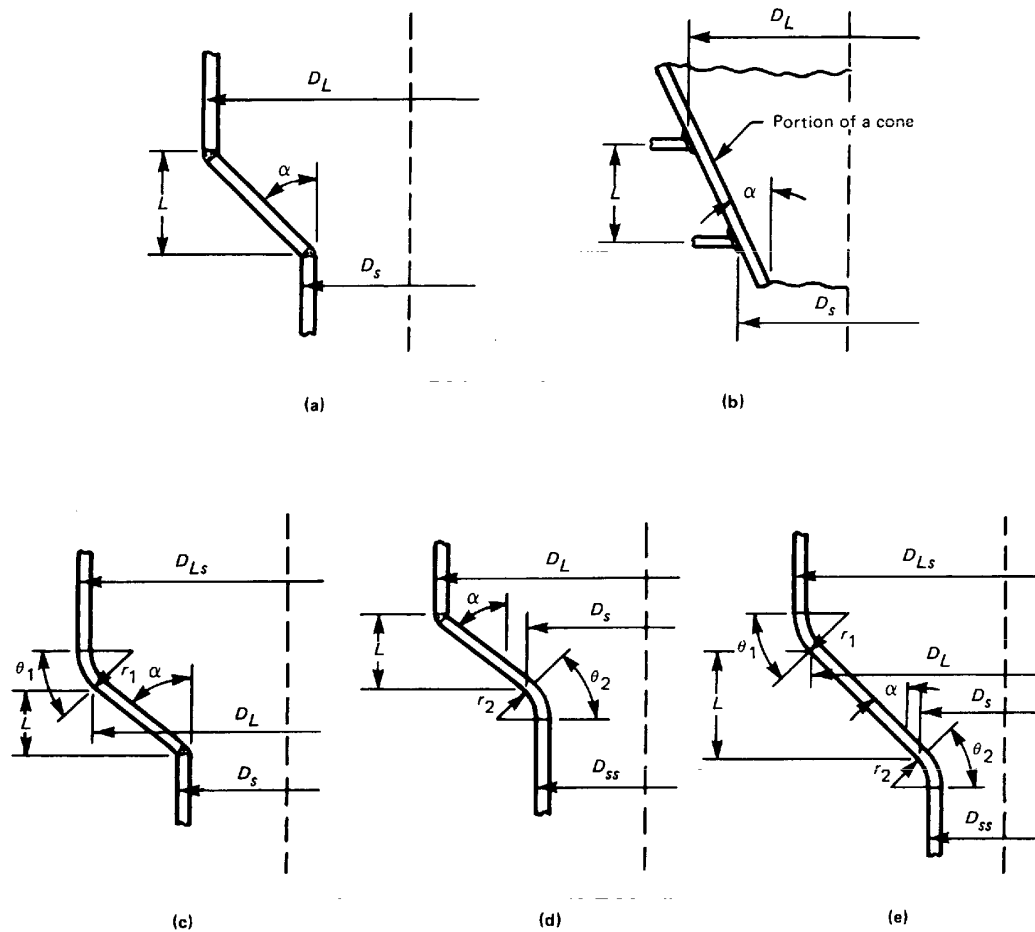


FIG. ND-3133.4-1 LENGTH L OF SOME TYPICAL CONICAL SECTIONS

FIG. ND-3133.4-1 LENGTH L OF SOME CONICAL SECTIONS

$$A = 2B/E$$

Step 6: Compute the value of the required moment of inertia from the equations for I_s or I'_s above.

Step 6

Step 7: Calculate the available moment of inertia I or I' of the stiffening ring using the section corresponding to that used

in Step 6.

Step 8: If the required moment of inertia is greater than the moment of inertia for the section selected in Step 1, a new section with a larger moment of inertia must be selected and a new moment of inertia determined. If the required moment of inertia is smaller than the moment of inertia for the section selected in Step 1, that section should be satisfactory.

(c) For fabrication and installation requirements for stiffening rings, see ND-4430.

ND-3133.6 Cylinders Under Axial Compression.

The maximum allowable compressive area to be used in the design of cylindrical shells and tubular products subjected to loadings that produce longitudinal compressive stresses in the shell or wall shall be the lesser of the values given in (a) and (b) below:

Page 62

(a) the S value for the applicable material at Design Temperature given in Tables 1A and 1B, Section II, Part D, Subpart 1;

(b) the value of the factor B determined from the applicable chart in Section II, Part D, Subpart 3. The value of B shall be determined from the applicable chart contained in Section II, Part D, Subpart 3 as given in Steps 1 through 5.

Step 1: Using the selected values of T and R , calculate the value of factor A using the following equation:

$$A = \frac{0.125}{(R/T)}$$

Step 2: Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 4.

Step 3: From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B . This is the maximum allowable compressive stress for the values of T and R used in Step 1.

Step 4: For values of A falling to the left of the applicable material/temperature line, the value of B shall be calculated using the following equation:

$$B = \frac{AE}{2}$$

Step 5: Compare the value of B determined in Steps 3 or 4 with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of T and R . If the value of B is smaller than the computed compressive stress, a greater value of T must be selected and the design procedure repeated until a value of B is obtained which is greater than the compressive stress computed for the loading on the cylindrical shell or tube. The joint efficiency for butt welded joints may be taken as unity.

ND-3133.7 Tubes and Pipes When Used as Tubes.

The required wall thickness for tubes and pipe under external pressure shall be determined in accordance with Fig. ND-3133.7-1.

ND-3135 Attachments

(a) Except as in (c) and (d) below, attachments and connecting welds within the jurisdictional boundary of the component as defined in ND-1130 shall meet the stress limits of the component.

(b) The design of the component shall include consideration of the interaction effects and loads transmitted through the attachment to and from the pressure retaining portion of the component.

(c) Beyond $2t$ from the pressure retaining portion of the component, where t is the nominal thickness of the pressure retaining material, the appropriate design rules of NF-3000 may be used as a substitute for the design rules of ND-3000 for portions of attachments which are in the component support load path.

(d) Nonstructural attachments shall meet the requirements of ND-4435.

ND-3300 VESSEL DESIGN

ND-3310 GENERAL REQUIREMENTS

Class 3 vessel requirements as stipulated in the Design Specifications (NCA-3250) shall conform to the design requirements of this Article.

ND-3320 DESIGN CONSIDERATIONS

ND-3321 Stress Limits for Design and Service Loadings

Stress² limits for Design and Service Loadings are specified in Table ND-3321-1. The symbols used in Table ND-3321-1

are defined as follows:

σ_m

= general membrane stress, psi. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.

σ_L

= local membrane stress, psi. This stress is the same as σ_m , except that it includes the effect of discontinuities.

2 Stress means the maximum normal stress

Page 63

Page 64

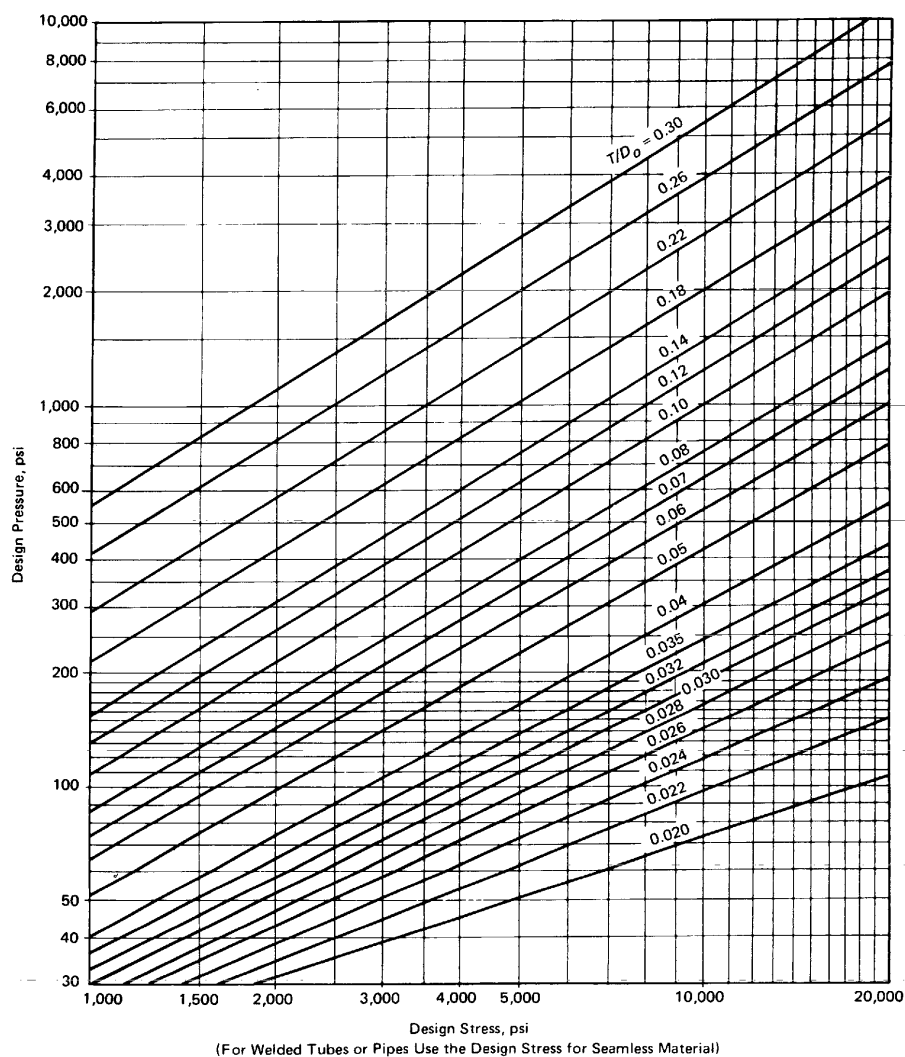


FIG. ND-3133.7-1 CHART FOR DETERMINING WALL THICKNESS OF TUBES UNDER EXTERNAL PRESSURE

FIG. ND-3133.7-1 CHART FOR DETERMINING WALL THICKNESS OF TUBES UNDER EXTERNAL PRESSURE

σ_b	= bending stress, psi. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.
S	= allowable stress value given in Tables 1A and 1B, Section II, Part D, Subpart 1, psi. The allowable stress shall correspond to the highest metal temperature at the section under consideration during the condition under consideration.

**TABLE ND-3321-1
STRESS LIMITS FOR DESIGN AND
SERVICE LOADINGS¹**

p

Service Limit	Stress Limits [Note (2)]
Design and Level A	$\sigma_m \leq 1.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5S$
Level B	$\sigma_m \leq 1.10S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65S$
Level C	$\sigma_m \leq 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$
Level D	$\sigma_m \leq 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$

NOTES:

(1) See ND-3321.1 for definitions of symbols.

(2) These limits do not take into account either local or general buckling which might occur in thin wall vessels.

TABLE ND-3321-1 STRESS LIMITS FOR DESIGN AND SERVICE LOADINGS¹

Typical examples of locations for which σ_m , σ_L , and σ_b are applicable are shown in Table ND-3321-2.

ND-3322 Special Considerations

The provisions of ND-3120 apply.

ND-3323 General Design Rules

The provisions of ND-3130 apply except as modified by the rules of this Subarticle. In case of conflict, this Subarticle governs the design of vessels.

ND-3324 Components Under Internal Pressure

ND-3324.1 General Requirements.

Equations are given for determining the minimum thicknesses under internal pressure loading in cylindrical and spherical shells and ellipsoidal, torispherical, conical, toriconical, and hemispherical heads. Provision shall be made for any of the other loadings listed in ND-3111 when such loadings are specified.

[98]

ND-3324.2 Nomenclature.

The symbols used in this paragraph and Fig. ND-3324.2-1 are defined as follows:

t	= minimum required thickness of shell or head after forming, exclusive of corrosion allowance, in.
P	= Design Pressure, psi
R	= inside radius of the shell course under consideration before corrosion allowance is added, in.
R_o	= outside radius of the shell course under consideration, in.
S	= maximum allowable stress value, psi (Tables 1A and 1B, Section II, Part D, Subpart 1)
D	= inside diameter of the head skirt; or inside length of the major axis of an ellipsoidal head; or inside diameter of a conical head at the point under consideration, measured perpendicular to the longitudinal axis, in.
D_o	= outside diameter of the head skirt; or outside length of the major axis of an ellipsoidal head; or outside diameter of a conical head at the point under consideration, measured perpendicular to the longitudinal axis, in.
D_1	= inside diameter of the conical portion of a toriconical head at its point of tangency to the knuckle, measured perpendicular to the axis of the cone, in.
L	= inside spherical or crown radius for torispherical and hemispherical heads, in.
L	= $K_1 D$ for ellipsoidal heads in which K_1 is obtained from Table ND-3332.2-1
L_o	= outside spherical or crown radius, in.
r	= inside knuckle radius, in.
h	= one-half of the length of the minor axis of the ellipsoidal head or the inside depth of the ellipsoidal head measured from the tangent line (head-bend line), in.

K

= a factor in the equations for ellipsoidal heads depending on the head proportion $D/2h$ (Table ND-3324.2-1)

$D/2h$

= ratio of the major to the minor axis of ellipsoidal heads, which equals the inside diameter of the skirt of the head divided by twice the inside height of the head and is used in Table ND-3324.2-1

α

= one-half of the included apex angle of the cone at the center line of the head

E

= joint efficiency for, or the efficiency of, appropriate joint in the shell or head; for hemispherical heads this includes head-to-shell joints. For welded construction use the value of E specified in ND-3352. For seamless heads use $E = 1$, except for hemispherical heads furnished without a skirt, in which case the head-to-shell joint must be considered.

[98]

Page 65

Page 67

Pages 66-66

TABLE ND-3321-2
CLASSIFICATION OF STRESS IN VESSELS FOR SOME TYPICAL CASES¹

Vessel Part	Location	Origin of Stress	Type of Stress	Classification
Cylindrical or spherical shell	Shell plate remote from discontinuities	Internal pressure	General membrane Gradient through plate thickness	σ_m Q
		Axial thermal gradient	Membrane Bending	Q Q
	Junction with head or flange	Internal pressure	Membrane Bending	σ_L Q [Note (2)]
Any shell or head	Any section across entire vessel	External load or moment, or internal pressure	General membrane averaged across full section. Stress component perpendicular to cross section.	σ_m
		External load or moment	Bending across full section. Stress component perpendicular to cross section.	σ_m
	Near nozzle or other opening	External load or moment, or internal pressure	Local membrane Bending Peak (fillet or corner)	σ_L Q F
	Any location	Temperature difference between shell and head	Membrane Bending	Q Q
Dished head or conical head	Crown	Internal pressure	Membrane Bending	σ_m σ_b
	Knuckle or junction to shell	Internal pressure	Membrane Bending	σ_L [Note (3)] Q
Flat head	Center region	Internal pressure	Membrane Bending	σ_m σ_b
	Junction to shell	Internal pressure	Membrane Bending	σ_L [Note (2)] Q
Perforated head or shell	Typical ligament in a uniform pattern	Pressure	Membrane (averaged through cross section) Bending (averaged through width of ligament, but gradient through plate) Peak	σ_m σ_b F
	Isolated or atypical ligament		Membrane Bending Peak	Q F F

TABLE ND-3321-2 (CONT'D)
CLASSIFICATION OF STRESS IN VESSELS FOR SOME TYPICAL CASES¹

Vessel Part	Location	Origin of Stress	Type of Stress	Classification
Nozzle	Within the limits of reinforcement defined by ND-3334	Pressure and external loads and moments, including those attributable to restrained free end displacements of attached piping	General membrane	σ_m
			Bending (other than gross structural discontinuity stresses) averaged through nozzle thickness	σ_m
	Outside the limits of reinforcement defined by ND-3334	Pressure and external axial, shear, and torsional loads other than those attributable to restrained free end displacements of attached piping	General membrane stresses	σ_m
		Pressure and external loads and moments other than those attributable to restrained free end displacements of the attached piping	Membrane	σ_L
			Bending	σ_b
	Nozzle wall	Pressure and all external loads and moments	Membrane	σ_L
			Bending	Q
			Peak	F
Cladding	Any	Differential expansion	Local membrane	σ_L
			Bending	Q
Any	Any	Radial temp. distribution [Note (4)]	Peak	F
			Membrane	Q
			Bending	F
Any	Any	Any	Nonlinear portion of stress distribution	F
			Stress concentration (notch effect)	F

NOTES:

- (1) Q and F classifications of stresses refer to other than Design Condition.
- (2) If the bending moment at the edge is required to maintain the bending stress in the middle within acceptable limits, the edge bending is classified as σ_b . Otherwise, it is classified as Q .
- (3) Consideration must also be given to the possibility of wrinkling and excessive deformation in vessels with a large diameter-thickness ratio.
- (4) Consider possibility of thermal stress ratchet.
- (5) Equivalent linear stress is defined as the linear distribution which has the same net bending moment as the actual stress distribution.

TABLE ND-3321-2 (CONT'D) CLASSIFICATION OF STRESS IN VESSELS FOR SOME TYPICAL CASES¹

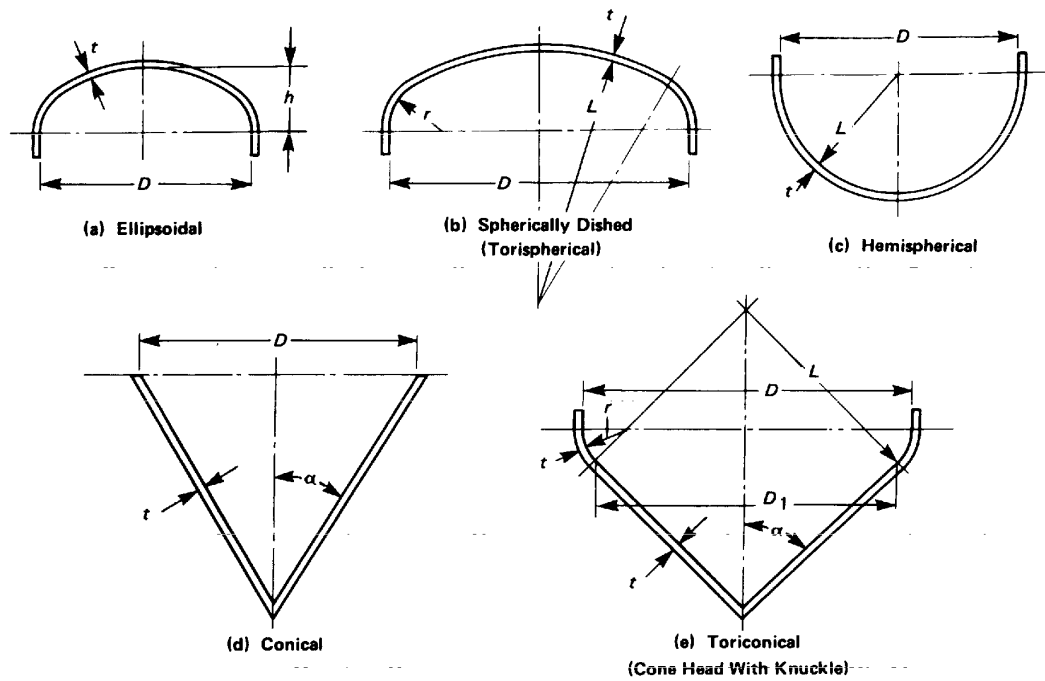


FIG. ND-3324.2-1 PRINCIPAL DIMENSIONS OF TYPICAL HEADS

FIG. ND-3324.2-1 PRINCIPAL DIMENSIONS OF TYPICAL HEADS

TABLE ND-3324.2-1
VALUES OF FACTOR K
Use Nearest Value of $D/2h$; Interpolation Unnecessary

$D/2h$	3.0	2.9	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.0
K	1.83	1.73	1.64	1.55	1.46	1.37	1.29	1.21	1.14	1.07	1.00
$D/2h$	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	...
K	0.93	0.87	0.81	0.76	0.71	0.66	0.61	0.57	0.53	0.50	...

TABLE ND-3324.2-1 VALUES OF FACTOR K

ND-3324.3 Cylindrical Shells.

The minimum thickness of cylindrical shells shall be the greater thickness as given by (a) through (d) below.

(a) *Circumferential Stress (Longitudinal Joints).* When the thickness does not exceed one-half of the inside radius, or P does not exceed $0.385SE$, the following equations shall apply:

$$t = \frac{PR}{SE - 0.6P} \quad \text{or} \quad P = \frac{SEt}{R + 0.6t}$$

(b) *Longitudinal Stress (Circumferential Joints)*. When the thickness does not exceed one-half of the inside radius, or P does not exceed $1.25SE$, the following equations shall apply:

Page 68

$$t = \frac{PR}{2SE + 0.4P} \quad \text{or} \quad P = \frac{2SEt}{R - 0.4t}$$

(c) *Thickness of Cylindrical Shells*. The following equations, in terms of the outside radius, are equivalent to and may be used instead of those given in (a) above:

$$t = \frac{PR_o}{SE + 0.4P} \quad \text{or} \quad P = \frac{SEt}{R_o - 0.4t}$$

(d) *Thick Cylindrical Shells*

(1) *Circumferential Stress (Longitudinal Joints)*. When the thickness of the cylindrical shell under internal pressure exceeds one-half of the inside radius or when P exceeds $0.385SE$, the following equations shall apply. When P is known and t is desired:

$$t = R (Z^{1/2} - 1) = R_o \frac{Z^{1/2} - 1}{Z^{1/2}}$$

where

$$Z = \frac{SE + P}{SE - P}$$

When t is known and P is desired:

$$P = SE \left(\frac{Z - 1}{Z + 1} \right)$$

where

$$Z = \left(\frac{R + t}{R} \right)^2 = \left(\frac{R_o}{R} \right)^2 = \left(\frac{R_o}{R_o - t} \right)^2$$

(2) *Longitudinal Stress (Circumferential Joints)*. When the thickness of the cylindrical shell under internal pressure exceeds one-half of the inside radius or when P exceeds $1.25SE$, the following equations shall apply. When P is known and t is desired:

$$t = R(Z^{1/2} - 1) = R_o \left(\frac{Z^{1/2} - 1}{Z^{1/2}} \right)$$

where

where

$$Z = \frac{P}{SE} + 1$$

When t is known and P is desired:

$$P = SE(Z - 1)$$

where

$$Z = \left(\frac{R + t}{R} \right)^2 = \left(\frac{R_o}{R} \right)^2 = \left(\frac{R_o}{R_o - t} \right)^2$$

ND-3324.4 Spherical Shells

(a) When the thickness of the shell of a spherical vessel does not exceed $0.356R$ or P does not exceed $0.665S$, the following equations shall apply. Any reduction in thickness within a shell course of a spherical shell shall be in accordance with ND-3361.

$$t = \frac{PR}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{R + 0.2t}$$

(b) The following equations, in terms of the outside radius, are equivalent and may be used instead of those given in (a) above:

$$t = \frac{PR_o}{2SE + 0.8P}$$

$$P = \frac{2SEt}{R_o - 0.8t}$$

(c) When the thickness of the shell of a spherical vessel under internal pressure exceeds $0.356R$ or when P exceeds $0.665SE$, the following equations shall apply. When P is known and t is desired:

$$t = R (Y^{1/3} - 1) = R_o \left(\frac{Y^{1/3} - 1}{Y^{1/3}} \right)$$

where

$$Y = \frac{2(SE + P)}{2SE - P}$$

When t is known and P is desired:

$$P = 2SE \left(\frac{Y - 1}{Y + 2} \right)$$

where

$$Y = \left(\frac{R + t}{R} \right)^3 = \left(\frac{R_o}{R_o - t} \right)^3$$

ND-3324.5 Formed Heads, General Requirements.

Formed heads shall meet the requirements of (a) through (i) below.

(a) All formed heads, thicker than the shell and concave to pressure, for butt welded attachment, shall have a skirt length sufficient to meet the requirements of Fig. ND-3358.1(a)-1 when a tapered transition is required.

(b) Any taper at a welded joint within a formed head shall be in accordance with ND-3361. The taper at a circumferential welded joint connecting a formed head to a main shell shall meet the requirements of ND-3358 for the respective type of joint shown therein.

(c) All formed heads concave to pressure and for butt welded attachment need not have an integral skirt when the thickness of the head is equal to or less than the thickness of the shell. When a skirt is provided, its thickness shall be at least that required for a seamless shell of the same diameter.

(d) The inside crown radius to which an unstayed head is dished shall be not greater than the outside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall be not less than 6% of the outside diameter of the skirt of the head but in no case less than three times the head thickness.

(e) When an ellipsoidal, torispherical, hemispherical, conical, or toriconical head is of a lesser thickness than required by the rules of ND-3324.5, it shall be stayed as a flat surface according to the rules of ND-3329.

(f) If a torispherical, ellipsoidal, or hemispherical head is formed with a flattened spot or surface, the diameter of the flat spot shall not exceed that permitted for flat heads as given by Eq. (4) or (5) of ND-3325.2 using $C = 0.25$.

(g) Openings in formed heads under internal pressure shall comply with the requirements of ND-3330.

(h) A dished head with a reversed skirt may be used in a component, provided the maximum allowable pressure for the head is established in accordance with the requirements of ND-6900.

(i) Heads concave to pressure, intended for attachment by brazing, shall have a skirt length sufficient to meet the requirements for circumferential joints (ND-4500).

ND-3324.6 Ellipsoidal Heads

(a) *2:1 Ellipsoidal Heads*. The required thickness of a dished head of semiellipsoidal form, in which one-half the minor axis (inside depth of the head minus the skirt) equals one-fourth the inside diameter of the head skirt, shall be determined by:

$$t = \frac{PD}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{D + 0.2t}$$

(b) *Ellipsoidal Heads of Other Ratios*. The minimum required thickness of an ellipsoidal head of other than a 2:1 ratio shall be determined by:

$$t = \frac{PDK}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{KD + 0.2t}$$

$$t = \frac{PD_o K}{2SE + 2P(K - 0.1)}$$

or

$$P = \frac{2SEt}{KD_o - 2t(K - 0.1)}$$

where

$$K = \frac{1}{6} \left[2 + \left(\frac{D}{2h} \right)^2 \right]$$

Numerical values of the factor K are given in Table ND-3324.2-1.

ND-3324.7 Hemispherical Heads

(a) When the thickness of a hemispherical head does not exceed $0.356L$ or P does not exceed $0.665SE$, the following equations shall apply:

$$t = \frac{PL}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{L + 0.2t}$$

(b) When the thickness of the hemispherical head under internal pressure exceeds $0.356L$ or when P exceeds $0.665SE$, the following equations shall apply:

$$t = L(Y^{1/3} - 1) = L_o \left(\frac{Y^{1/3} - 1}{Y^{1/3}} \right)$$

where

$$Y = \frac{2(SE + P)}{2SE - P}$$

or

$$P = 2S \left(\frac{Y - 1}{Y + 2} \right)$$

where

$$Y = \left(\frac{L + t}{L} \right)^3 = \left(\frac{L_o}{L_o - t} \right)^3$$

ND-3324.8 Torispherical Heads

(a) *Torispherical Heads With 6% Knuckle Radius.* The required thickness of a torispherical head in which the knuckle radius is 6% of the inside crown radius shall be determined by:

$$t = \frac{0.885PL}{SE - 0.1P} \quad \text{or} \quad P = \frac{SEt}{0.885L + 0.1t}$$

(b) *Torispherical Heads of Other Proportions.* The required thickness of a torispherical head in which the knuckle radius is other than 6% of the crown radius shall be determined by:

$$t = \frac{PLM}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{LM + 0.2t}$$

$$t = \frac{PL_oM}{2SE + P(M - 0.2)} \quad (1)$$

(1)

or

$$P = \frac{2SEt}{ML_o - t(M - 0.2)} \quad (2)$$

(2)

where

$$M = \frac{1}{4} \left(3 + \sqrt{\frac{L}{r}} \right) \quad (3)$$

(3)

Numerical values of the factor M are given in Table ND-3324.8(b)-1.

(c) Torispherical heads made of material having a specified minimum tensile strength exceeding 80.0 ksi (552 MPa) shall be designed using a value of S equal to 20.0 ksi (138 MPa) at room temperature and reduced in proportion to the reduction in maximum allowable stress values at temperature for the material as shown in Tables 1A and 1B, Section II, Part D, Subpart 1.

ND-3324.9 Conical Heads Without Transition Knuckle.

The required thickness of conical heads or conical shell sections that have a half-apex angle α not greater than 30 deg shall be determined by:

$$t = \frac{PD}{2 \cos \alpha (SE - 0.6P)} \quad \text{or} \quad P = \frac{2SEt \cos \alpha}{D + 1.2t \cos \alpha}$$

For α greater than 30 deg, see ND-3324.11(b)(5). A compression ring shall be provided when required by the rule in ND-3324.11(b).

ND-3324.10 Toriconical Heads.

Toriconical heads in which the inside knuckle radius is neither less than 6% of the outside diameter of the head skirt nor less than three times the knuckle thickness shall be used when the angle α exceeds 30 deg except when the design complies with ND-3324.11. The required thickness of the knuckle shall be determined by the first equation of ND-3324.8(b) in which:

$$L = \frac{D_1}{2 \cos \alpha}$$

The required thickness of the conical portion shall be determined by the equation in ND-3324.9, using D_1 in place of D .

ND-3324.11 Reducer Sections

(a) General Requirements

(1) The rules of ND-3324.11(a) apply to concentric reducer sections.

(2) The symbols used are defined as follows:

D_1	= inside diameter of reducer section at point of tangency to the knuckle or reverse curve, in.
A	= required area of reinforcement, sq in.
A_e	= effective area of reinforcement, due to excess metal thickness, sq in.
Δ	= value to indicate need for reinforcement at cone-to-cylinder intersection having a half-apex angle $\alpha \leq 30$ deg. When $\Delta \geq \alpha$, no reinforcement at the junction is required [Tables ND-3324.11(b)(2)-1 and ND-3324.11(b)(3)-1]
m	= the lesser of $(t_s/t) \cos (\alpha - \Delta)$ or

$$\frac{[t_c \cos \alpha \cos (\alpha - \Delta)]}{t}$$

R_L	= inside radius of larger cylinder, in.
R_s	= inside radius of smaller cylinder, in.
r_L	= inside radius of knuckle at larger cylinder, in.

r_s

= radius to the inside surface of flare at the small end, in.

 t_s

= nominal thickness of cylinder at cone-to-cylinder junction, exclusive of corrosion allowance, in.

Page 71

 t_c

= nominal thickness of cone at cone-to-cylinder junction, exclusive of corrosion allowance, in.

 t_e = the smaller of $(t_s - t)$ or $[t_c - (t/\cos \alpha)]$, in.

TABLE ND-3324.8(b)-1
VALUES OF FACTOR M
 Use Nearest Value of L/r ; Interpolation Unnecessary

L/r	1.0	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50
M	1.00	1.03	1.06	1.08	1.10	1.13	1.15	1.17	1.18	1.20	1.22
L/r	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
M	1.25	1.28	1.31	1.34	1.36	1.39	1.41	1.44	1.46	1.48	1.50
L/r	9.5	10.00	10.5	11.0	11.5	12.0	13.0	14.0	15.0	16.0	16.67 [Note (1)]
M	1.52	1.54	1.56	1.58	1.60	1.62	1.65	1.69	1.72	1.75	1.77

NOTE:(1) Maximum ratio allowed by ND-3324.5(d) when L equals the outside diameter of the skirt of the head.

TABLE ND-3324.8(b)-1 VALUES FOR FACTOR M

(3) The thickness of each element of a reducer, as defined in (4) below, under internal pressure shall not be less than that computed by the applicable equation. In addition, provisions shall be made for any of the other loadings listed in ND-3111 when such loadings are expected.

(4) A transition section reducer consisting of one or more elements may be used to join two cylindrical shell sections of different diameters but with a common axis, provided the requirements of (a) and (b) below are met.

(a) *Conical Shell Section.* The required thickness of a conical shell section or the allowable pressure for such a section of given thickness shall be determined by the equations given in ND-3324.9.

(b) *Knuckle Tangent to the Larger Cylinder.* Where a knuckle is used at the large end of a reducer section, its shape shall be that of a portion of an ellipsoidal, hemispherical, or torispherical head. The thickness and other dimensions shall satisfy the requirements of ND-3324.

(5) When elements of (4) above having different thicknesses are combined to form a reducer, the joints, including the plate taper required by ND-3361, shall lie entirely within the limits of the thinner element being joined.

(6) A reducer may be a simple conical shell section [Fig. ND-3324.11(a)(6)-1 sketch (a)] without knuckle provided the half apex angle α is not greater than 30 deg, except as provided for in (b) below. A reinforcement ring shall be provided at either or both ends of the reducer when required by (b) below.

(7) A toriconical reducer [Fig. ND-3324.11(a)(6)-1 sketch (b)] may be shaped as a portion of a toriconical shell, a portion of a hemispherical head plus a conical section, or a portion of an ellipsoidal head plus a conical section provided the half apex angle α is not greater than 30 deg, except as provided for in (b) below. A reinforcement ring shall be provided at the small end of a conical reducer element when required by (b) below.

(8) Reverse curve reducers [Fig. ND-3324.11(a)(6)-1 sketches (c) and (d)] may be shaped of elements other than those as illustrated.

(b) Supplementary Requirements for Reducer Sections and Conical Heads Under Internal Pressure

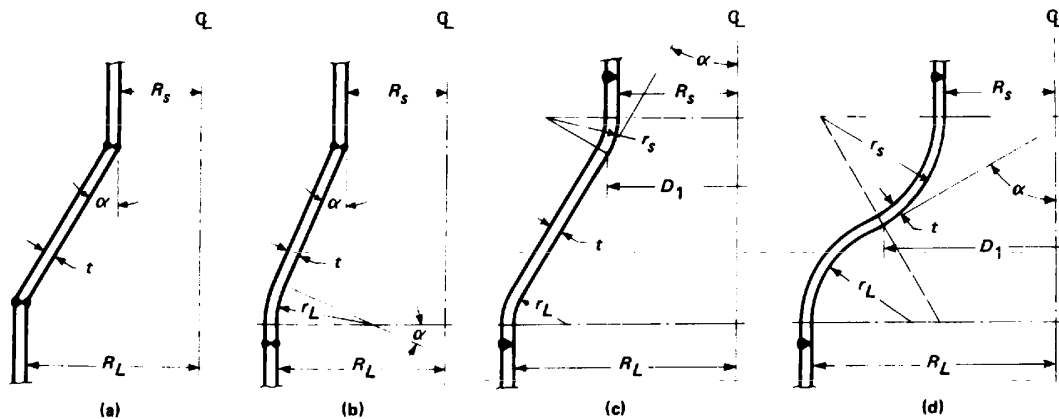
(1) The equations of (2) and (3) below provide for the design of reinforcement, if needed, at the cone-to-cylinder junctions for reducer sections and conical heads where all the elements have a common axis and the half apex angle $\alpha \leq 30$ deg. In (5) below, provision is made for special analysis in the design of cone-to-cylinder intersections with or without reinforcing rings where α is greater than 30 deg.

(2) Reinforcement shall be provided at the junction of the cone with the large cylinder for conical heads and reducers without knuckles when the value of Δ , obtained from Table ND-3324.11(b)(2)-1, using the appropriate ratio P/SE , is less than α . Interpolation may be made in the Table.

(a) The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following equation:

$$A = \frac{P(R_L)^2}{2SE} \left(1 - \frac{\Delta}{\alpha} \right) \tan \alpha$$

(b) When the thickness, less corrosion allowance, of both the reducer and cylinder exceeds that



GENERAL NOTES:

- (1) r_L shall not be less than the smaller of $0.12 (R_L + t)$ or $3t$
- (2) r_s has no dimensional requirement

FIG. ND-3324.11(a)(6)-1 LARGE HEAD OPENINGS, REVERSE CURVE, AND CONICAL SHELL REDUCER SECTIONS

FIG. ND-3324.11(a)(6)-1 LARGE HEAD OPENINGS, REVERSE CURVE, AND CONICAL SHELL REDUCER SECTIONS

required by the applicable design equations, the minimum excess thickness may be considered to contribute to the required reinforcement ring in accordance with the following equation:

**TABLE ND-3324.11(b)(2)-1
VALUES OF Δ FOR JUNCTIONS AT THE
LARGE CYLINDER FOR $\alpha \leq 30$ deg**

<i>P/SE</i>	0.001	0.002	0.003	0.004	0.005
Δ, deg	11	15	18	21	23
<i>P/SE</i>	0.006	0.007	0.008	0.009 [Note (1)]	...
Δ, deg	25	27	28.5	30	...

NOTE:

(1) $\Delta = 30$ deg for greater values of P/SE .

TABLE ND-3324.11(b)(2)-1 VALUES OF Δ FOR JUNCTIONS AT THE LARGE CYLINDER FOR $\alpha \leq 30$ deg

$$A_e = 4t_e \sqrt{R_{Ls} t_s}$$

(c) Any additional area of reinforcement which is required shall be situated within a distance of $\sqrt{R_{Ls} t_s}$ from the junction of the reducer and the cylinder. The centroid of the added area shall be within a distance of $0.5\sqrt{R_{Ls} t_s}$ from the junction.

(3) Reinforcement shall be provided at the junction of the conical shell of a reducer without a flare and the small cylinder when the value of Δ obtained from

**TABLE ND-3324.11(b)(3)-1
VALUES OF Δ FOR JUNCTIONS AT THE
SMALL CYLINDER FOR $\alpha \leq 30$ deg**

P/SE	0.002	0.005	0.010	0.02
Δ, deg	4	6	9	12.5
P/SE	0.04	0.08	0.10	0.125 [Note (1)]
Δ, deg	17.5	24	27	30

NOTE:

(1) $\Delta = 30$ deg for greater values of P/SE .

TABLE ND-3324.11(b)(3)-1 VALUES OF Δ FOR JUNCTIONS AT THE SMALL CYLINDER FOR $\alpha \leq 30$ deg

Table ND-3324.11(b)(3)-1, using the appropriate ratio P/SE , is less than α .

(a) The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following equation:

$$A = \frac{PR_s^2}{2SE} \left(1 - \frac{\Delta}{\alpha} \right) \tan \alpha$$

(b) When the thickness, less corrosion allowance, of either the reducer or cylinder exceeds that required by the applicable design equation, the excess thickness may be considered to contribute to the required reinforcement ring in

$$A_e = m \sqrt{R_s t} [t_c - (t / \cos \alpha) + (t_s - t)]$$

(c) Any additional area of reinforcement which is required shall be situated within a distance of $\sqrt{R_s t_s}$ from the junction, and the centroid of the added area shall be within a distance of $0.5\sqrt{R_s t_s}$ from the junction.

(4) Reducers not described in ND-3324.11(a)(3), such as those made up of two or more conical frustums having different slopes, may be designed in accordance with (5) below.

(5) When the half apex angle α is greater than 30 deg, cone-to-cylinder junctions without a knuckle may be used, with or without reinforcing rings, if the design is based on stress analysis. When such an analysis is made, the calculated localized stresses at the discontinuity shall not exceed the following values.

(a) Membrane hoop stress plus average discontinuity hoop stress shall not be greater than $1.5 SE$.

(b) Membrane longitudinal stress plus discontinuity longitudinal stress due to bending shall not be greater than $4SE$, where the average discontinuity hoop stress is the average hoop stress across the wall thickness due to the discontinuity at the junction, disregarding the effect of Poisson's ratio times the longitudinal stress at the surfaces.

(c) The angle joint between the cone and cylinder shall be designed equivalent to a double butt welded joint, and, because of the high bending stress, there shall be no weak zones around the angle joint. The thickness of the cylinder may have to be increased to limit the difference in thickness so that the angle joint has a smooth contour.

ND-3324.12 Nozzles

(a) The wall thickness of a nozzle or other connection shall not be less than the nominal thickness of the connecting piping. In addition, the wall thickness shall not be less than the thickness computed for the applicable loadings in ND-3111 plus the thickness added for corrosion allowance. Except for access openings and openings for inspection only, the wall thickness shall not be less than the smaller of (1) and (2) below:

(1) the required thickness of the shell or head to which the connection is attached plus the corrosion allowance provided in the shell or head adjacent to the connection;

³ The minimum thickness for all pipe materials is the nominal wall thickness listed in Table 2 of ANSI B36.10 less $12\frac{1}{2}\%$. For diameters other than those listed in the table, this shall be based on the next larger pipe size.

(2) the minimum thickness³ of standard wall pipe plus the corrosion allowance on the connection; for nozzles larger than the largest pipe size included in ANSI B36.10, the wall thickness of that largest size plus corrosion allowance.

(b) The allowable stress value for shear in a nozzle neck shall be 70% of the allowable tensile stress for the vessel material.

ND-3324.13 Nozzle Piping Transitions.

The stress limits of Table ND-3321-1 shall apply to all portions of nozzles which lie within the limits of reinforcement given in ND-3334, except as provided for in ND-3324.14. Stresses in the extension of any nozzle beyond the limits of reinforcement shall be subject to the stress limits of ND-3600.

ND-3324.14

(a) Where a nozzle-to-shell junction is reinforced in accordance with the rules of ND-3334, the stresses in this region due to internal pressure may be considered to satisfy the limits of Table ND-3321-1. Under these conditions no analysis is required to demonstrate compliance for pressure induced stresses in the nozzle region.

(b) Where external piping loads are specified, membrane plus bending stresses due to these loads shall be calculated in the nozzle, and membrane stresses shall be calculated in the local nozzle-to-shell region. These stresses, in conjunction with pressure induced stresses, shall meet the limits of Table ND-3321-1 for $(\sigma_m \text{ or } \sigma_L) + \sigma_b$. In this case the pressure induced stresses in the $(\sigma_m \text{ or } \sigma_L) + \sigma_b$ category may be assumed to be no greater than the limit for σ_m in Table ND-3321-1 for a given condition.

ND-3324.15 Other Loadings.

When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in ND-3111 other than pressure and temperature.

ND-3325 Flat Heads and Covers

4 Special consideration shall be given to the design of shells, nozzle neck, or flanges to which noncircular heads or cover are attached.

The minimum thickness of unstayed flat heads, cover plates, and blind flanges shall conform to the requirements given in this paragraph. These requirements apply to both circular and noncircular⁴ heads and covers. Some acceptable types of flat heads and covers are shown in Fig. ND-3325-1. In this figure, the dimensions of the component parts and the dimensions of the welds

Page 74

are exclusive of extra metal required for corrosion allowance.

ND-3325.1 Nomenclature.

The symbols used are defined as follows:

C	= a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in ND-3325.3, dimensionless
D	= long span of noncircular heads or covers measured perpendicular to short span, in.
d	= diameter, or short span, measured as indicated in Fig. ND-3325-1, in.
h_G	= gasket moment arm, equal to the radial distance from the center line of the bolts to the line of the gasket reaction, as shown in Table XI-3221.1-2, in.
L	= perimeter of noncircular bolted head measured along the centers of the bolt holes, in.
l	= length of flange of flanged heads, measured from the tangent line of knuckle, as indicated in Fig. ND-3325-1 sketches (a) and (c), in.
m	= the ratio t_r/t_s
P	= Design Pressure, psi
r	= inside corner radius on a head formed by flanging or forging, in.
S	= maximum allowable stress value, psi, from Tables 1A and

1B, Section II, Part D, Subpart 1

t	= minimum required thickness of flat head or cover, exclusive of corrosion allowance, in.
t_f	= actual thickness of the flange on a forged head, at the large end, exclusive of corrosion allowance, as indicated in Fig. ND-3325-1 sketches (b-1) and (b-2), in.
t_h	= actual thickness of flat head or cover, exclusive of corrosion allowance, in.
t_p	= the smallest dimension from the face of the head to the edge of the weld preparation, in.
t_r	= required thickness of seamless shell, for pressure, in.
t_s	= actual thickness of shell, exclusive of corrosion allowance, in.
t_w	= thickness through the weld joining the edge of a head to the inside of a vessel, as indicated in Fig. ND-3325-1 sketch (g), in.
t_1	= throat dimension of the closure weld, as indicated in Fig. ND-3325-1 sketch (r), in.
W	= total bolt load, lb, given for circular heads for Formulas (3) and (4), XI-3223
Z	= a factor of noncircular heads and covers that depends on the ratio of short span to long span (ND-3325.2), dimensionless

ND-3325.2 Thickness.

The thickness of unstayed flat heads, covers, and blind flanges shall conform to one of the following four requirements.⁵

(a) Circular blind flanges of ferrous materials conforming to ANSI B16.5 shall be acceptable for the diameters and pressure-temperature ratings in Tables 2 to 8 of that Standard, when of the types shown in Fig. ND-3325-1 sketches (j) and (k).

(b) The minimum required thickness of flat unstayed circular heads, covers, and blind flanges shall be calculated by Eq. (4):

$$(4) t = d \sqrt{CP/S}$$

except when the head, cover, or blind flange is attached by bolts causing an edge moment [Fig. ND-3325-1 sketches (j) and (k)], in which case the thickness shall be calculated by Eq. (5):

$$(5) t = d \sqrt{CP/S + 1.9 W h_G / S d^3}$$

When using Eq. (5), the thickness t shall be calculated for both Service Loadings and gasket seating and the greater of the two values shall be used. For Service Loadings, the value of P shall be the Design Pressure and the values of S at the Design Temperature and W from Eq. (3) of XI-3223(c) shall be used. For gasket seating, P equals zero and the values of S at atmospheric temperature and W from Eq. (4) of XI-3223 shall be used.

(c) Flat unstayed heads, covers, or blind flanges may be square, rectangular, elliptical, obround, segmental, or otherwise noncircular. Their required thickness shall be calculated by Eqs. (6) and (7):

$$(6) t = d \sqrt{ZCP/S}$$

where

(7)

with the limitation that Z need not be greater than 2.5.

5 The equation provide safe construction as far as stress is concerned. Greater thicknesses may be necessary if deflection would cause leakage at threaded or gasketed joints.

(d) Equation (6) does not apply to noncircular heads, covers, or blind flanges attached by bolts causing a bolt edge moment [Fig. ND-3325-1 sketches (j) and (k)]. For noncircular heads of this type, the required thickness shall be calculated by the following equation:

Page 75

Page 76

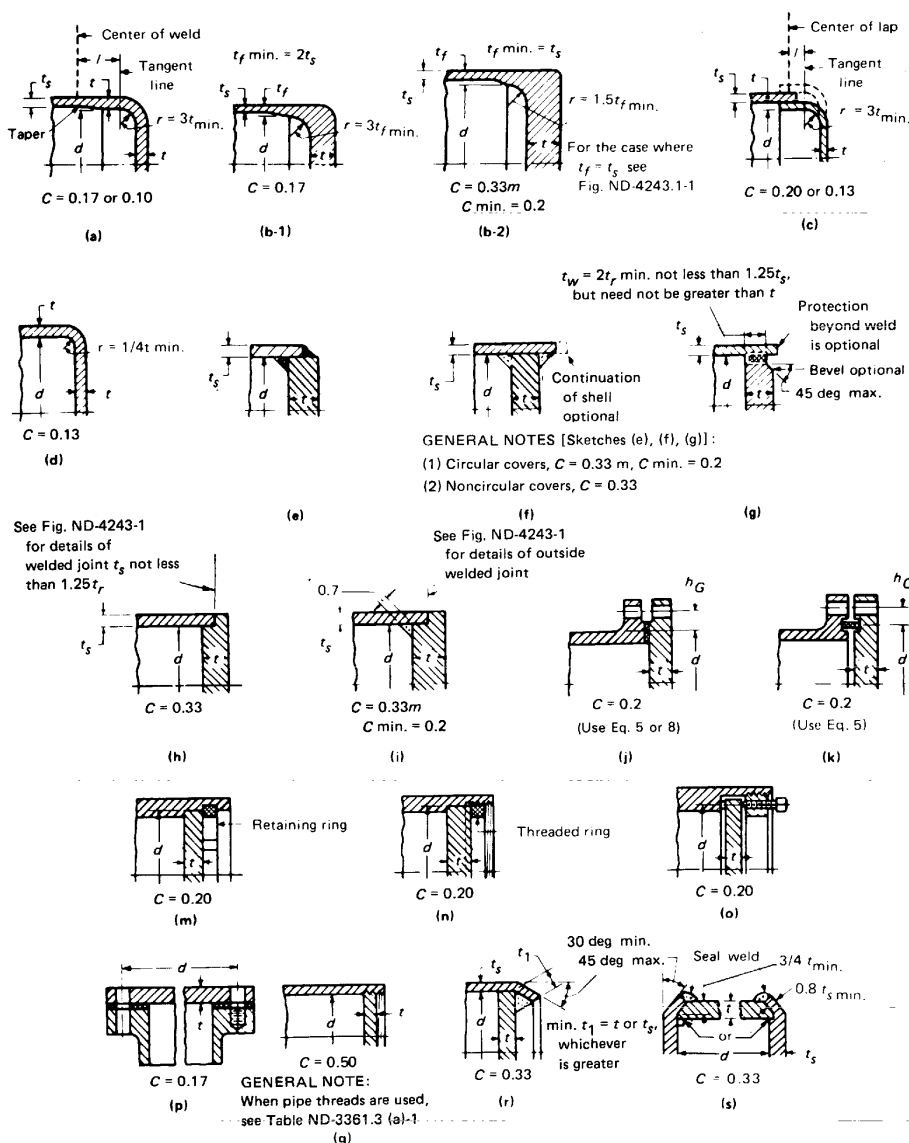


FIG. ND-3325-1 SOME ACCEPTABLE TYPES OF UNSTAYED FLAT HEADS AND COVERS
The Above Illustrations Are Diagrammatic Only. Other Designs That Meet The Requirements of ND-3325 Are Acceptable.

FIG. ND-3325-1 SOME ACCEPTABLE TYPES OF UNSTAYED FLAT HEADS AND COVERS

$$(8) t = d \sqrt{ZCP/S + 4 W h_G / S L d^2}$$

When using Eq. (8), the thickness t shall be calculated in the same way as specified above for Eq. (5).

ND-3325.3 Values of C .

For the types of construction shown in Fig. ND-3325-1, the minimum values of C to be used in Eqs. (4), (5), (6), and (8) are given in (a) through (n) below.

(a) In sketch (a), $C = 0.17$ for flanged circular and noncircular heads forged integral with or butt welded to the vessel with an inside corner radius not less than three times the required head thickness, with no special requirement with regard to length of flange.

(1) $C = 0.10$ for circular heads, when the flange length for heads of the above design is not less than:

$$l = \left(1.1 - 0.8 \frac{t_s^2}{t_h^2} \right) \sqrt{d t_h}$$

(2) $C = 0.10$ for circular heads, when the flange length l is less than the requirement in (a)(1) above but the shell thickness is not less than:

$$t_s = 1.12 t_h \sqrt{1.1 - l / \sqrt{d t_h}}$$

for a length of at least $2\sqrt{d t_s}$.

(3) When $C = 0.10$ is used, the taper shall be 1:4.

(b) In sketch (b-1), $C = 0.17$ for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than two times the shell thickness, the corner radius on the inside is not less than three times the flange thickness, and the welding meets all the requirements for circumferential joints given in ND-4000.

(c) In sketch (b-2), $C = 0.33m$ but not less than 0.3 for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than the shell thickness, the corner radius on the inside is not less than 1.5 times the flange thickness, and the welding meets all the requirements for circumferential joints given in ND-4000. [See Fig. ND-4243.1-1 sketches (a) and (b) for the special case where t_f equals t_s .]

(d) In sketch (c), $C = 0.13$ for circular heads lap-welded or brazed to the shell with corner radius not less than $3t$ and l not less than required by (a)(1) above and the requirements of ND-3358 are met.

(1) $C = 0.20$ for circular and noncircular lap-welded or brazed construction as above but with no special requirement with regard to l .

(2) $C = 0.20$ for circular flanged plates screwed over the end of the vessel with inside corner radius not less than $3t$, in which the design of the threaded joint against failure by shear, tension, or compression, resulting from the end force due to pressure, is based on a factor of safety of at least 4 and the threaded parts are at least as strong as the threads for standard piping of the same diameter. Seal welding may be used, if desired.

(e) In sketch (d), $C = 0.13$ for integral flat circular heads when the dimension d does not exceed 24 in., the ratio of thickness of the head to the dimension d is not less than 0.05 nor greater than 0.25, the head thickness t_h is not less than the shell thickness t_s , the inside corner radius is not less than $0.25t$, and the construction is obtained by special techniques of upsetting and spinning the end of the shell, such as employed in closing header ends.

(f) In sketches (e), (f), and (g), $C = 0.33m$ but not less than 0.2 for circular plates, welded to the inside of a vessel, and otherwise meeting the requirements for the respective types of welded vessels. If a value of m less than 1 is used in calculating t , the shell thickness t_s shall be maintained along a distance inwardly from the inside face of the head equal to at least $2\sqrt{dt_s}$. The throat thickness of the fillet welds in sketches (e) and (f) shall be at least $0.7t_s$. The size of the weld t_w in sketch (g) shall be not less than two times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness, but need not be greater than the head thickness; the weld shall be deposited in a welding groove with the root of the weld at the inner face of the head as shown in the figure.

For noncircular plates, welded to the inside of a vessel and otherwise meeting the requirements for the respective types of welded vessels, $C = 0.33$. The throat thickness of the fillet welds in sketches (e) and (f) shall be at least $0.7t_s$. The size of the weld t_w in sketch (g) shall be not less than two times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness, but need not be greater than the head thickness; the weld shall be deposited in a welding groove with the root of the weld at the inner face of the head as shown in the figure.

(g) In sketch (h), $C = 0.33$ for circular plates welded to the end of the shell when t_s is at least $1.25t_r$ and the weld details conform to the requirements of ND-3358.3(e) and Fig. ND-4243-1 sketches (a) to (g), inclusive.

(h) In sketch (i), $C = 0.33m$ but not less than 0.3 for circular plates if an inside fillet weld with minimum throat thickness of $0.7t_s$ is used and the details of the

Page 77

outside weld conform to the requirements of ND-3358.3(e) and Fig. ND-4243-1 sketches (a) to (g), inclusive, in which the inside weld can be considered to contribute an amount equal to t_s to the sum of the dimensions a and b .

(i) In sketches (j) and (k), $C = 0.2$ for circular and noncircular heads and covers bolted to the vessel as indicated in the figures. Note that Eq. (5) or (8) shall be used because of the extra moment applied to the cover by bolting. When the cover plate is grooved for a peripheral gasket, as shown in sketch (k), the net cover plate thickness under the groove or between the groove and the outer edge of the cover plate shall be not less than

$$d\sqrt{1.27Wh_G\bar{S}d^3}$$

for circular heads and covers, nor less than

d

$$d\sqrt{4Wh_G/SLd}$$

for noncircular heads and covers.

(j) In sketches (m), (n), and (o), $C = 0.2$ for a circular plate inserted into the end of a vessel and held in place by a positive mechanical locking arrangement and when all possible means of failure (either by shear, tension, compression, or radial deformation, including flaring, resulting from pressure and differential thermal expansion) are resisted using stresses consistent with this Article. Seal welding may be used, if desired.

(k) In sketch (p), $C = 0.17$ for circular and noncircular covers bolted with a full face gasket to shells, flanges, or side plates.

(l) In sketch (q), $C = 0.50$ for circular plates screwed into the end of a vessel having an inside diameter d not exceeding 12 in. or for heads having an integral flange screwed over the end of a vessel having an inside diameter d not exceeding 12 in. (305 mm) and when the design of the threaded joint against failure by shear, tension, compression, or radial deformation, including flaring, resulting from pressure and differential thermal expansion, is based on stresses consistent with this Subsection. If a tapered pipe thread is used, the requirements of ND-3361.3 shall also be met. Seal welding may be used, if desired.

(m) In sketch (r), $C = 0.33$ for circular plates having a dimension d not exceeding 18 in. (457 mm) inserted into the vessel as shown and otherwise meeting the requirements for the respective types of welded vessels. The end of the vessel shall be crimped over at least 30 deg, but not more than 45 deg. The crimping may be done cold only when this operation will not injure the metal. The throat of the weld shall be not less than the thickness of the flat head or shell, whichever is greater.

(n) In sketch (s), $C = 0.33$ for circular beveled plates having a diameter d not exceeding 18 in. (457 mm), inserted into a vessel, the end of which is crimped over at least 30 deg but not more than 45 deg and when the undercutting for seating leaves at least 80% of the shell thickness. The beveling shall be not less than 75% of the head thickness. The crimping shall be done when the entire circumference of the cylinder is uniformly heated to the proper forging temperature for the material used. For this construction, the ratio t/d shall be not less than the ratio P/S nor less than 0.05. The maximum allowable pressure for this construction shall not exceed $P = S/5d$.

(o) In Fig. ND-4243.1-1, $C = 0.33m$, but not less than 0.3 when the dimensional requirements of ND-3358.4 are met.

ND-3326 Spherically Dished Covers With Bolting Flanges

ND-3326.1 Nomenclature.

The symbols used are defined as follows:

t	= minimum required thickness of head plate after forming, in.
L	= inside spherical or crown radius, in.
r	= inside knuckle radius, in.
P	= Design Pressure, psi
S	= maximum allowable stress value, psi
T	= flange thickness, in.
M_o	= the total moment, in.-lb, determined as in XI-3230 for heads concave to pressure, and XI-3260 for heads convex to pressure; except that, for heads of the type shown in Fig. ND-3326.1-1 sketch (d), H_D and h_D shall be as defined below, and an additional moment $H_r h_r$ shall be included ⁶
H_r	= radial component of the membrane load in the spherical segment = $H_D \cot \beta_1$, lb, acting at the intersection of the inside of the flange ring with the center line of the dished cover thickness

h_r

= lever arm of H_r about centroid of flange ring, in.

H_D

= axial component of the membrane load in the spherical segment, lb, acting at the inside of the flange ring

$$= 0.785B^2P$$

6 Since $H_r h_r$ in some cases will subtract from the total moment, the moment in the flange ring when the internal pressure is zero may be determining loading for the flange design.

Page 78

h_D

= radial distance from the bolt circle to the inside of the flange ring, in.

β_1

= angle formed by the tangent to the center line of the dished cover thickness at its point of intersection with the flange ring, and a line perpendicular to the axis of the dished cover where

$$\beta_1 = \arcsin \left(\frac{B}{2L + t} \right)$$

A

= outside diameter of flange, in.

B

= inside diameter of flange, in.

C

= bolt circle diameter, in.

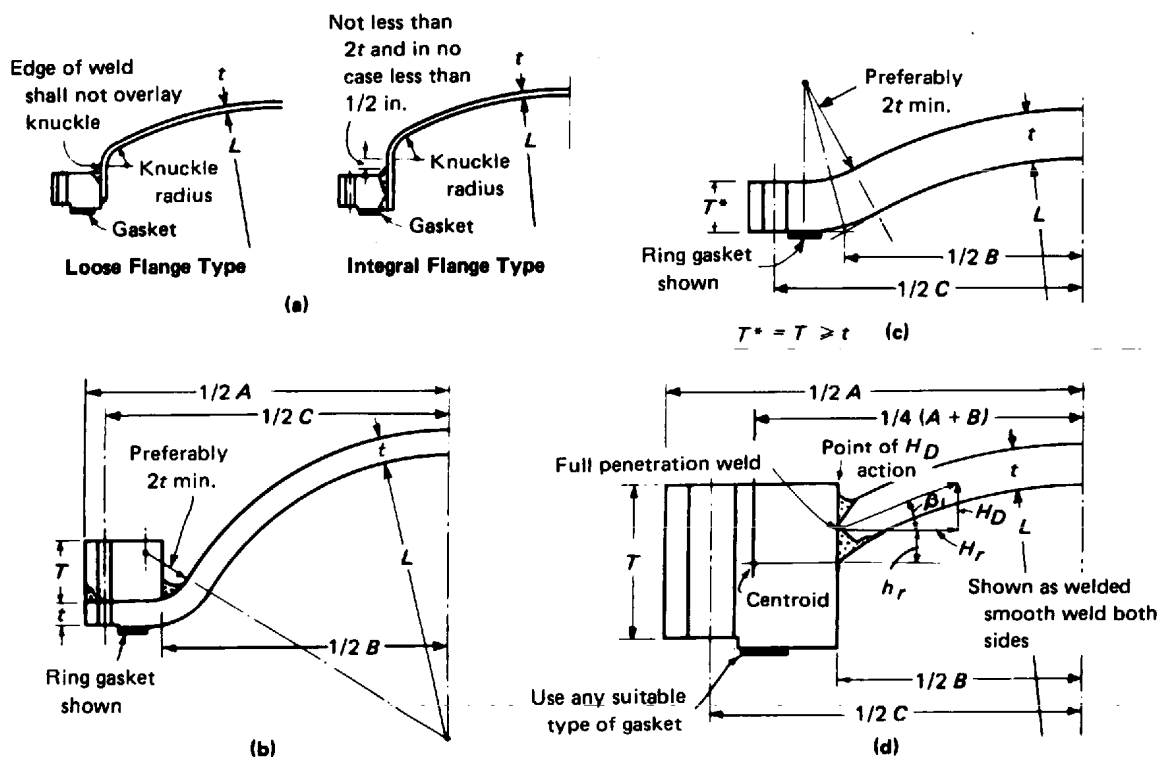


FIG. ND-3326.1-1 SPHERICALLY DISHED COVERS WITH BOLTING FLANGES

FIG. ND-3326.1-1 SPHERICALLY DISHED COVERS WITH BOLTING FLANGES

ND-3326.2 Spherically Dishd Heads With Bolting Flanges.

Circular spherically dishd heads with bolting flanges, both concave and convex to the pressure, and conforming to the several types illustrated in Fig. ND-3326.1-1, shall be designed in accordance with the requirements of (a) through (d) below. For heads convex to pressure, the spherical segments shall be thickened, if necessary, to meet the requirements of ND-3133. The actual value of the total moment M_o may calculate to be either plus or minus for both the heads concave to pressure and the heads convex to pressure. However, for use in all of the formulas which follow, the absolute values for both P and M_o shall be used.

(a) Heads of the Type Shown in Fig. ND-3326.1-1 Sketch (a)

- (1) The thickness of the head t shall be determined by the appropriate equation in ND-3324.
- (2) The head radius L or the knuckle radius r shall not exceed the limitations given in ND-3324.
- (3) The flange shall comply at least with the requirements of Fig. XI-3120-1 and shall be designed in accordance with the applicable provisions of Appendix XI. Within the range of ANSI B16.5, the flange facings and drillings should conform to those Standards and the thickness specified therein shall be considered as a minimum requirement.

(b) Heads of the Type Shown in Fig. ND-3326.1-1 Sketch (b)

- (1) Head thickness:

$$t = \frac{5PL}{6S}$$

(2) Flange thickness T :

For ring gasket:

Page 79

$$T = \sqrt{\frac{M_o}{SB} \left(\frac{A + B}{A - B} \right)}$$

For full face gasket:

$$T = 0.6 \sqrt{\frac{P}{S} \left[\frac{B(A + B)(C - B)}{(A - B)} \right]}$$

NOTE: The radial components of the membrane load in the spherical segment are assumed to be resisted by its flange.

Within the range of ANSI B16.5, the flange facings and drillings should conform to those Standards, and the thickness specified therein shall be considered as a minimum requirement.

(c) Heads of the Type Shown in Fig. ND-3326.1-1 Sketch (c)

(1) Head thickness:

$$t = \frac{5PL}{6S} \quad (9)$$

(9)

(2) Flange thickness for ring gaskets shall be calculated as follows:

(a) for heads with round bolting holes:

$$T = Q + \sqrt{\frac{1.875 M_o(C + B)}{SB(7C - 5B)}} \quad (10)$$

(10)

where

$$Q = \frac{PL}{4S} \left(\frac{C + B}{7C - 5B} \right) \quad (11)$$

(11)

(b) for heads with bolting holes slotted through the edge of the head:

$$T = Q + \sqrt{\frac{1.875 M_o(C + B)}{SB(3C - B)}} \quad (12)$$

(12)

where

$$Q = \frac{PL}{4S} \left(\frac{C + B}{3C - B} \right) \quad (13)$$

(13)

(3) Flange thickness for full face gaskets shall be calculated by the following equation:

$$T = Q + \sqrt{Q^2 + \frac{3BQ(C - B)}{L}} \quad (14)$$

(14)

The value of Q in Eq. (14) is calculated by Eq. (11) for round bolting holes or by Eq. (13) for bolting holes slotted through the edge of the head [see (c)(2) above].

(4) The required flange thickness shall be T as calculated in (c)(2) or (c)(3) above, but in no case less than the value of t calculated in (1) above.

(d) Heads of the Type Shown in Fig. ND-3326.1-1 Sketch (d)

(1) Head thickness:

$$t = \frac{5PL}{6S} \quad (15)$$

(15)

(2) Flange thickness:

$$T = F + \sqrt{F^2 + J} \quad (16)$$

(16)

where

$$F = \frac{PB \sqrt{4L^2 - B^2}}{8S(A - B)} \quad (17)$$

(17)

and

$$J = \left(\frac{M_o}{SB} \right) \left(\frac{A + B}{A - B} \right) \quad (18)$$

(18)

NOTE: These equations are approximate in that they do not take into account continuity between the flange ring and the dished head. A more exact method of analysis which takes this into account may be used. Such a method may parallel the method of analysis and allowable stresses for flange design in Appendix XI. The dished portion of a cover designed under this rule may, if welded, require evaluation of any welded joint.

ND-3327 Quick Actuating Closures

Closures other than the multibolted type designed to provide access to the contents space of a component shall have the locking mechanism or locking device so designed that failure of any one locking element or component in the locking mechanism cannot result in the failure of all other locking elements and the release of the closure. Quick actuating closures shall be so designed and installed that it may be determined by visual external observation that the holding elements are in good condition and that their locking elements, when the closure is in the closed position, are in full engagement.

ND-3327.1 Positive Locking Devices.

Quick actuating closures that are held in position by positive locking devices and that are fully released by partial rotation or limiting movement of the closure itself or the locking

Page 80

mechanism and any closure that is other than manually operated shall be so designated that when the vessel is installed the conditions of (a) through (c) below are met.

(a) The closure and its holding elements are fully engaged in their intended operating position before pressure can be built up in the vessel.

(b) Pressure tending to force the closure clear of the vessel will be released before the closure can be fully opened for access.

(c) In the event that compliance with (a) and (b) is not inherent in the design of the closure and its holding elements, provision shall be made so that devices to accomplish this can be added when the vessel is installed.

ND-3327.2 Manual Operation.

Quick actuating closures that are held in position by a locking device or mechanism that requires manual operation and are so designed that there will be leakage of the contents of the vessel prior to disengagement of the locking elements and release of closure need not satisfy ND-3327.1, but such closures shall be equipped with an audible or visible warning device that will serve to warn the operator if pressure is applied to the vessel before the closure and its holding elements are fully engaged in their intended position and further will serve to warn the operator if an attempt is made to operate the locking mechanism or device before the pressure within the vessel is released.

ND-3327.3 Pressure Indicating Device.

When installed, all vessels having quick actuating closures shall be provided with a pressure indicating device visible from the operating area.

ND-3328 Combination Units

When a vessel consists of more than one independent chamber, operating at the same or different pressures and temperatures, each such chamber shall be designed and constructed to withstand the most severe condition of coincident pressure and temperature expected in normal service.

ND-3329 Braced and Stayed Surfaces, Staybolts, and Ligaments

ND-3329.1 Braced and Stayed Surfaces

(a) The minimum thickness and maximum allowable pressure for braced and stayed flat plates and those parts which, by these rules, require staying as flat plates with braces or staybolts of uniform diameter symmetrically spaced shall be calculated by the following equations:

$$t = p \sqrt{\frac{P}{SC}} \quad (19)$$

(19)

$$P = \frac{t^2 SC}{p^2} \quad (20)$$

(20)

where

t

= minimum thickness of plate, exclusive of corrosion allowance, in.

P	= Design Pressure, psi
S	= maximum allowable stress value, psi, given in Tables 1A and 1B, Section II, Part D, Subpart 1
p	= maximum pitch measured between straight lines passing through the centers of the staybolts in the different rows, which lines may be horizontal, vertical, or inclined, in.
C	= 2.1 for welded stays or stays screwed through plates not over $\frac{7}{16}$ in. in thickness with ends riveted over = 2.2 for welded stays or stays screwed through plates over $\frac{7}{16}$ in. in thickness with ends riveted over = 2.5 for stays screwed through plates and fitted with single nuts outside of plate or with inside and outside nuts, omitting washers = 2.8 for stays with heads not less than 1.3 times the diameter of the stays screwed through plates, or made a taper fit and having the heads formed on the stays before installing them and not riveted over = 3.2 for stays fitted with inside and outside nuts and outside washers where the diameter of washers is not less than $0.4p$ and thickness not less than t

(b) The minimum thickness of plates to which stays may be applied, in other than cylindrical or spherical outer shell plates, shall be $\frac{5}{16}$ in. (8 mm) except for welded construction (ND-3329.3).

(c) If a stayed jacket extends completely around a cylindrical or spherical vessel, or completely covers a formed head, it shall meet the requirements given in (a) above and shall also meet the applicable requirements for shells or heads (ND-3324).

(d) When two plates are connected by stays and but one of these plates requires staying, the value of C shall be governed by the thickness of the plate requiring staying.

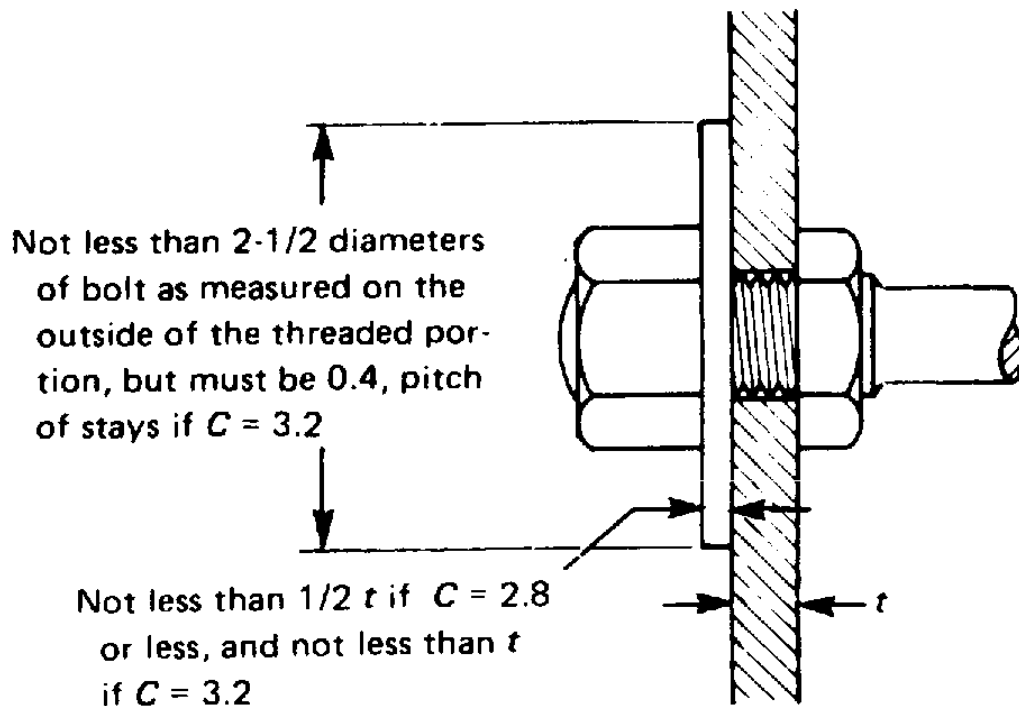


FIG. ND-3329.1(e)-1 ACCEPTABLE PROPORTIONS FOR ENDS OR THROUGH STAYS

FIG. ND-3329.1(e)-1 ACCEPTABLE PROPORTIONS FOR ENDS OR THROUGH STAYS

(e) The acceptable proportions for the ends of through stays with washers are indicated in Fig. ND-3329.1(e)-1.

(f) The maximum pitch shall be $8\frac{1}{2}$ in. (216 mm), except that for welded-in staybolts the pitch may be greater, provided it does not exceed 15 times the diameter of the staybolt.

(g) When the staybolting of shells is unsymmetrical by reason of interference with butt straps or other construction, it is permissible to consider the load carried by each staybolt as the area calculated by taking the distance from the center of the spacing on one side of the bolt to the center of the spacing on the other side.

ND-3329.2 Threaded Staybolts

(a) The ends of staybolts or stays screwed through the plate shall extend beyond the plate not less than two threads when installed, after which they shall be riveted over or upset by an equivalent process without excessive scoring of the plates, or they shall be fitted with threaded nuts through which the bolt or stay shall extend.

(b) The ends of steel stays upset for threading shall be fully annealed.

ND-3329.3 Welded Stayed Construction.

For welded stayed construction, the provisions of ND-4470 and ND-5260 shall be met in addition to the requirements of (a) through (d) below.

(a) Welded-in staybolts shall meet the requirements of (1) through (4) below.

(1) The arrangement shall conform to one of those illustrated in Fig. ND-4470-1.

(2) The required thickness of the plate shall not exceed $1\frac{1}{2}$ in. (38 mm) but, if greater than $\frac{3}{4}$ in. (19 mm), the staybolt pitch shall not exceed 20 in. (508 mm).

(3) The provisions of ND-3329.1 and ND-3329.4 shall be met.

(4) The required area of the staybolt shall be determined in accordance with ND-3329.5.

(b) Welded stays, as shown in Fig. ND-4470-1, may be used to stay jacketed vessels provided the requirements of (1) through (8) below are met.

(1) The pressure does not exceed 300 psi (2070 kPa).

(2) The required thickness of the plate does not exceed $\frac{1}{2}$ in. (13 mm).

(3) The size of the fillet welds is not less than the plate thickness.

(4) The inside welds are properly inspected before the closing plates are attached.

(5) The allowable load on the fillet welds is computed in accordance with ND-3356(c).

(6) The maximum diameter or width of the hole in the plate does not exceed $1\frac{1}{4}$ in. (32 mm).

(7) The welders are qualified under the rules of Section IX.

(8) The maximum spacing of stays is determined by the equation in ND-3329.1(a), using:

C	$= 2.1$ if either plate is not over $\frac{7}{16}$ in. (11 mm) thick
C	$= 2.2$ if both plates are over $\frac{7}{16}$ in. (11 mm) thick

(c) Welded stayed construction, consisting of a dimpled or embossed plate welded to another like plate or to a plain plate, may be used provided the requirements of (1) through (4) below are met.

(1) The pressure does not exceed 300 psi (2070 kPa).

(2) The welded attachment is made by fillet welds around holes or slots as shown in Fig. ND-4470-1 and is calculated in accordance with ND-4470.

(3) The maximum allowable pressure of the dimpled or embossed components is established in accordance with the requirements of ND-6900.

(4) The plain plate, if used, shall meet the requirements for braced and stayed surfaces.

(d) The welds need not be radiographed, nor need they be postweld heat treated unless the vessel is required to be postweld heat treated.

[98]

ND-3329.4 Location of Staybolts

(a) The distance from the edge of a staybolt hole to the edge of a flat stayed plate shall not be greater than the pitch of the stays.

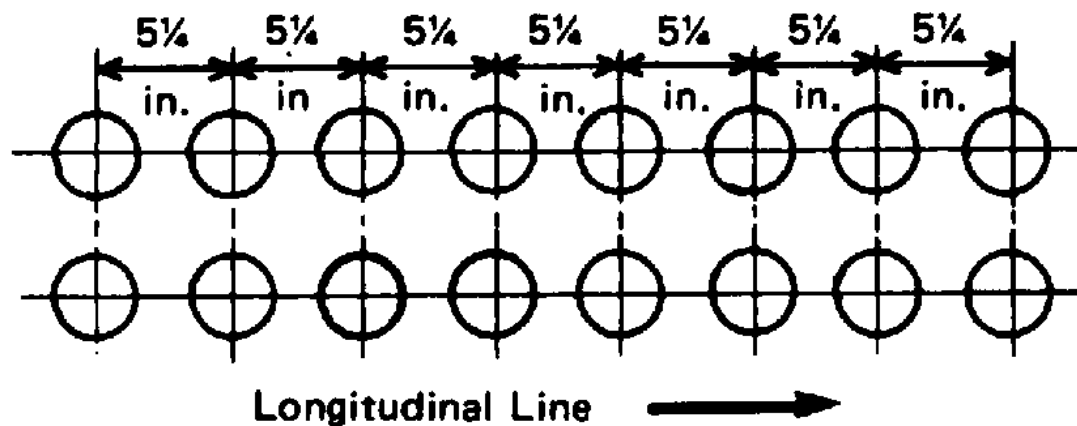


FIG. ND-3329.6(b)-1 EXAMPLE OF TUBE SPACING WITH PITCH OF HOLES EQUAL IN EVERY ROW

FIG. ND-3329.6(b)-1 EXAMPLE OF TUBE SPACING WITH PITCH OF HOLES EQUAL IN EVERY ROW

(b) When the edge of a flat stayed plate is flanged, the distance from the center of the outermost stays to the inside of the supporting flange shall not be greater than the pitch of the stays plus the inside radius of the flange.

ND-3329.5 Dimensions of Staybolts

(a) The required area of a staybolt at its minimum cross section⁷ and exclusive of any allowance for corrosion shall be obtained by dividing the load on the staybolt, computed in accordance with (b) below, and by increasing the allowable stress value by a factor of 1.10 for the material used (Tables 1A and 1B, Section II, Part D, Subpart 1).

(b) The area supported by a stay shall be computed on the basis of the full pitch dimensions, with a deduction for the area occupied by the stay. The load carried by a stay is the product of the area supported by the stay and the maximum allowable pressure.

(c) Stays made of parts joined by welding shall be designed using a joint efficiency of 0.60 for the weld.

ND-3329.6 Ligaments

(a) The symbols used in the equations and chart of this paragraph are defined as follows:

p	= longitudinal pitch of tube holes, in.
p_1	= unit length of ligament, in.

p'	= diagonal pitch of tube holes, in.
d	= diameter of tube holes, in.
n	= number of tube holes in length p_1

(b) When a cylindrical shell is drilled for tubes in a line parallel to the axis of the shell for substantially the full length of the shell as shown in Figs. ND-3329.6(b)-1 through ND-3329.6(b)-3, the efficiency of the ligaments between the tube holes shall be determined as follows:

7 The minimum cross section is usually at the root of the thread.

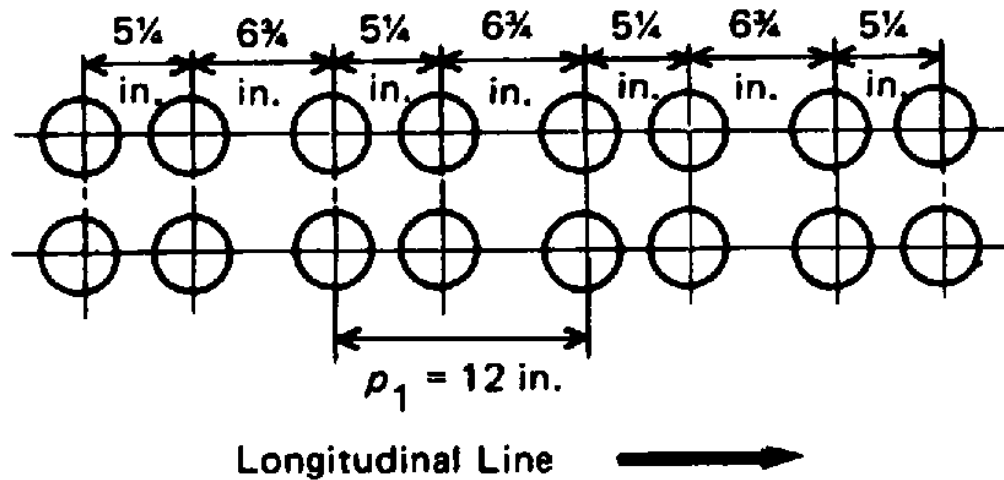


FIG. ND-3329.6(b)-2 EXAMPLE OF TUBE SPACING WITH PITCH OF HOLES UNEQUAL IN EVERY SECOND ROW

FIG. ND-3329.6(b)-2 EXAMPLE OF TUBE SPACING WITH PITCH OF HOLES UNEQUAL IN EVERY SECOND ROW

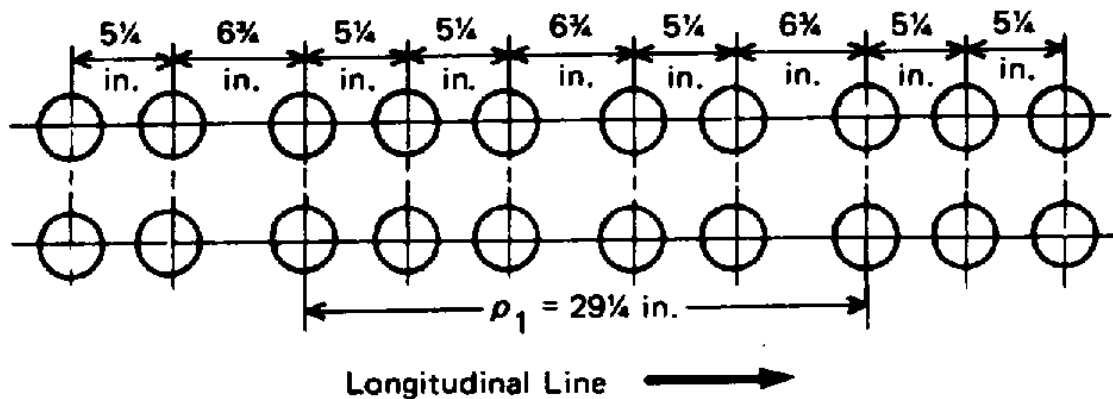


FIG. ND-3329.6(b)-3 EXAMPLE OF TUBE SPACING WITH PITCH OF HOLES VARYING IN EVERY SECOND AND THIRD ROW

FIG. ND-3329.6(b)-3 EXAMPLE OF TUBE SPACING WITH PITCH OF HOLES VARYING IN EVERY SECOND AND THIRD ROW

(1) when the pitch of the tube holes on every row is equal [Fig. ND-3329.6(b)-1], the formula is $(p-d)/p$ = efficiency of ligament;

(2) when the pitch of tube holes on any one row is unequal [Figs. ND-3329.6(b)-2 and ND-3329.6(b)-3], the equation is $(p_1 - nd)/p_1$ = efficiency of ligament.

(c) The strength of ligaments between tube holes measured circumferentially shall be at least 50% of the strength of ligaments of similar dimensions taken in a line parallel to the axis of the cylindrical shell.

(d) When a cylindrical shell is drilled for tube holes so as to form diagonal ligaments, as shown in Fig. ND-3329.6(d)-1, the efficiency of these ligaments shall be that given by the diagram in Fig. ND-3329.6(d)-2. The pitch of tube holes shall be measured either on the flat plate before rolling or on the middle line of the plate after rolling. To use the diagram in Fig. ND-3329.6(d)-2, compute the value of p/p_1 and also the efficiency of the longitudinal ligament. Next find in the diagram the vertical line corresponding to the longitudinal efficiency of the ligament and follow this line vertically to the point where it intersects the diagonal line representing the ratio of p/p_1 . Then

Page 83

project this point horizontally to the left and read the diagonal efficiency of the ligament on the scale at the edge of the diagram. The shell thickness and the maximum allowable pressure shall be based on the ligament that has the lower efficiency.

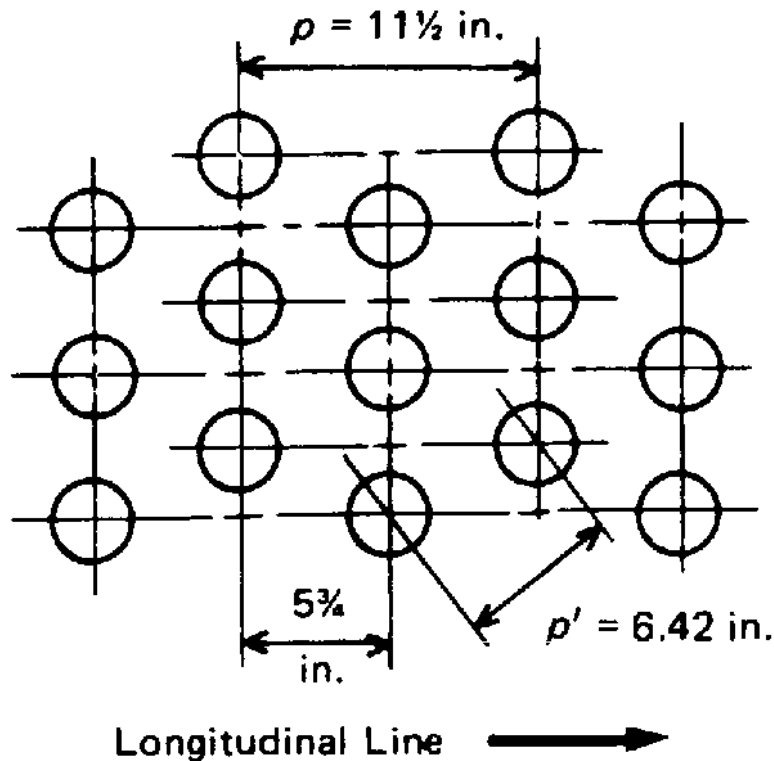


FIG. ND-3329.6(d)-1 EXAMPLE OF TUBE SPACING WITH TUBE HOLES ON DIAGONAL LINES

FIG. ND-3329.6(d)-1 EXAMPLE OF TUBE SPACING WITH TUBE HOLES ON DIAGONAL LINES

(e) When tube holes in a cylindrical shell are arranged in symmetrical groups which extend a distance greater than the inside diameter of the shell along lines parallel to the axis and the same spacing is used for each group, the efficiency for one of the groups shall be not less than the efficiency on which the maximum allowable pressure is based.

(f) The average ligament efficiency in a cylindrical shell, in which the tube holes are arranged along lines parallel to the axis with either uniform or nonuniform spacing, shall be computed by the following rules and shall satisfy the requirements of both (1) and (2) below.⁸

(1) For a length equal to the inside diameter of the shell for the position which gives the minimum efficiency, the efficiency shall be not less than that on which the maximum allowable pressure is based. When the diameter of the shell exceeds 60 in. (1520 mm), the length shall be taken as 60 in. (1520 mm) in applying this rule.

8 The rules in this paragraph apply to ligaments between tube holes and not to single openings. They may give lower efficiencies in some cases than those for symmetrical groups which extend a distance greater than the inside diameter of the shell as covered in (c). When this occurs, the efficiencies computed by the rules under (b) shall govern.

(2) For a length equal to the inside radius of the shell for the position which gives the minimum efficiency, the efficiency shall be not less than 80% of that on which the maximum allowable pressure is based. When the radius of the shell exceeds 30 in. (762 mm), the length shall be taken as 30 in. (762 mm) in applying this rule.

(g) For holes which are not in line, placed longitudinally along a cylindrical shell, the rules in (f) above for calculating efficiency shall hold, except that the equivalent longitudinal width of a diagonal ligament shall be used. To obtain the equivalent width, the longitudinal pitch of the two holes having a diagonal ligament shall be multiplied by the efficiency of the diagonal ligament. The efficiency to be used for the diagonal ligaments is given in Fig. ND-3329.6(g)-1.

ND-3330 OPENINGS AND REINFORCEMENT⁹

ND-3331 General Requirements for Openings

(a) Openings¹⁰ in cylindrical or conical portions of vessels or in formed heads shall preferably be circular, elliptical, or obround.¹¹ When the long dimension of an elliptical or obround opening exceeds twice the short dimensions, the reinforcement across the short dimensions shall be increased as necessary to provide against excessive distortion due to twisting moment.

(b) Openings may be of other shapes than those given in (a) above, and all corners shall be provided with a suitable radius. When the openings are of such proportions that their strength cannot be computed with assurance of accuracy or when doubt exists as to the safety of a vessel with such openings, the part of the vessel affected shall be subjected to a proof hydrostatic test as prescribed in ND-6900.

(c)(1) The rules for reinforcement of openings given in ND-3330 are intended to apply to openings not exceeding the following:

(a) for vessels 60 in. (1520 mm) diameter and less: one-half the vessel diameter but not to exceed 20 in. (508 mm);

9 The rules governing openings as given in this Subsection are based on the stress intensification created by the existence of a hole in an otherwise symmetrical section. They are based on experience with vessels designed with design factors of 4 and 5 applied to the ultimate strength of the shell material. External loadings such as those due to the thermal expansion or unsupported weight of connecting piping have not been evaluated. These factors should be given attention in unusual designs or under conditions of cyclic loading.

10 The opening made by a pipe or a circular nozzle, the axis of which is not perpendicular to the vessel wall or head, may be considered an elliptical opening for design purposes.

11 An obround opening is one which is formed by two parallel sides and semicircular ends.

Page 84

Page 85

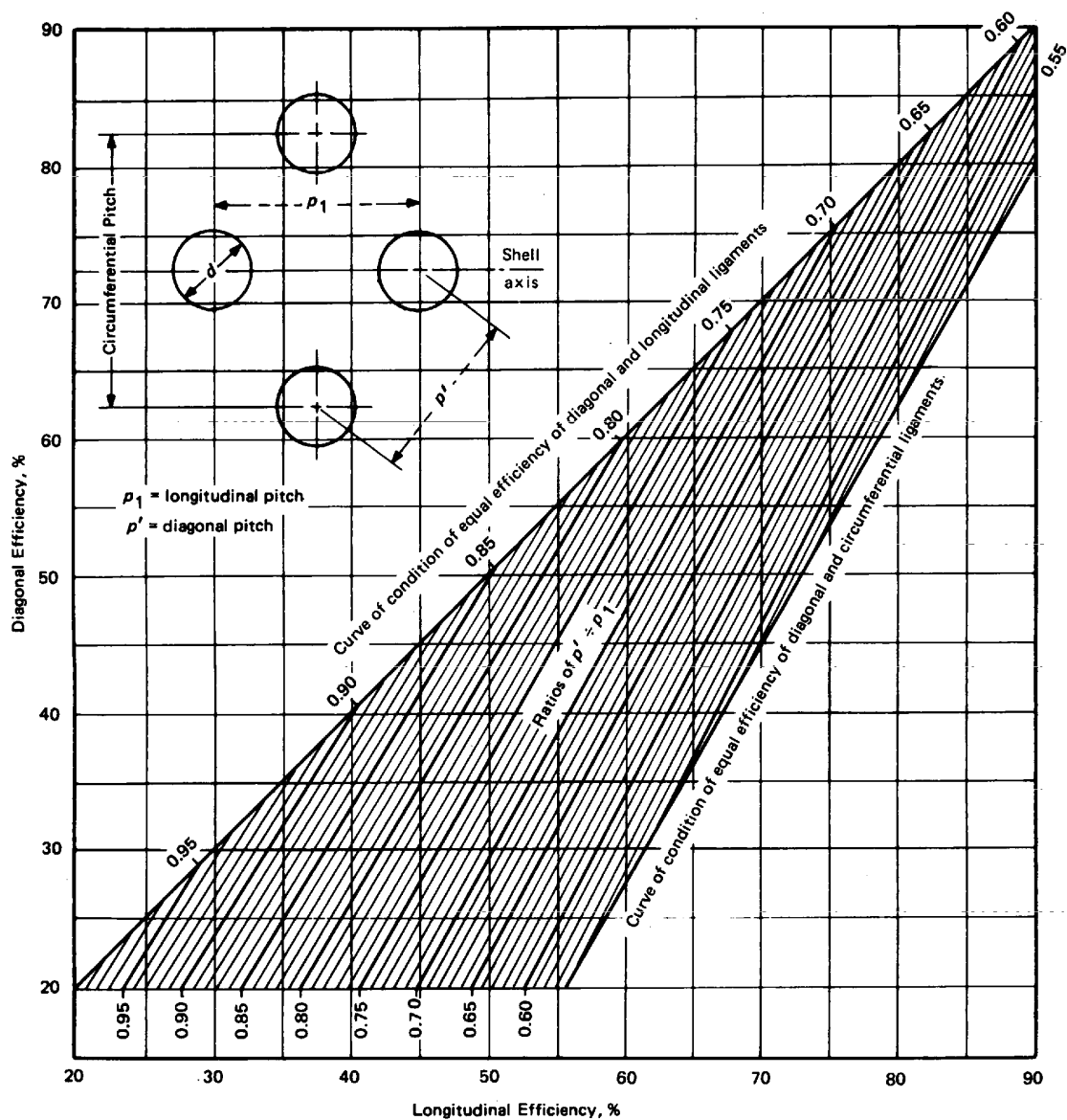


FIG. ND-3329.6(d)-2 DIAGRAM FOR DETERMINING THE EFFICIENCY OF LONGITUDINAL AND DIAGONAL LIGAMENTS BETWEEN OPENINGS IN CYLINDRICAL SHELLS

FIG. ND-3329.6(d)-2 DIAGRAM FOR DETERMINING THE EFFICIENCY OF LONGITUDINAL AND DIAGONAL LIGAMENTS BETWEEN OPENINGS IN CYLINDRICAL SHELLS

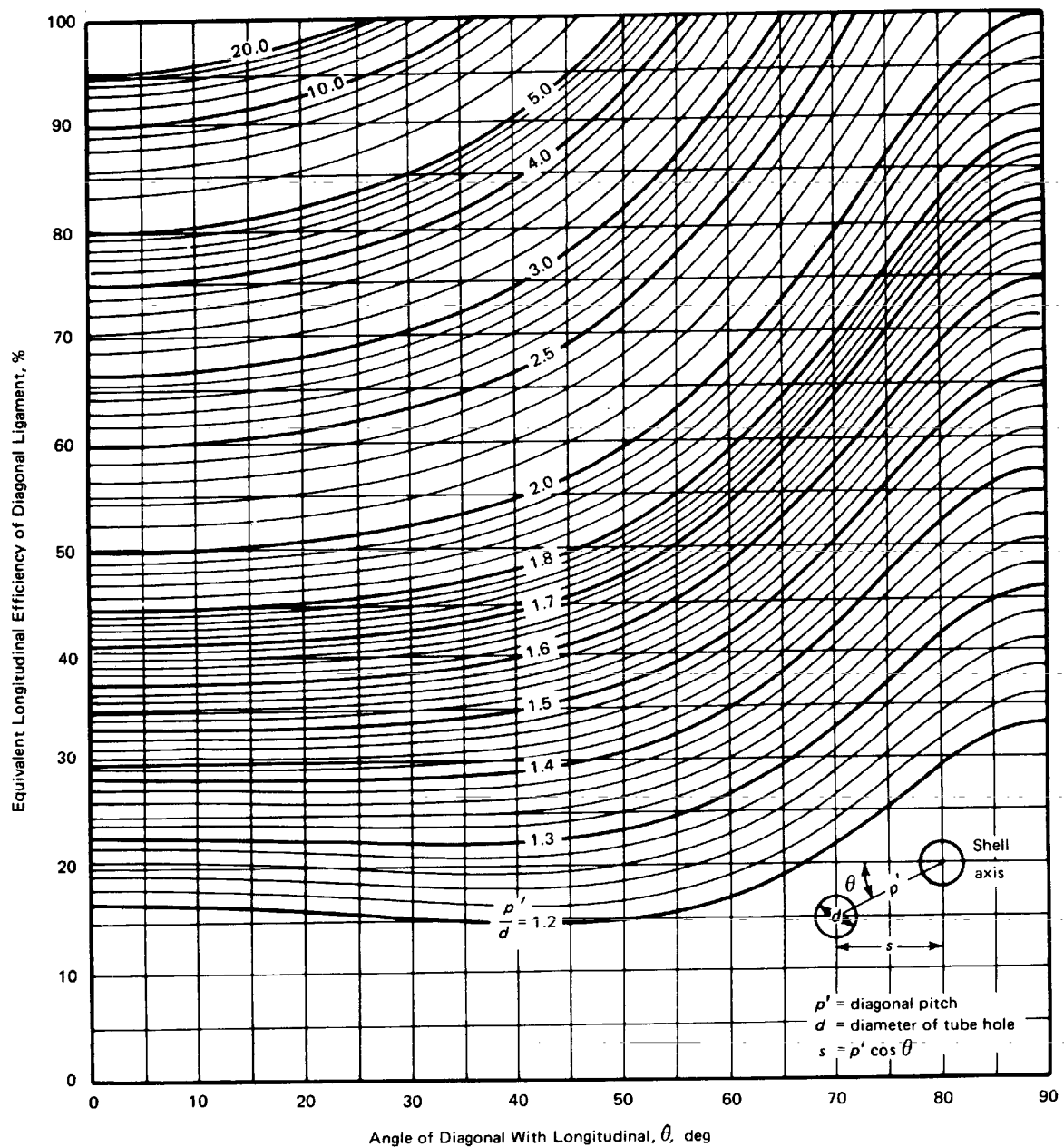


FIG. ND-3329.6(g)-1 DIAGRAM FOR DETERMINING EQUIVALENT LONGITUDINAL EFFICIENCY OF DIAGONAL LIGAMENTS

FIG. ND-3329.6(g)-1 DIAGRAM FOR DETERMINING EQUIVALENT LONGITUDINAL EFFICIENCY OF DIAGONAL LIGAMENTS

(b) for vessels over 60 in. (1520 mm) diameter: one-third the vessel diameter but not to exceed 40 in. (1000 mm).

(2) Larger openings shall be given special attention. Two-thirds of the required reinforcement shall be within $\frac{1}{2}r$ parallel to the vessel surface and measured from the edge of the opening, where r is the radius of the finished opening. The limit normal to the vessel wall is the smaller of the limits specified in ND-3334.2. Special consideration shall be given to the fabrication details used and examination employed. Reinforcement often may be advantageously obtained by use of heavier shell plate for a vessel course or inserted locally around the opening. Welds may be ground to concave contour and the inside corners of the opening rounded to a generous radius to reduce stress concentrations.

(d) All references to dimensions in ND-3330 apply to the finished dimensions, excluding material added as corrosion allowance.

(e) Any type of opening may be located in a welded joint.

ND-3332 Reinforcement Requirements for Openings in Shells and Formed Heads

ND-3332.1 Openings Not Requiring Reinforcement.

Reinforcement shall be provided in amount and distribution such that the requirements for area of reinforcement are satisfied for all planes through the center of the opening and normal to the surface of the vessel, except that single circular openings need not be provided with reinforcement if the openings have diameters equal to or less than NPS 2 (DN 50).

ND-3332.2 Required Area of Reinforcement.

The total cross-sectional area of reinforcement A required in any given plane for a vessel under internal pressure shall not be less than:

$$A = dt_r F$$

where

d

= finished diameter of a circular opening or finished dimension (chord length) of an opening on the plane being considered for elliptical and obround openings in corroded condition, in.

F

= a correction factor which compensates for the variation in pressure stresses on different planes with respect to the axis of a vessel. A value of 1.00 shall be used for all configurations except that Fig. ND-3332.2-1 may be used for integrally reinforced openings in cylindrical shells and cones.

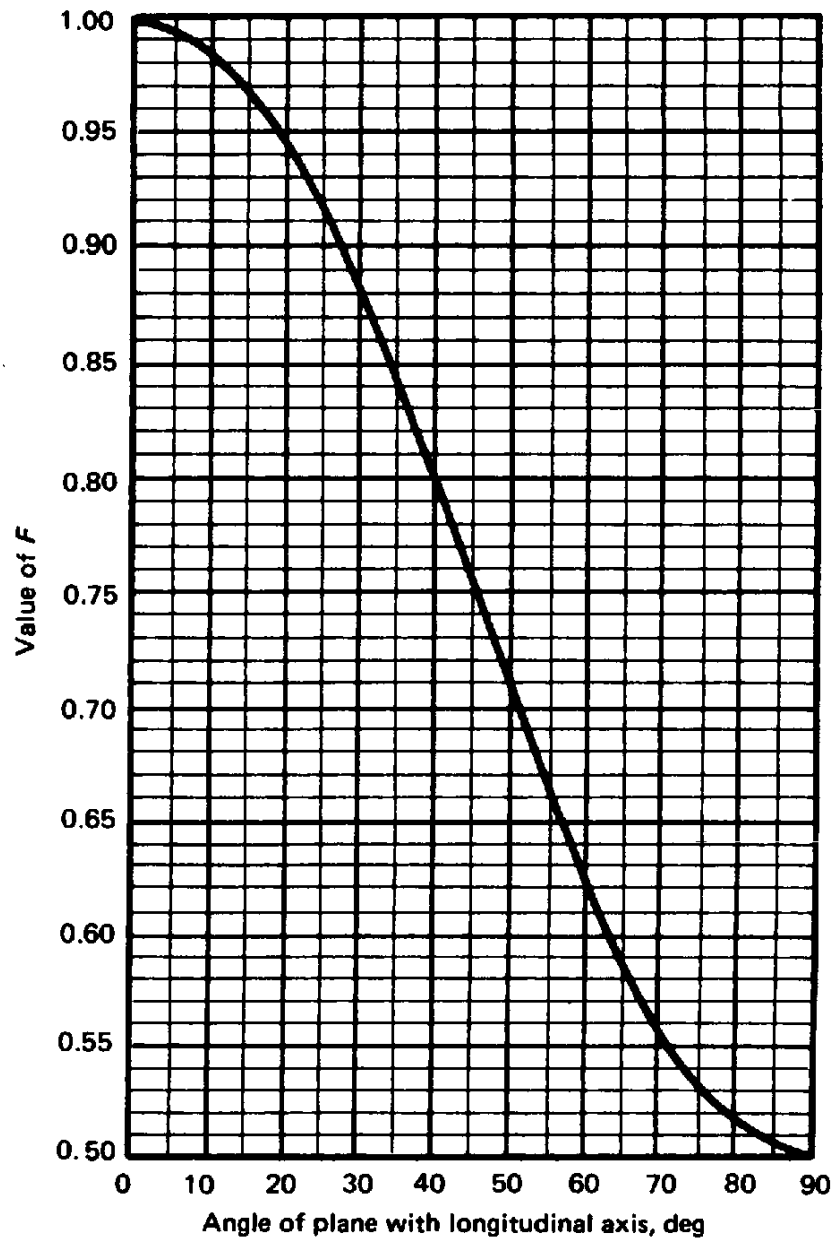
t_r

= the required thickness of a shell or head computed in accordance with the rules of this Article for the Design Pressure, in., except that:

(a) when the opening and its reinforcement are entirely within the spherical portion of a torispherical head, t_r is the thickness required by ND-3324.8(b), using $E=1$ and $M=1$;

(b) when the opening is in a cone, t_r is the thickness required for a seamless cone of diameter D measured where the nozzle axis pierces the inside wall of the cone;

(c) when the opening and its reinforcement are in an ellipsoidal head and are located entirely within a circle the center of which coincides with the center of the head and the diameter of which is equal to 80% of the shell diameter, t_r is the thickness required for a seamless sphere of radius $K_1 D$, where D is the shell diameter and K_1 is given by Table



**FIG. ND-3332.2-1 CHART FOR DETERMINING
VALUE OF F**

FIG. ND-3332.2-1 CHART FOR DETERMINING VALUE OF F

TABLE ND-3332.2-1
VALUES OF SPHERICAL RADIUS FACTOR K_1
 Equivalent Spherical Radius = $K_1 D$; $D/2h$ = Axis Ratio.
 Interpolation Permitted for Intermediate Values.

$D/2h$	...	3.0	2.8	2.6	2.4	2.2
K_1	...	1.36	1.27	1.18	1.08	0.99
$K/2h$	2.0	1.8	1.6	1.4	1.2	1.0
K_1	0.90	0.81	0.73	0.65	0.57	0.50

TABLE ND-3332.2-1 VALUES OF SPHERICAL RADIUS FACTOR K_1

At least one-half of the required reinforcing shall be on each side of the center line of the opening.

ND-3332.3 Reinforcement for External Pressure

(a) The reinforcement required for openings in vessels designed for external pressure need only be 50% of that required in the equation for area in ND-3332.2 except t_r is the wall thickness required by the rules for components under external pressure.

(b) The reinforcement required for openings in each shell of a multiple walled vessel shall comply with (a) above when the shell is subject to external pressure and with ND-3332.2 when the shell is subject to internal pressure.

ND-3332.4 Reinforcement for Internal and External Pressure.

Reinforcement of vessels subject to both internal and external pressures shall meet the requirements of ND-3332.2 for internal pressure and of ND-3332.3 for external pressure.

ND-3333 Reinforcement Required for Openings in Flat Heads

(a) Flat heads that have an opening with a diameter that does not exceed one-half of the head diameter shall have a total cross-sectional area of reinforcement not less than that given by the equation:

$$A = 0.5 d t_r$$

where d is as defined in ND-3332.2 and t_r is the thickness, in., which meets the requirements of ND-3325 in the absence of the opening.

(b) As an alternative to (a) above, the thickness of flat heads may be increased to provide the necessary opening reinforcement as follows:

(1) in Eq. (4) of ND-3325.2, by using $2C$ or 0.75 in place of C , whichever is less;

(2) in Eq. (5) of ND-3325.2, by doubling the quantity under the square root sign.

(c) Flat heads that have an opening with a diameter that exceeds one-half of the head diameter or shortest span, as defined in ND-3325.1, shall be designed as follows.

(1) When the opening is a single, circular, centrally located opening and when the shell-head juncture is integrally formed or integrally attached by a full penetration weld similar to those shown in Fig. ND-3325-1 sketches (a), (b-1), (b-2), (d), or (g), the head shall be designed according to Appendix XIX and related parts of Appendix XI. The required head thickness which satisfies all the requirements of Appendix XIX also satisfies the intent of ND-3225. The opening in the head may have a nozzle which is integrally formed or integrally attached by a full penetration weld or it may be an opening without an attached nozzle or hub.

(2) When the opening is of any other type than that described in (1) above, no specific rules are given. Consequently, the requirements of ND-1100(c) shall be met.

ND-3334 Limits of Reinforcement

The boundaries of the cross-sectional area in any plane normal to the vessel wall and passing through the center of the opening and within which metal shall be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane and are given in the following subparagraphs.

ND-3334.1 Limits of Reinforcement Along the Vessel Wall.

The limits of reinforcement, measured along the midsurface of the nominal wall thickness, shall meet the following.

(a) One hundred percent of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) the diameter of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus the sum of the thicknesses of the vessel wall and the nozzle wall.

(b) Two-thirds of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) $r + 0.5\sqrt{Rt}$, where R is the mean radius, in., of shell or head, t is the nominal vessel wall thickness, in., r is the radius, in., of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus two-thirds the sum of the thicknesses of the vessel wall and the nozzle wall.

ND-3334.2 Limits of Reinforcement Normal to the Vessel Wall.

The limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to the lesser of (a) or (b) below:

(a) $2\frac{1}{2}$ times the nominal shell thickness less corrosion allowance;

(b) $2\frac{1}{2}$ times the nozzle wall thickness less corrosion allowance, plus the thickness of any added reinforcement exclusive of weld metal on the side of the shell under consideration.

ND-3335 Metal Available for Reinforcement

ND-3335.1 Openings.

Metal within the limits of reinforcement that may be considered to have reinforcing value shall be that given in (a) through (d) below:

(a) metal in the vessel wall over and above the thickness required to resist pressure and the thickness specified as corrosion allowance. The area in the vessel wall available as reinforcement is the larger of the values of A_1 given by:

$$A_1 = (E_1 t - F t_r) d$$

or

$$A_1 = 2(E_1 t - F t_r)(t + t_n)$$

(b) metal over and above the thickness required to resist pressure and the thickness specified as corrosion allowance in that part of a nozzle wall extending outside the vessel wall. The maximum area in the nozzle wall available as reinforcement is the lesser of the values of A_2 given by:

$$A_2 = (t_n - t_{rn}) 5t$$

or

$$A_2 = (t_n - t_{rn})(5t_n + 2t_e)$$

(c) all metal in the nozzle wall extending inside the vessel wall may be included after proper deduction for corrosion allowance on all the exposed surface is made. No allowance shall be taken for the fact that a differential pressure on an inwardly extending nozzle may cause opposing stress to that of the stress in the shell around the opening where:

A_1	= area in excess thickness in the vessel wall available for reinforcement, sq in. (ND-3334)
A_2	= area in excess thickness in the nozzle wall available for reinforcement, sq in. (ND-3334)
E_1	= 1 when an opening is in the plate or when the opening passes through a circumferential joint in a shell or cone exclusive of head-to-shell joints; or = the joint efficiency obtained from ND-3352 when any part of the opening passes through any other welded joint
F	= a correction factor which compensates for the variation in pressure stresses on different planes with respect to the axis of a vessel. A value of 1.00 shall be used for all configurations, except that Fig. ND-3332.2-1 may be used for integrally reinforced openings in cylindrical shells and cones.
t_e	= thickness of attached reinforcing pad or height of the largest 60 deg right triangle supported by the vessel and nozzle outside diameter projected surfaces and lying completely within the area of integral reinforcement, in. [Fig. ND-3335.1(b)-1]
t	= nominal thickness of the vessel wall, less corrosion allowance, in.
t_r	= required thickness of a seamless shell or head as defined in ND-3332.2, in.
t_n	= nominal thickness of nozzle wall, less corrosion allowance, in.
t_{rn}	= required thickness of a seamless nozzle wall, in.
d	= diameter in the plane under consideration of the finished opening in its corroded condition, in. (ND-3332.2)

(d) metal added as reinforcement and metal in attachment welds.

ND-3335.2 Reinforcement of Multiple Openings

(a) When any two openings in a group of two or more openings are spaced at less than two times their average diameter so that their limits of reinforcement overlap, the two openings shall be reinforced in the plane connecting the centers (Fig. ND-3335.2-1), in accordance with ND-3330 through ND-3336, with a combined reinforcement that has an area equal to the combined area of the reinforcements required for separate openings. No portion of the cross section is to be considered as applying to more than one opening, or

Page 89

to be evaluated more than once in a combined area. The following additional requirements shall also apply.

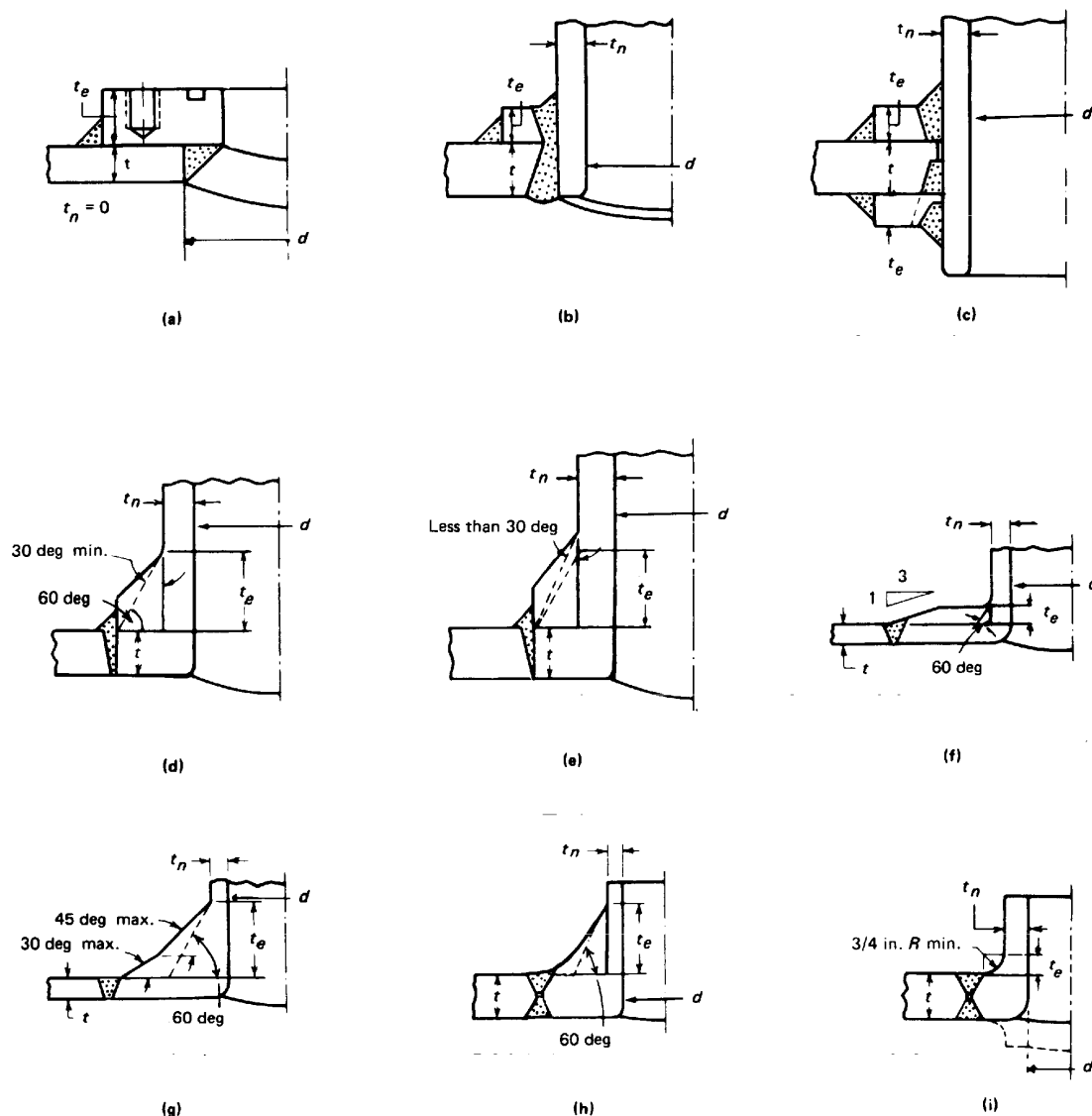
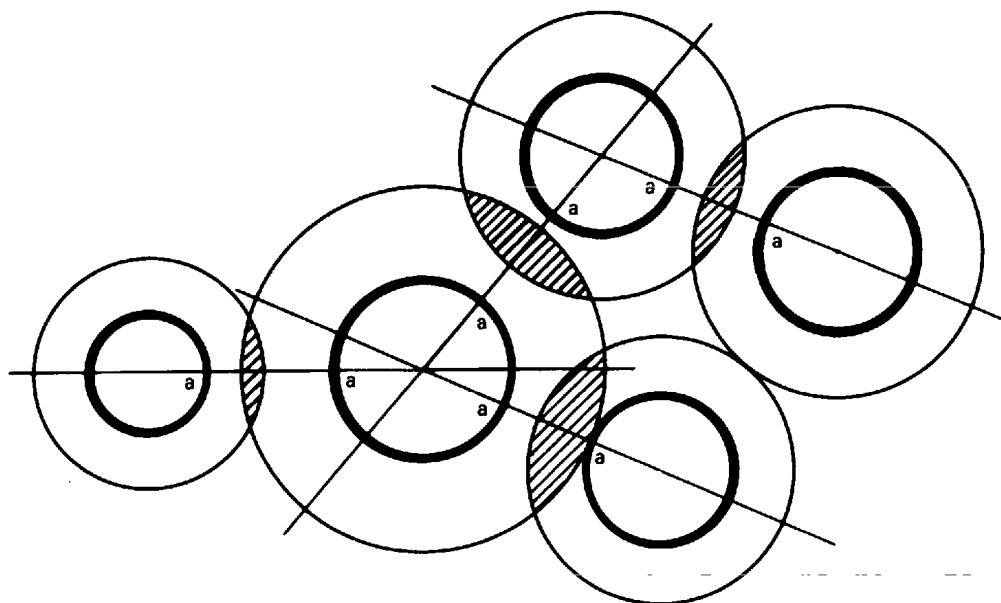


FIG. ND-3335.1(b)-1 SOME REPRESENTATIVE CONFIGURATIONS DESCRIBING THE t_e REINFORCEMENT DIMENSION

FIG. ND-3335.1(b)-1 SOME REPRESENTATIVE CONFIGURATIONS DESCRIBING THE t_e REINFORCEMENT

DIMENSION



GENERAL NOTES:

- (1) Hatched area represents overlapping of the reinforcement limits.
- (2) Each cross-section indicated by a straight line a-a must be investigated for adequacy of reinforcement.
- (3) Heavy circles represent openings, and light circles represent limits of reinforcement.

FIG. ND-3335.2-1 ARRANGEMENT OF MULTIPLE OPENINGS

FIG. ND-3335.2-1 ARRANGEMENT OF MULTIPLE OPENINGS

(1) When the distance between the centers of the openings is greater than $1\frac{1}{3}$ times their average diameter, the area of reinforcement between them shall be not less than 50% of the total required for these openings.

(2) When the distance between the centers of the openings is less than $1\frac{1}{3}$ times their average diameter, no credit for reinforcement shall be taken for any of the material between these openings, and the openings shall be reinforced as described in (b) below.

(b) Any number of adjacent openings, in any arrangement, may be reinforced for an assumed opening of a diameter enclosing all such openings. The diameter of the assumed opening shall not exceed the following:

- (1) for vessels 60 in. (1520 mm) diameter and less, one-half the vessel diameter, but not to exceed 20 in. (508 mm);
- (2) for vessels over 60 in. (1520 mm) diameter, one-third the vessel diameter, but not to exceed 40 in. (1000 mm).

(c) When a group of openings is reinforced by a thicker section butt welded into the shell or head, the edges of the inserted section shall be tapered as prescribed in ND-3361.

(d) When a series of two or more openings in a pressure vessel are arranged in a regular pattern, reinforcement of the openings may be provided in accordance with the requirements of ND-3329.6.

ND-3335.3 Flued Openings in Formed Heads

(a) Flued openings in formed heads made by inward or outward forming of the head plate shall meet the requirements

for reinforcement in ND-3332.

(b) The minimum depth of flange of a flued opening exceeding 6 in. (152 mm) in any inside dimension, when not stayed by an attached pipe or flue, shall equal $3t_r$ or $(t_r + 3)$ in., whichever is less, where t_r is the required head thickness. The depth of flange shall be determined by placing a straight edge across the side opposite the flued opening along the major axis and measuring from the straight edge to the edge of the flanged opening [Fig. ND-3335.3(b)-1].

(c) The minimum width of bearing surface for a gasket on a self-sealing flued opening shall be in accordance with ND-3363.7.

Page 91

Minimum depth of flange; the smaller of $3t_r$ or $t_r + 3$ in. when d exceeds 6 in.

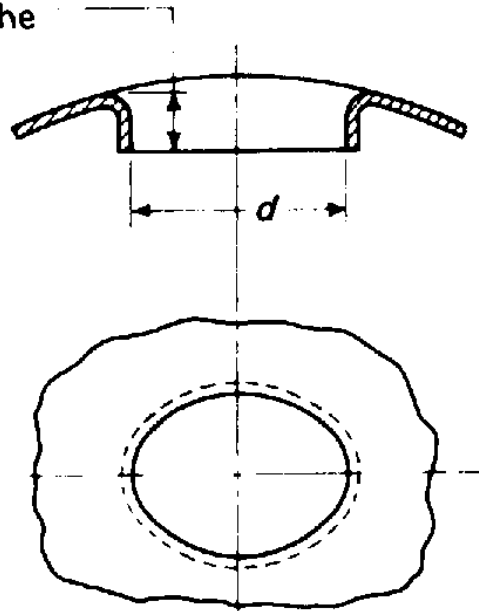


FIG. ND-3335.3(b)-1 MINIMUM DEPTH FOR FLANGE OF FLUED OPENINGS

FIG. ND-3335.3(b)-1 MINIMUM DEPTH FOR FLANGE OF FLUED OPENINGS

ND-3336 Strength of Reinforcement

Material used for reinforcement shall preferably be the same as that of the vessel wall. If the material of the nozzle wall or reinforcement has a lower design stress value S than that for the vessel material, the amount of area provided by the nozzle wall or reinforcement in satisfying the requirements of ND-3332 shall be taken as the actual area provided multiplied by the ratio of the nozzle or reinforcement material design stress value to the vessel material design stress value. No reduction in the reinforcing required may be taken for the increased strength of reinforcing material and weld metal having higher design stress values than that of the material of the vessel wall. Deposited weld metal outside of either the

vessel wall or any reinforcing pad used as reinforcement shall be credited with an allowable stress value equivalent to the weaker of the materials connected by the weld. Vessel-to-nozzle or pad-to-nozzle attachment weld metal within the vessel wall or within the pad may be credited with a stress value equal to that of the vessel wall or pad, respectively.

ND-3336.1 Strength of Weld.

On each side of the plane defined in ND-3334, the strength of the attachment joining the vessel wall and reinforcement or any two parts of the attached reinforcement shall be at least equal to the lesser of (a) or (b) below:

(a) the strength in tension of the cross section of the element of reinforcement being considered;

(b) the strength in tension of the area defined in ND-3332 less the strength in tension of the reinforcing area which is integral in the vessel wall.

ND-3336.2 Strength of Attachment.

The strength of the attachment joint shall be considered for its entire length on each side of the plane of the area of reinforcement defined in ND-3334. For obround openings, consideration shall also be given to the strength of the attachment joint on one side of the plane transverse to the parallel sides of the opening which passes through the center of the semicircular end of the opening.

ND-3350 DESIGN OF WELDED CONSTRUCTION

ND-3351 Welded Joint Categories

The term *Category* defines the location of a joint in a vessel but not the type of joint. The categories are for use in specifying special requirements regarding joint type and method of examination for certain welded joints. Since these special requirements, which are based on service, material, and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in the categories. The special requirements apply to joints of a given category only when specifically stated. The joints included in each category are designated as joints of Categories A, B, C, and D. Figure ND-3351-1 illustrates typical joint locations included in each category.

ND-3351.1 Category A.

Category A comprises longitudinal welded joints within the main shell, communicating chambers,¹² transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head, or within the side plates¹³ of a flat sided vessel; circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameters, to nozzles, or to communicating chambers.

ND-3351.2 Category B.

Category B comprises circumferential welded joints within the main shell, communicating chambers,¹² nozzles, or transitions in diameter, including joints between the transition and a cylinder at either the large or small end; circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers.

¹² Communicating chambers are defined as appurtenances to the vessel which intersect the shell or head of a vessel and form an integral part of the pressure retaining closure, e.g., sumps.

¹³ Side plates of a flat sided vessel are defined as any of the flat plates forming an integral part of the pressure retaining enclosure.

ND-3351.3 Category C.

Category C comprises welded joints connecting flanges, Van Stone laps, tube sheets, or flat heads to main shell, to formed heads, to transitions in diameter, to nozzles or to communicating

chambers;¹² any welded joint connecting one side plate¹³ to another side plate of a flat sided vessel.

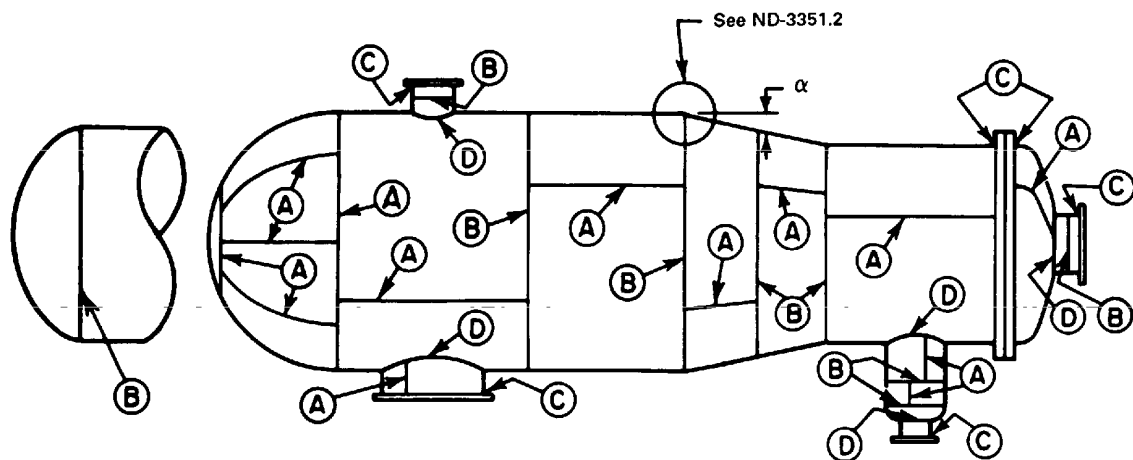


FIG. ND-3351-1 WELDED JOINT LOCATIONS TYPICAL OF CATEGORIES A, B, C, AND D

FIG. ND-3351-1 WELDED JOINT LOCATIONS TYPICAL OF CATEGORIES A, B, C AND D

ND-3351.4 Category D.

Category D comprises welded joints connecting communicating chambers or nozzles to main shells, to spheres, to transitions in diameter, to heads or to flat sided vessels and those joints connecting nozzles to communicating chambers. For nozzles at the small end of a transition in diameter, see Category B.

ND-3352 Permissible Types of Welded Joints

The design of the vessel shall meet the requirements for each category of joint. Butt joints are full penetration joints between plates or other elements that lie approximately in the same plane. Category B angle joints between plates or other elements that have an offset angle α not exceeding 30 deg are considered as meeting the requirements for butt joints. Figure ND-3352-1 shows typical butt welds for each category joint.

[98]

ND-3352.1 Joints of Category A.

All welded joints of Category A as defined in ND-3351 shall meet the fabrication requirements of ND-4241 and shall be capable of being examined in accordance with ND-5210. The joint efficiency E shall not exceed that given in (a) through (e) below.

(a) When the butt weld is fully radiographed in accordance with ND-5211.1(a), E used in the design calculations for determining the thickness of the part shall not exceed 1.00 for Type 1 butt welds and 0.90 for Type 2 butt welds.

(b) When the vessel section or part is spot radiographed in accordance with ND-5211.1(b), the value of E used in the design calculations for determining the thickness of the part shall not exceed 0.85 for Type 1 butt welds and 0.80 for Type 2 butt welds.

(c) When the vessel section or part is neither fully radiographed nor spot radiographically examined as allowed by ND-5211.1(c), the value of E used in the design calculations for determining the thickness of the part shall not exceed 0.70 for Type 1; 0.65 for Type 2; 0.60 for Type 3; 0.55 for Type 4; 0.50 for Type 5; and 0.45 for Type 6 welds. In other cases, the allowable stresses used in the design calculations shall not exceed 80% of the listed values in the stress tables. This 80% factor does not apply to allowable stresses for S_a , S_b , S_p and S_n used in flange design and defined in XI-3130 or for calculating the thickness of braced and stayed surfaces for Eqs. (19) and (20) of ND-3329.1(a). The value of E for

vessels designed for external pressure only may be taken as 1.00.

(d) For vessels constructed of unalloyed titanium, all weld joints of Category A shall be Type 1 or Type 2.

(e) For vessels constructed of SB-443, SB-444, and SB-446, all weld joints of Category A shall be Type 1 or Type 2.
[98]

ND-3352.2 Joints of Category B.

All welded joints of Category B as defined in ND-3351 shall meet the fabrication requirements of ND-4242 and shall be capable of being examined in accordance with ND-5220. The joint efficiency E shall not exceed that given in (a) through (e) below.

(a) When the butt weld is fully radiographed, the design provisions of ND-3352.1(a) shall apply.

Page 93

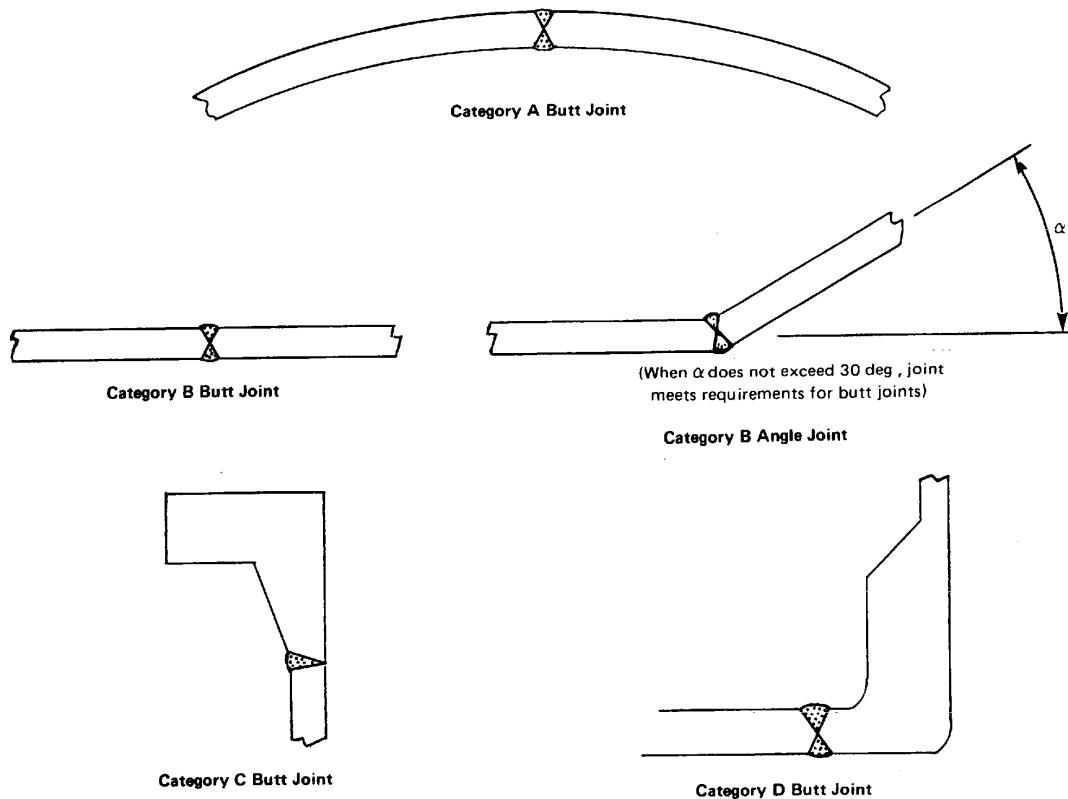


FIG. ND-3352-1 TYPICAL BUTT JOINTS

FIG. ND-3352-1 TYPICAL BUTT JOINTS

(b) When the butt weld is partially radiographed as allowed by ND-5221(b) or when the vessel section or part is spot radiographed in accordance with ND-5221(c), the value of E used in the longitudinal stress calculations shall be as stated in ND-3352.1(b). When seamless vessel sections or heads with Category B butt weld joints are spot radiographed, the allowable stresses used in the design calculations for determining the thickness of the vessel section or part shall not exceed 85% of the values listed in the stress tables. This factor does not apply to allowable stresses for S_a , S_b , S_p and S_n used in flange design and defined in XI-3130 or for calculating the thickness of braced or stayed surfaces for Eqs. (19)

and (20) of ND-3329.1(a).

(c) When the vessel section or part is neither fully radiographed, partially radiographed, nor spot radiographed, the design provisions of ND-3352.1(c) apply.

(d) For vessels constructed of unalloyed titanium, all weld joints of Category B shall be Type 1 or Type 2.

(e) For vessels constructed of SB-443, SB-444, and SB-446, all weld joints of Category B shall be Type 1 or Type 2.

ND-3352.3 Joints of Category C.

All welded joints of Category C as defined in ND-3351 shall meet the fabrication requirements of ND-4243 and shall be capable of being examined in accordance with ND-5230. The design for attaching flanged heads shall meet the requirements of ND-3358. The design requirements of Category C butt welds are given in (a) through (e) below.

Page 94

(a) When a Category C butt weld is fully radiographed, the design provisions of ND-3352.1(a) shall apply.

(b) When a Category C butt weld is spot radiographed, the design provisions of ND-3352.2(b) shall apply.

(c) When a Category C butt weld is not radiographed, the design provisions of ND-3352.1(c) shall apply.

(d) When a Category C corner joint is used, the design requirements of ND-3325 and the dimensional requirements of Fig. ND-4243-1 specified in ND-3358.3 shall be met.

(e) For vessels constructed of SB-443, SB-444, and SB-446, all weld joints of Category C shall be Type 1 or Type 2 when the Design Temperature is 1000°F or higher.

ND-3352.4 Joints of Category D.

All welded joints of Category D as defined in ND-3351 shall be in accordance with the requirements of ND-3359 and one of (a) through (h) below.

(a) *Butt Welded Attachments.* Nozzles shall meet the fabrication requirements of ND-4244(a) and shall be capable of being examined in accordance with ND-5241. The minimum dimensions and geometrical requirements of Fig. ND-4244(a)-1 shall be met, where:

t	= nominal thickness of part penetrated, in.
t_n	= nominal thickness of penetrating part, in.
r_1	= $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2	= $\frac{1}{4}$ in. (6 mm) minimum

(b) *Full Penetration Corner Welded Attachments.* Nozzles shall meet the fabrication requirements of ND-4244(b) and shall be capable of being examined as required in ND-5241. Inserted-type nozzles having added reinforcement in the form of a separate reinforcing plate shall be attached by welds at the outer edge of the reinforcement plate and at the nozzle periphery. The weld at the outer edge of the reinforcement shall be a fillet weld with a minimum throat dimension of $\frac{1}{2}t_{\min}$. The minimum dimensions of Fig. ND-4244(b)-1 shall be met, where:

t	= nominal thickness of part penetrated, in.
t_n	= nominal thickness of penetrating part, in.
t_c	= $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
r_1	= $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2	= $\frac{1}{4}$ in. (6 mm) minimum
t_e	= thickness of reinforcing element, in.

$t_{\min}$	= the lesser of $\frac{3}{4}$ in. (19 mm) or the thickness of the
$t_{\min}$	= the lesser of $\frac{3}{4}$ in. (19 mm) or the thickness of the thinner of the parts joined

(c) *Use of Deposited Weld Metal for Openings and Attachments*

(1) Nozzles shall meet the requirements of ND-4244(c) and shall be capable of being examined in accordance with ND-5241.

(2) When the deposited weld metal is used as reinforcement, the coefficients of thermal expansion of the base metal, the weld metal, and the nozzle shall not differ by more than 15% of the lowest coefficient involved.

(3) The minimum dimensions of Fig. ND-4244(c)-1 shall be met, where:

t	= nominal thickness of part penetrated, in.
t_n	= nominal thickness of penetrating part, in.
t_c	= $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
r_1	= $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less

(4) The corners of the end of each nozzle extending less than $\sqrt{dt_n}$ beyond the inner surface of the part penetrated shall be rounded to a radius of one-half the thickness t_n of the nozzle or $\frac{3}{4}$ in. (19 mm), whichever is less.

(d) *Attachment of Nozzles Using Partial Penetration Welds*

(1) Partial penetration welds shall meet the requirements of ND-4244(d). Typical details are shown in Fig. ND-4244(d)-1. For inserted nozzles without reinforcing elements, two partial penetration welds or a combination of fillet, single bevel, and single J-welds may be used. Inserted-type nozzles having added reinforcement in the form of a separate reinforcing plate shall be attached by welds at the outer edge of the reinforcement plate and at the nozzle periphery. The weld at the outer edge of the reinforcement shall be a fillet weld with a minimum throat dimension of $\frac{1}{2}t_{\min}$. The welds attaching the nozzles to the vessel wall and to the reinforcement shall consist of one of the combinations given in (a) through (c) below.

(a) A single bevel or single J-weld in the shell plate and a single bevel or single J-weld in each reinforcement plate. The dimension t_w of each weld shall be not less than $0.7t_{\min}$ [ND-4244(d)-1].

(b) A full penetration groove weld in the shell plate and a fillet, single bevel, or single J-weld with a weld dimension t_w not less than $0.7t_{\min}$ in each reinforcement plate [Fig. ND-4244(d)-1 sketch (f)].

(c) A full penetration groove weld in each reinforcement plate and a fillet, single bevel, or single J-weld with a weld dimension t_w not less than $0.7t_{\min}$ in the shell plate [Fig. ND-4244(d)-1 sketch (e)]. These welds shall be capable of being examined in accordance with the requirements of ND-5241.

(2) The minimum dimensions of Fig. ND-4244(d)-1 shall be met, where:

$t_1 + t_2$	= $\frac{1}{4}t_{\min}$
-------------	-------------------------

Page 95

t_1 or t_2	= not less than the lesser of $\frac{1}{4}$ in. or $0.7t_{\min}$
$t_{\min}$	= the lesser of $\frac{3}{4}$ in. or the thickness of the thinner of the parts joined
t_e	= thickness of reinforcement element, in.
t	= nominal thickness of part penetrated, in.
t_n	= nominal thickness of penetrating part, in.

$$\begin{aligned}
 t_c &= 0.7t_n \text{ or } 1/4 \text{ in., whichever is less} \\
 c &= 1/2 t_{\min} \\
 t_w &= 0.7t_n \text{ except } t_w = 0.7t_{\min} \text{ for sketch (e)}
 \end{aligned}$$

(e) *Attachment of Fittings With Internal Threads.*¹⁴ The attachment of internally threaded fittings shall meet the requirements of (1) through (3) below.

(1) Except as provided for in (2) and (3) below, the provisions of ND-4244(e) shall be met. The minimum weld dimensions shall be as shown in Fig. ND-4244(e)-1 where:

$$\begin{aligned}
 t_{\min} &= \text{lesser of } 3/4 \text{ in. or the thickness of the parts joined} \\
 t_c &= 1/4 \text{ in., minimum}
 \end{aligned}$$

Sketches (a) and (b):

$$t_1 + t_2 = 1/4 t_{\min}$$

Sketch (c):

$$t_w = \text{thickness of Sch. 160 pipe (ANSI-B36.10)}$$

$$t_1 + t_2 \text{ not less than the lesser of } 1/4 \text{ in. or } 0.7t_{\min}$$

Sketch (d):

$$t_w = 0.7t_{\min}$$

(2) Fittings shown in Fig. ND-4244(e)-1 sketches (a-2), (b-2), (c-2), and (d) not exceeding NPS 3 may be attached by welds that are exempt from size requirements other than those specified in ND-3359.

(3)(a) When internally threaded fittings and bolting pads not exceeding NPS 3 (DN 80) are attached to vessels having a wall thickness not greater than $3/8$ in. (10 mm) by a fillet weld deposited from the outside only, the welds shall comply with the dimensions shown in Fig. ND-4244(e)-2. These openings do not require reinforcement other than that inherent in the construction as permitted in ND-3332.1.

(b) If the opening exceeds $5/8$ in. (136 mm) in any direction or is greater than one-half the vessel diameter, the part of the vessel affected shall be subjected to a proof test as required in ND-6900 or the opening shall be reinforced in accordance with ND-3332 with the nozzle or other connections attached, using a suitable detail in Fig. ND-4244(e)-1.

¹⁴ Written for fittings with internal threads but also applicable to externally threaded and socket or butt welded fittings.

(f) *Attachment of Tubed Connections.* Nozzles or tubes recessed into thick walled vessels or headers, welded from only one side, shall have a welding groove in the vessel wall not deeper than t_n on the longitudinal axis of the opening. A recess $1/16$ in. (1.6 mm) deep shall be provided at the bottom of the groove in which to center the nozzle. The dimension t_w of the attachment weld shall not be less than t_n nor less than $1/4$ in. (6 mm). The minimum dimension for t_c shall be $1/4$ in. (6 mm) [Fig. ND-4244(f)-1 sketches (a) and (b)].

(g) *Nozzles With Integral Reinforcing.* Nozzles and other connections having integral reinforcement in the form of extended nozzles or saddle type pads shall have the throat dimension of the outer weld not less than $1/2 t_{\min}$ [Fig. ND-4244(g)-1]. The dimension t_w of the inner weld shall be not less than $0.7t_{\min}$, where:

$$\begin{aligned}
 t_n &= \text{nominal thickness of neck, in.} \\
 t &= \text{nominal thickness of shell, in.} \\
 t_e &= \text{thickness of reinforcement element, in.} \\
 t_c &= 0.7t_n \text{ or } 1/4 \text{ in. (6 mm), whichever is less}
 \end{aligned}$$

c	$= \frac{1}{2}t_{\min}$
$t_{\min}$	$= \text{lesser of } \frac{3}{4} \text{ in. (19 mm) or the thickness of the thinner of the parts joined}$
t_w	$= 0.7t_{\min}$

(h) For vessels constructed of SB-443, SB-444, and SB-446, all weld joints of Category D shall be Type 1 or Type 2 when the Design Temperature is 1000°F (538°C) or higher.

ND-3354 Structural Attachment Welds

Welds for structural attachments shall meet the requirements of ND-4430.

ND-3355 Welding Grooves

The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration. Qualification of the welding procedure, as required in ND-4000, is acceptable as proof that the welding groove is satisfactory.

ND-3356 Fillet Welds, Lap Joints, and Plug Welds

ND-3356.1 Fillet Welds

(a) Fillet welds may be used as strength welds within the limitations given in ND-3352 and Fig. ND-4427-1. Particular care shall be taken in the layout of joints in which fillet welds are to be used in order to assure complete fusion at the root of the fillet.

(b) Corner or tee joints may be made with fillet welds provided the plates are properly supported independently

Page 96

of such welds, except that independent supports are not required for joints used for lugs or clips.

(c) The allowable load on fillet welds shall equal the product of the weld area based on minimum leg dimensions, the allowable stress value in tension of the material being welded, and a joint efficiency of 0.55.

[98]

ND-3356.2 Lap Joints.

For lap joints, the surface overlap shall be not less than four times the thickness of the inner plate except as otherwise provided for heads in ND-3358 and for tanks in ND-4246.

[98]

ND-3356.3 Plug Welds

(a) Plug welds may be used in lap joints, in reinforcements around openings, and in structural attachments. Plug welds shall be properly spaced to carry no more than 30% of the total load to be transmitted.

(b) Plug weld holes shall have a diameter not less than $t + \frac{1}{4}$ in. and not more than $2t + \frac{1}{4}$ in., where t is the thickness in inches of the plate or attached part in which the hole is made.

(c) Plug weld holes shall be completely filled with weld metal when the thickness of the plate or attached part in which the weld is made is $\frac{5}{16}$ in. (8 mm) or less; for thicker plates or attached parts, the holes shall be filled to a depth of at least half the plate thickness or $\frac{5}{16}$ of the hole diameter, whichever is larger, but in no case less than $\frac{5}{16}$ in. (8 mm).

(d) The allowable load on a plug weld in either shear or tension shall be computed by the following equation:

$$P = 0.63S(d - \frac{1}{4})^2$$

where

P	= total allowable load on the plug weld, lb
d	= the bottom diameter of the hole in which the weld is made, in.
S	= maximum allowable stress, psi (Tables 1A and 1B, Section II, Part D, Subpart 1)

ND-3357 Welded Joints Subject to Bending Stresses

Except where specific details are permitted in other paragraphs, fillet welds shall be added where necessary to reduce stress concentration. Corner joints, with fillet welds only, shall not be used unless the plates forming the corner are properly supported independently of such welds [ND-3356.1(b)].

ND-3358 Design Requirements for Head Attachments

ND-3358.1 Skirt Length of Formed Heads

(a) Ellipsoidal and other types of formed heads, concave or convex to the pressure, shall have a skirt length not less than that shown in Fig. ND-3358.1(a)-1. Heads that are fitted inside or over a shell shall have a driving fit before welding.

(b) A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections as shown in Fig. ND-3358.1(a)-1 shall be provided at joints between formed heads and shells that differ in thickness by more than one-fourth the thickness of the thinner section or by more than $\frac{1}{8}$ in. (3.2 mm), whichever is less. When a taper is required on any formed head thicker than the shell and intended for butt welded attachment [Fig. ND-3358.1(a)-1], the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.

(c) All formed heads concave to pressure and intended for butt welded attachment need not have an integral skirt when the thickness of the head is equal to or less than the thickness of the shell. When a skirt is provided, its thickness shall be at least that required for a seamless shell of the same diameter.

ND-3358.2 Unstayed Flat Heads Welded to Shells.

The requirements for the attachment of unstayed flat heads welded to shells are given in ND-3325, ND-3358.3, and ND-3358.6.

ND-3358.3 Head Attachments Using Corner Joints.

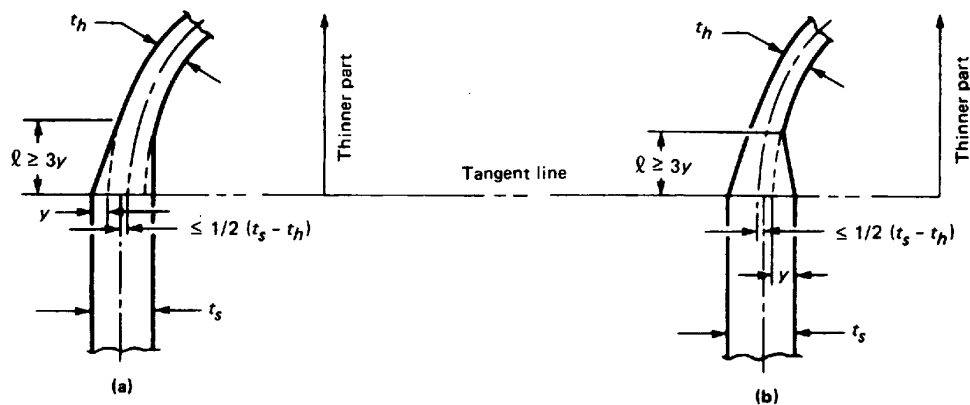
When shells, heads, or other pressure parts are welded to a forged or rolled plate to form a corner joint, as in Fig. ND-4243-1, the joint shall meet the requirements of (a) through (f) below.

(a) On the cross section through the welded joint, the line of fusion between the weld metal and the forged or rolled plate being attached shall be projected on planes both parallel to and perpendicular to the surface of the plate being attached, in order to determine the dimensions a and b , respectively.

(b) For flange rings of bolted flanged connections and for flat heads and unsupported tube sheets with a projection having holes for a bolted connection, the sum of a and b shall be not less than three times the nominal wall thickness of the abutting pressure part.

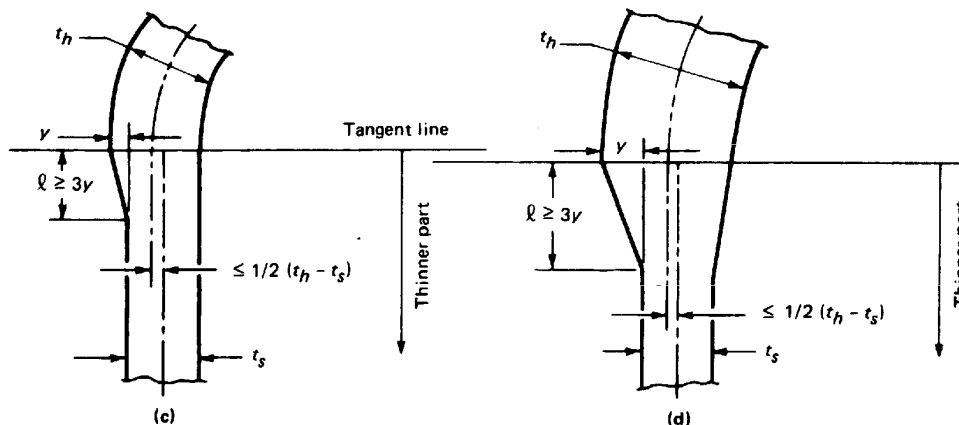
(c) For supported tube sheets with a projection having holes for a bolted connection, the sum of a and b shall not be less than two times the nominal wall thickness of the abutting pressure part. A supported tubesheet is defined as one in which not less than 80%

of the pressure load on the tubesheet is carried by tubes, stays, or braces.



GENERAL NOTES [sketches (a) and (b)]:

- (a) Length of required taper ℓ may include the width of the weld.
- (b) In all cases, the projected length of taper ℓ shall be not less than $3y$.
- (c) The shell plate center line may be on either side of the head plate center line.



GENERAL NOTES [sketches (c) and (d)]:

- (a) In all cases ℓ shall be not less than 3 times y when t_h exceeds $1.25 t_s$; minimum length of skirt is $3 t_h$, but need not exceed 1-1/2 in. except when necessary to provide required length of taper.
- (b) When t_h is equal to or less than $1.25 t_s$, length of skirt shall be sufficient for any required taper.
- (c) Length of required taper ℓ may include the width of the weld.
- (d) The shell plate center line may be on either side of the head plate center line.

FIG. ND-3358.1(a)-1 HEADS ATTACHED TO SHELLS

FIG. ND-3358.1(a)-1 HEADS ATTACHED TO SHELLS

(d) For other components, the sum of a and b shall be not less than two times the nominal wall thickness of the abutting pressure part. Examples of such components are flat heads and supported and unsupported tubesheets without a projection having holes for a bolted connection and the side plates of a rectangular vessel.

(e) Other dimensions at the joint shall be in accordance with details as shown in Fig. ND-4243-1:

(1) sketch (a):

$$a + b \text{ not less than } 2t_s, (b = 0)$$

$$t_w \text{ not less than } t_s$$

$$t_s = \text{actual thickness of shell, in.}$$

(2) sketch (b):

$$a + b \text{ not less than } 2t_s$$

$$t_w \text{ not less than } t_s$$

$$t_p \text{ not less than } t_s$$

$$t_s = \text{actual thickness of shell, in.}$$

(3) sketch (c):

$$a + b \text{ not less than } 2t_s$$

$$a \text{ not less than } t_s$$

$$t_p \text{ not less than } t_s$$

$$t_s = \text{actual thickness of shell, in.}$$

(4) sketch (d):

$$a + b \text{ not less than } 2t_s$$

$$a \text{ not less than } t_s$$

$$t_p \text{ not less than } t_s$$

$$t_s = \text{actual thickness of shell, in.}$$

(5) sketch (e):

$$a + b \text{ not less than } 2t_s, (b = 0)$$

$$t_s = \text{actual thickness of shell, in.}$$

(6) sketch (f):

$$a + b \text{ not less than } 2t_s$$

$$t_s = \text{actual thickness of shell, in.}$$

(7) sketch (g):

$$a + b \text{ not less than } 2t_s$$

$$a_1 \text{ not less than } 0.5a_2 \text{ nor greater than } 2a_2$$

$$a_1 + a_2 = a$$

$$t_s = \text{actual thickness of shell, in.}$$

(8) sketches (h) through (j):

$$t_r = \text{required thickness of shell, in.}$$

$$c = 0.7t_s$$

$t_w = 2t_r$ but not less than $1.25t_s$

t_w need not be greater than t

t_s = actual thickness of shell, in.

(9) sketches (k) through (o):

(a) for supported tubesheets:

$a + b$ not less than $2t_s$

c not less than $0.7t_s$ or $1.4t_r$, whichever is less

a_1 not less than $0.5a_2$

t_s = actual thickness of shell, in.

(b) for flange rings, flat heads, and unsupported tubesheets:

$a + b$ not less than $3t_s$

c not less than t_s or $2t_r$, whichever is less

a_1 not less than $0.5a_2$

t_s = actual thickness of shell, in.

(10) sketch (p):

a not less than $3t_r$ ($b = 0$)

c not less than t_n or t_D^{15} whichever is less

(11) sketch (q):

$a + b$ not less than $3t_n$

c not less than t_n or t_D^{15} whichever is less

(f) Joint details that have a dimension through the joint less than the thickness of the shell, head, or other pressure part, or that provide eccentric attachment, are not permissible [Fig. ND-4243-1 sketches (r), (s), and (t)].

ND-3358.4 Intermediate Heads

(a) Intermediate heads of the type shown in Fig. ND-4245-1 sketch (f), without limit to thickness, may be used for all types of vessels provided that the outside diameter of the head skirt is a close fit inside the overlapping ends of the adjacent length of cylinder.

(b) The butt weld and fillet weld shall be designed to take shear based on 1.5 times the maximum differential pressure that can exist. The allowable stress value for the butt weld shall be 70% of the stress value for the vessel material, and the allowable value for the fillet weld shall be 55% of the stress value for the vessel material. The area of the fillet weld is the minimum leg dimension times the length of the weld. The area of the butt weld in shear is the smaller of the width at the root of the weld or the thickness of the vessel shell to which it is attached times the length of the weld.

(c) This construction may also be used for end closures when the thickness of the shell section of the vessel does not exceed $\frac{5}{8}$ in. (16 mm).

ND-3358.5 Heads Concave to Pressure.

Heads concave to pressure may be attached to shells using a butt weld with one plate offset as shown in Fig. ND-4245-1 sketch (k). The offset shall be smooth and symmetrical, and shall not be machined or otherwise reduced in thickness. There shall be a uniform force fit with the mating section at the root of the weld.

ND-3358.6 Flat Heads and Tubesheets With Hubs.

Hubs for butt welding to the adjacent shell, head, or other pressure part, as in Fig. ND-4243.1-1, shall not be machined from rolled plate. The component having

Page 99

the hub shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material, in a direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension test specimen (subsize if necessary) taken in this direction and as close to the hub as is practical.

In Fig. ND-4243.1-1, the minimum dimensions are as follows:

(a) sketch (a):

r not less than $1.5t_s$

(b) sketch (b):

r not less than $1.5t_s$

e not less than t_s

(c) sketch (c):

h not less than $1.5t_s$

(d) sketch (d):

t_f not less than $2t_s$

r not less than $3t_f$

(e) sketch (e):

t_f not less than $2t_s$

r not less than $3t_f$

e not less than t_f

ND-3359 Design Requirements for Nozzle Attachment Welds

In addition to the requirements of ND-3352.4, the minimum design requirements for nozzle attachment welds are given in (a) and (b) below.

(a) *Required Weld Strength.* Sufficient welding shall be provided on either side of the line through the center of the opening parallel to the longitudinal axis of the shell to develop the strength of the reinforcing parts as required in ND-3336, through shear or tension in the weld, whichever is applicable. The strength of groove welds shall be based on the area subjected to shear or to tension. The strength of fillet welds shall be based on the area subjected to shear, computed on the minimum leg dimension. The inside diameter of a fillet weld shall be used in figuring its length. Calculations are not required when full penetration welds are used.

(b) *Allowable Stress Values for Welds.* The allowable stress values for groove and fillet welds and for shear in nozzles, in percentage of stress values for the vessel material, are as follows:

Nozzle wall shear	70%
Groove weld tension	74%
Groove weld shear	60%
Fillet weld shear	49%

ND-3360 SPECIAL VESSEL REQUIREMENTS

ND-3361 Tapered Transitions, Staggered Welds, and Threaded Connections

ND-3361.1 Tapered Transitions.

A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections (Fig. ND-3361.1-1) shall be provided at joints between sections that differ in thickness by more than one-fourth of the thickness of the thinner section or by more than $\frac{1}{8}$ in. (3.2 mm), whichever is less. The transition may be formed by any process that will provide a uniform taper. The weld may be in the tapered section or adjacent to it. This paragraph also applies when there is a reduction in thickness within a spherical shell or cylindrical shell course and to a taper at a Category A joint within a formed head. Provisions for tapers at circumferential butt welded joints connecting formed heads to main shells are contained in ND-3358.1(b).

ND-3361.2 Staggered Welds.

Except when radiographed 4 in. each side of each welded intersection, vessels made up of two or more courses shall have the centers of the welded longitudinal joints of adjacent courses staggered or separated by a distance of at least five times the thickness of the thicker plate.

ND-3361.3 Threaded Connections

(a) Pipes, tubes, and other threaded connections that conform to ANSI B2.1, Pipe Threads, may be screwed into a threaded hole in a vessel wall provided the pipe engages the minimum number of threads specified in Table ND-3361.3(a)-1 after allowance has been made for curvature of the vessel wall. A built-up pad or a properly attached plate or fitting may be used to provide the metal thickness and number of threads required in Table ND-3361.3(a)-1, or to furnish reinforcement when required.

(b) Threaded connections larger than NPS 3 (DN 80) shall not be used when the maximum allowable pressure exceeds 125 psi (861 kPa), except that this NPS 3 (DN 80) restriction does not apply to plug closures used for inspection openings, end closures, or similar purposes.

ND-3362 Bolted Flange and Studded Connections

(a) It is recommended that the dimensional requirements of bolted flange connections to external piping conform to ANSI Standard B16.5, Steel Pipe Flanges and Flanged Fittings; ANSI B16.24, Brass or Bronze

Page 100

and Flanged Fittings 150 and 300 lb; MSS SP-42, 150 lb Corrosion Resistant Cast Flanged Valves; or to API Standard 605, Large Diameter Carbon Steel Flanges. Such flanges and flanged fittings may be used for the pressure-temperature ratings given in the appropriate standard. Flanges and flanged fittings to other standards are acceptable provided they have been designed in accordance with the rules of Appendix XI for the vessel design loadings and are used within the pressure-temperature ratings so determined.

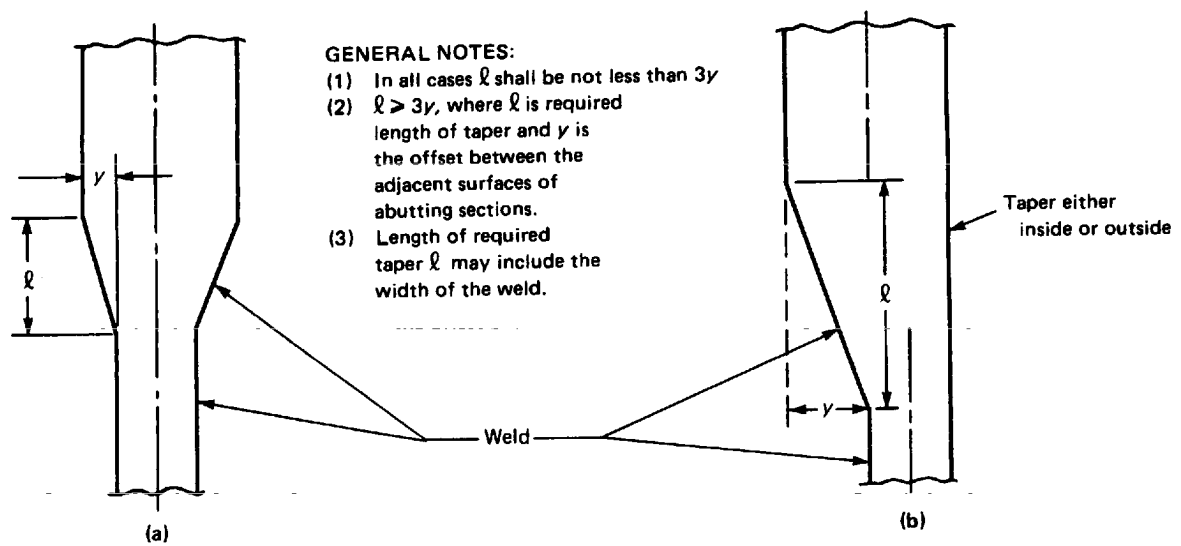


FIG. ND-3361.1-1 BUTT WELDING OF PLATES OF UNEQUAL THICKNESSES

FIG. ND-3361.1-1 BUTT WELDING OF PLATES OF UNEQUAL THICKNESSES

TABLE ND-3361.3(a)-1
MINIMUM NUMBER OF PIPE THREADS FOR CONNECTIONS

Size of pipe connections, in.	$\frac{1}{2}, \frac{3}{4}$	1, $1\frac{1}{4}$, $1\frac{1}{2}$	2	$2\frac{1}{2}$, 3	4-6	8	10	12
Threads engaged	6	7	8	8	10	12	13	14
Min. plate thickness required, in.	0.43	0.61	0.70	1.0	1.25	1.5	1.62	1.75

TABLE ND-3361.3(a)-1 MINIMUM NUMBER OF PIPE THREADS FOR CONNECTIONS

(b) Where tapped holes are provided for studs, the threads shall be full and clean and shall engage the stud for a length not less than the larger of d_s or:

$$0.75d_s \times \frac{\text{Maximum allowable stress value of stud material at Design Temperature}}{\text{Maximum allowable stress value of tapped material at Design Temperature}}$$

in which d_s is the diameter of the stud. The thread engagement need not exceed $1\frac{1}{2}d_s$.

ND-3363 Access or Inspection Openings¹⁶

ND-3363.1 General Requirements

(a) All vessels for use with compressed air, except as otherwise permitted, and those subject to internal corrosion or having parts subject to erosion or mechanical abrasion (ND-3121), shall be provided with suitable manhole, handhole, or other inspection openings for examination and cleaning.

16 All dimensions given, for size of vessel on which inspection openings are required, are nominal.

(b) Vessels over 12 in. (305 mm) inside diameter under air pressure which also contain other substances which will prevent corrosion need not have openings for inspection only, providing the vessel contains suitable

Page 101

openings through which inspection can be made conveniently and providing such openings are equivalent in size and number to the requirements for inspection openings in ND-3363.3.

(c) Compressed air is not intended to include air which has had moisture removed to the degree that it has an atmospheric dew point of -50°F (+46°C) or less. The Certificate Holder's Data Report shall include a statement for "noncorrosive service" when inspection openings are not provided.

(d) When provided with telltale holes complying with the provisions of (e) below, inspection openings as required in ND-3363 may be omitted in vessels subject only to corrosion. This provision does not apply to vessels for compressed air.

(e) Telltale holes may be used to provide some positive indication when the thickness has been reduced to a dangerous degree. When telltale holes are provided they shall be at least $\frac{3}{16}$ in. (4.8 mm) in diameter and have a depth not less than 80% of the thickness required for a seamless shell of like dimensions. These holes shall be provided in the surface opposite to that where deterioration is expected.

ND-3363.2 Requirements for Vessels 12 in. (305 mm) Inside Diameter and Smaller.

For vessels 12 in. (305 mm) or less inside diameter, openings for inspection only may be omitted if there are at least two removable pipe connections not less than NPS $\frac{3}{4}$ (DN 20).

ND-3363.3 Requirements for Vessels Over 12 in. (305 mm), but Not Over 16 in. (406 mm) Inside Diameter.

Vessels over 12 in. (305 mm), but not over 16 in. (406 mm) inside diameter, that are to be installed so that they may be

disconnected from an assembly to permit inspection, need not be provided with openings for inspection only, if there are at least two removable pipe connections not less than NPS 1½ (DN 40).

ND-3363.4 Equipment of Vessels Requiring Access or Inspection Openings.

Vessels that require access or inspection openings shall be equipped as required in (a) through (f) below.

(a) All vessels less than 18 in. (457 mm) and over 12 in. (305 mm) inside diameter shall have at least two handholes or two plugged, threaded inspection openings of not less than NPS 1½ (DN 40).

(b) All vessels 18 in. to 36 in. (457 mm to 914 mm), inclusive, inside diameter shall have a manhole or at least two handholes or two threaded pipe plug inspection openings of not less than NPS 2 (DN 50).

(c) All vessels over 36 in. (914 mm) inside diameter shall have a manhole, except that those whose shape or use makes one impracticable shall have at least two handholes 4 in. × 6 in. (102 mm × 152 mm) or two equal openings of equivalent areas.

(d) When handholes or pipe plug openings are permitted for inspection openings in place of a manhole, one handhole or one pipe plug opening shall be in each head or in the shell near each head.

(e) Openings with removable heads or cover plates intended for other purposes may be used in place of the required inspection openings provided they are equal at least to the size of the required inspection openings.

(f) A single opening with removable head or cover plate may be used in place of all the smaller inspection openings provided it is of such size and location as to afford at least an equal view of the interior.

ND-3363.5 Size and Type of Access and Inspection Openings.

When inspection or access openings are required, they shall comply at least with the requirements of (a) and (b) below.

(a) An elliptical or obround manhole shall be not less than 11 in. × 15 in. (280 mm × 381 mm) or 10 in. × 16 in. (254 mm × 406 mm). A circular manhole shall be not less than 15 in. (381 mm) inside diameter.

(b) A handhole opening shall be not less than 2 in. × 3 in. (51 mm × 76 mm), but should be as large as is consistent with the size of the vessel and the location of the opening.

ND-3363.6 Design of Access and Inspection Openings in Shells and Heads.

All access and inspection openings in a shell or unstayed head shall be designed in accordance with the rules for openings.

ND-3363.7 Minimum Gasket Bearing Width for Manhole Cover Plates.

Manholes of the type in which the internal pressure forces the cover plate against a flat gasket shall have a minimum gasket bearing width of 1½ in. (38 mm).

ND-3363.8 Threaded Openings.

When a threaded opening is to be used for inspection or cleaning purposes, the closing plug or cap shall be of a material suitable for the pressure and no material shall be used at a temperature exceeding the maximum temperature allowed for that material. The thread shall be a standard taper pipe thread, except that a straight thread of equal strength may be used if other sealing means to prevent leakage are provided.

ND-3364 Attachments

Attachments used to transmit support loads shall meet the requirements of ND-3135.

Page 102

ND-3365 Supports

All vessels shall be so supported and the supporting members shall be arranged or attached to the vessel wall in such a way as to withstand the maximum imposed loadings (ND-3111 and Subsection NF).

ND-3366 Bellows Expansion Joints

Expansion joints of the bellows type may be used to provide flexibility for vessels. Expansion joints in piping portions of vessels shall meet the requirements of ND-3649. The design, material, fabrication, examination, and testing of expansion joints which are constructed as a part or appurtenance of a vessel shall conform with the requirements of (a) through (i) below.

(a) Bellows may be used to absorb axial movement, lateral deflection, angular rotation, or any combination of these movements. They are not normally designed for absorbing torsion. The layout, anchorage, guiding, and support shall be such as to avoid the imposition of motions or forces on the bellows other than those for which they have been designed.

(b) In all systems containing bellows, the hydrostatic end force caused by either or both pressure or the bellows spring force shall be resisted by rigid anchors, cross connections of the expansion joint ends, or other means.

(c) The expansion joint shall be installed in such locations as to be accessible for scheduled inspection, where applicable.

(d) The joints shall be provided with bars or other suitable members for maintaining the proper face-to-face dimension during shipment and installation. Bellows shall not be extended or compressed to make up deficiencies in length or offset to accommodate connecting parts which are not properly aligned unless such movements have been specified by the system designer or can be justified by the expansion joint manufacturer.

(e) The expansion joints shall be marked to show the direction of flow, if applicable, and shall be installed in accordance with this marking.

(f) Internal sleeves shall be provided for expansion joints over 6 in. in diameter when flow velocities exceed the following values:

(1) air, steam, and other gases - 25 ft/sec (9.6 m/s);

(2) water and other liquids - 10 ft/sec (3.0 m/s).

(g) Pressure retaining material in the expansion joint shall comply with the requirements of ND-2000.

(h) All welded joints shall comply with the requirements of ND-4400.

(i) Design of bellows-type expansion joints shall comply with the requirements of ND-3649.4.

ND-3400 PUMP DESIGN

ND-3410 GENERAL REQUIREMENTS FOR CENTRIFUGAL PUMPS

ND-3411 Scope

ND-3411.1 Applicability.

The rules of ND-3400 apply to (a) through (j) below:

(a) pump casings;

(b) pump inlets and outlets;

(c) pump covers;

(d) clamping rings;

(e) seal housings, seal glands, and packing glands;

(f) related bolting;

(g) pump internal heat exchanger piping;

(h) pump auxiliary nozzle connections up to the face of the first flange or circumferential joint in welded connections, excluding the connecting weld;

(i) piping identified with the pump and external to and forming part of the pressure retaining boundary, and supplied with the pump;

(j) external and internal integral attachments to the pressure retaining boundary;

Hydrostatic test of seal glands and packing glands is not required.

[98]

ND-3411.2Exemptions.

The rules of ND-3400 do not apply to (a) through (c) below:

(a) pump shafts and impellers; shafts may be designed in accordance with Appendix S

(b) nonstructural internals

(c) seal packages

[98]

ND-3412 Acceptability

The requirements for the design of pumps are given in (a) and (b) below.

(a) The design shall be such that the requirements of ND-3100 are satisfied.

(b) The rules of this Subarticle shall be met.

ND-3413 Design Specifications

Design and Service Conditions (NCA-2142) shall be stipulated in the Design Specification (NCA-3250). Loads from thermal expansion, dead weight, and applicable seismic forces from the connected piping shall be included in the Design Specification.

TABLE ND-3416-1
STRESS AND PRESSURE LIMITS FOR DESIGN AND
SERVICE LOADINGS

Service Limits	Stress Limits ¹	$P_{\max}$ ²
Design and Level A	$\sigma_m \leq S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5S$	1.0
Level B	$\sigma_m \leq 1.1S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65S$	1.1
Level C	$\sigma_m \leq 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$	1.2
Level D	$\sigma_m \leq 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$	1.5

NOTES:

- (1) These requirements for acceptability of pump design are not intended to assure the operability of the pump.
- (2) The maximum pressure shall not exceed the tabulated factors listed under $P_{\max}$ times the Design Pressure.

TABLE ND-3416-1 STRESS AND PRESSURE LIMITS FOR DESIGN AND SERVICE LOADINGS

ND-3414 Design and Service Loadings

The general design considerations, including definitions, of ND-3100 plus the requirements of ND-3320, ND-3330, ND-3361, and ND-3362, are applicable to pumps. The pump shall conform to the requirements of ND-3400. The stress limits listed in ND-3416 shall be used for the specified Design and Service Conditions. Classical bending and direct stress equations, where free body diagrams determine a simple stress distribution that is in equilibrium with the applied loads, or any design equations, which have been demonstrated to be satisfactory may be used.

ND-3415 Loads From Connected Piping

Loads imposed on pump inlets and outlets by connected piping shall be considered in the pump casing design.

17 Stress means the maximum normal stress.

ND-3416 Stress and Pressure Limits for Design and Service Loadings

Stress¹⁷ limits for Design and Service Loadings are specified in Table ND-3416-1. The symbols used in Table ND-3416-1 are defined as follows:

σ_m	= general membrane stress, ksi. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.
σ_L	= local membrane stress, ksi. This stress is the same as σ_m , except that it includes the effect of discontinuities.
σ_b	= bending stress, ksi. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.
S	= allowable stress, ksi, given in Tables 1A and 1B, Section II, Part D, Subpart 1. The allowable stress shall correspond to the highest metal temperature of the section under consideration during the condition under consideration.

ND-3417 Earthquake Loadings

(a) The effects of earthquake shall be considered in the design of pumps, pump supports, and restraints. The stresses resulting from these earthquake effects shall be included with the stresses resulting from pressure or other applied loads.

(b) Where pumps are provided with drivers on extended supporting structures and these structures are essential to maintaining pressure integrity, an analysis shall be performed when required by the Design Specifications.

ND-3418 Corrosion

The requirements of ND-3121 apply.

ND-3419 Cladding

Cladding design dimensions used in the design of pumps shall be as required in ND-3122.

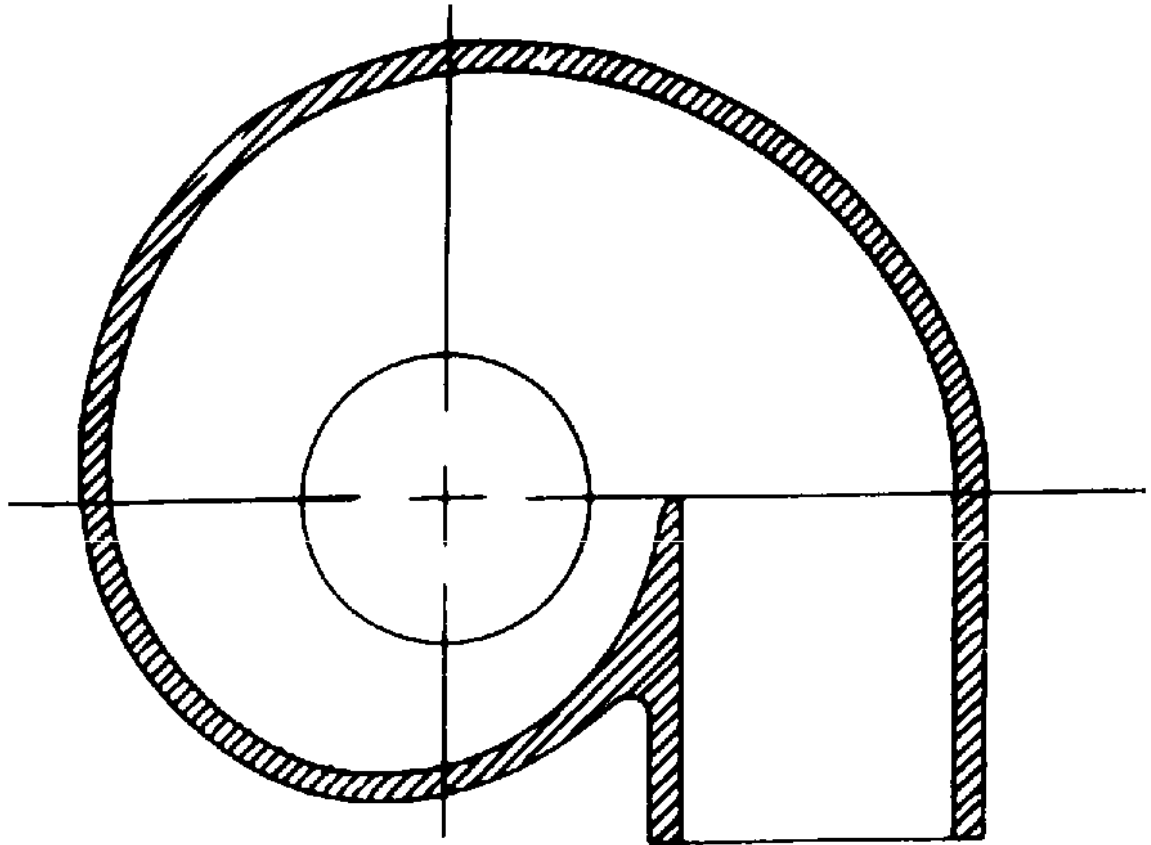
ND-3420 DEFINITIONS

ND-3421 Radially Split Casing

A radially split casing shall be interpreted as one in which the primary sealing joint is radially disposed around the shaft.

ND-3422 Axially Split Casing

An axially split casing shall be interpreted as one in which the primary sealing joint is axially disposed with respect to the shaft.



**FIG. ND-3423-1 TYPICAL SINGLE
VOLUTE CASING**

FIG. ND-3423-1 TYPICAL SINGLE VOLUTE CASING

ND-3423 Single and Double Volute Casings

Figures ND-3423-1 and ND-3423-2 show typical single and double volute casings, respectively.

ND-3424 Seal Housing

A *seal housing* is defined as that portion of the pump cover or casing assembly which contains the seal and forms a part

of the primary pressure boundary.

ND-3425 Typical Examples of Pump Types

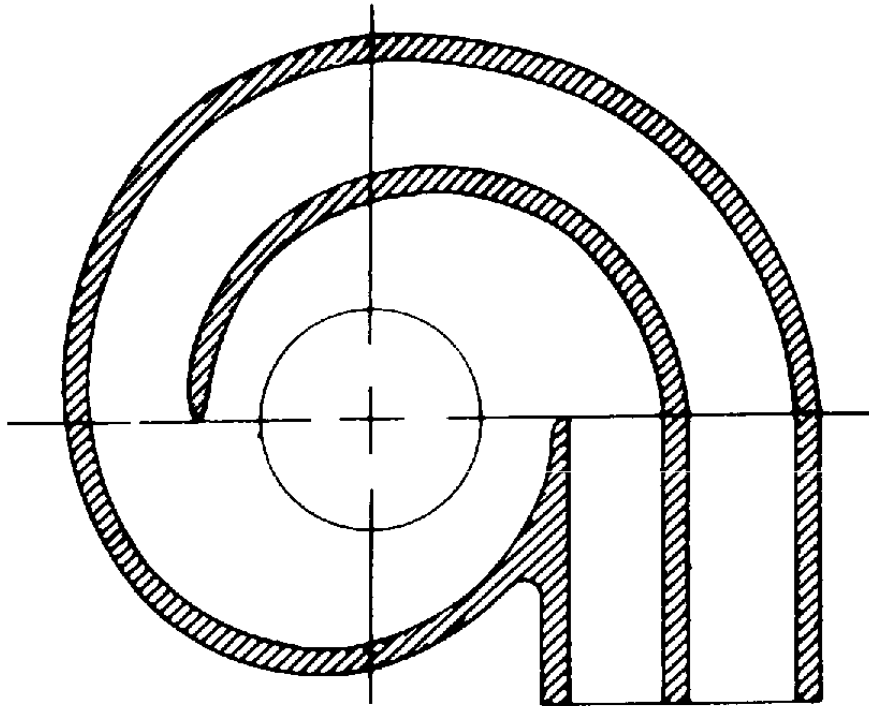
Figures ND-3441.1-1 through ND-3441.9-2 are intended to be typical examples to aid in the determination of a pump type and are not to be considered as limiting. Bearing locations and inlet and outlet orientations are optional.

ND-3430 DESIGN REQUIREMENTS FOR CENTRIFUGAL PUMPS

ND-3431 Design of Welded Construction

(a) The design of welded construction shall be in accordance with ND-3350.

(b) Partial penetration welds, as shown in Fig. ND-4244(e)-1 sketch (c-3) and Fig. ND-4244(f)-1 sketches (a) and (b), are allowed for nozzles such as vent and drain connections and openings for instrumentation. Nozzles shall not exceed NPS 2 (DN 50). For such nozzles, all reinforcement shall be integral with the portion of the shell penetrated. Partial penetration welds shall be of sufficient size to develop the full strength of the nozzles.



**FIG. ND-3423-2 TYPICAL DOUBLE
VOLUTE CASING**

ND-3432 Flanged Connections

[98]

ND-3432.1 Pressure Design

(a) Pumps with flanged connections that are cast integrally with the casing and meet all dimensional requirements (including tolerances) of flanged fittings (as shown in Table ND-3132-1) with regard to the flange dimensions and required wall thicknesses, shall be considered to meet the pressure design requirements of this subarticle and are suitable for use within the pressure-temperature range shown in Appendix I for the material utilized.

(b) Flanged connections not meeting the requirements of (a) shall be designed in accordance with XI-3000 or L-3000.

(c) Pump flanges meeting all requirements of Table ND-3132-1 and welded onto the integral inlets and outlets of the casing, shall be considered as meeting the pressure design requirements of this subarticle,

Page 105

provided that the inlet and outlet wall thicknesses comply with the standard flanged fitting. However, the nozzle-to-flange welds shall meet the requirements of ND-1130.

[98]

ND-3432.2 External Loads.

When external nozzle loads interact with pumps, it is very likely that operability will dictate the maximum allowable loads. The major areas of concern are distortion of the casing and misalignment of driver and driven equipment. The casing shall be capable of withstanding the external loading plus the design pressure, provided in the Design Specification, without distortion that would impair the operation of the pump. In addition, the pump supports shall be capable of accommodating the external loads without sustaining any significant displacements that would cause unacceptable misalignment of rotating parts.

(a) Flanged connections meeting the requirements of ND-3432.1 do not require further analysis when all requirements of ND-3658.2 or ND-3658.3 are met. All other flanged connections shall all meet the requirements of ND-3432.2(b) below.

(b) Flanged connections shall meet the requirements of ND-3658.1.

ND-3433 Reinforcement of Pump Casing Inlets and Outlets

ND-3433.1 Axially Oriented Inlets and Outlets

(a) An axially oriented pump casing inlet or outlet shall be considered similar to an opening in a vessel and shall be reinforced. It shall be treated as required in ND-3330.

(b) To avoid stress concentrations, the outside radius r_2 of Figs. ND-3441.1(a)-1 and ND-3441.3-2 shall not be less than one-half the thickness of the inlets and outlets as reinforced.

ND-3433.2 Radially Oriented Inlets and Outlets.

Reinforcement of radially oriented inlets and outlets is required. The applicable portions of ND-3330 shall apply.

ND-3433.3 Tangential Inlets and Outlets.

Except as modified in ND-3433.4, any design method which has been demonstrated to be satisfactory for the specified Design Loadings may be used.

ND-3433.4 Minimum Tangential Inlet and Outlet Wall Thicknesses.

In Fig. ND-3433.4-1, the value of l , in., shall be determined from the relationship:

In Fig. ND-3433.4-1, the value of l , in., shall be determined from the relationship:

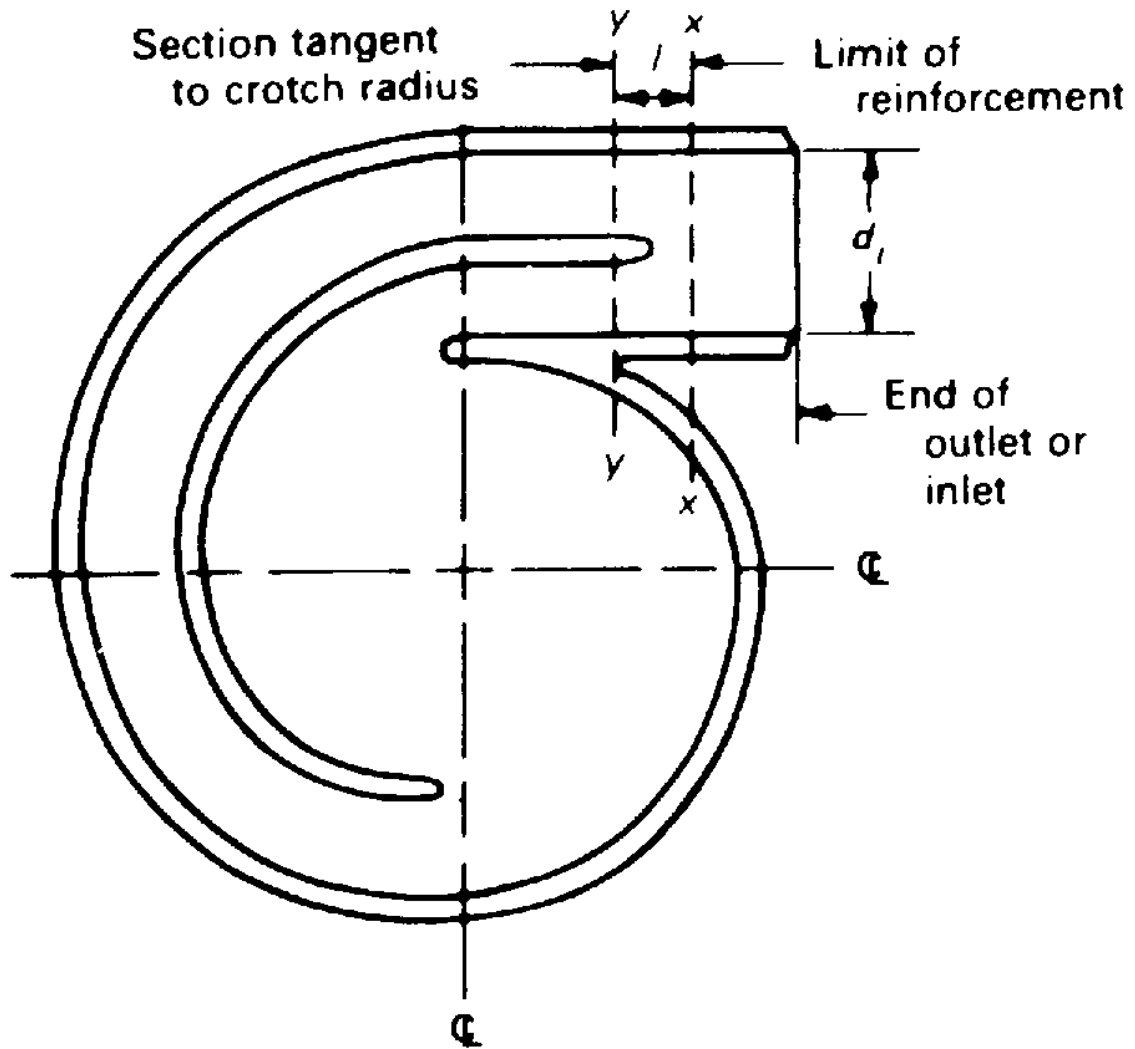


FIG. ND-3433.4-1 MINIMUM TANGENTIAL INLET AND OUTLET WALL THICKNESSES

FIG. ND-3433.4-1 MINIMUM TANGENTIAL INLET AND OUTLET WALL THICKNESSES

$$l = 0.5 \sqrt{r_m t_m}$$

where

$$r_m = r_i + 0.5 t_m \text{ in.}$$

r_i

= maximum inlet or outlet inside radius, in.

$$= d_i/2$$

 t_m

= mean inlet or outlet wall thickness, in., taken between section x-x and a parallel section y-y tangent to crotch radius

The wall thicknesses of the inlet and outlet shall not be less than the minimum wall thickness of the casing for a distance l as shown in Fig. ND-3433.4-1. The wall thickness beyond the distance l may be reduced to the minimum wall thickness of the connected piping. The change in wall thickness shall be gradual and have a maximum slope as indicated in Fig. ND-4250-1.

ND-3434 Bolting

ND-3434.1 Radially Split Configurations.

Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with the procedure described in Appendix XI. Bolting requirements for Type K pumps are given in ND-3441.9(a)(3) and (b)(1) and for Type L pumps in ND-3441.10(b) and (c).

Page 106

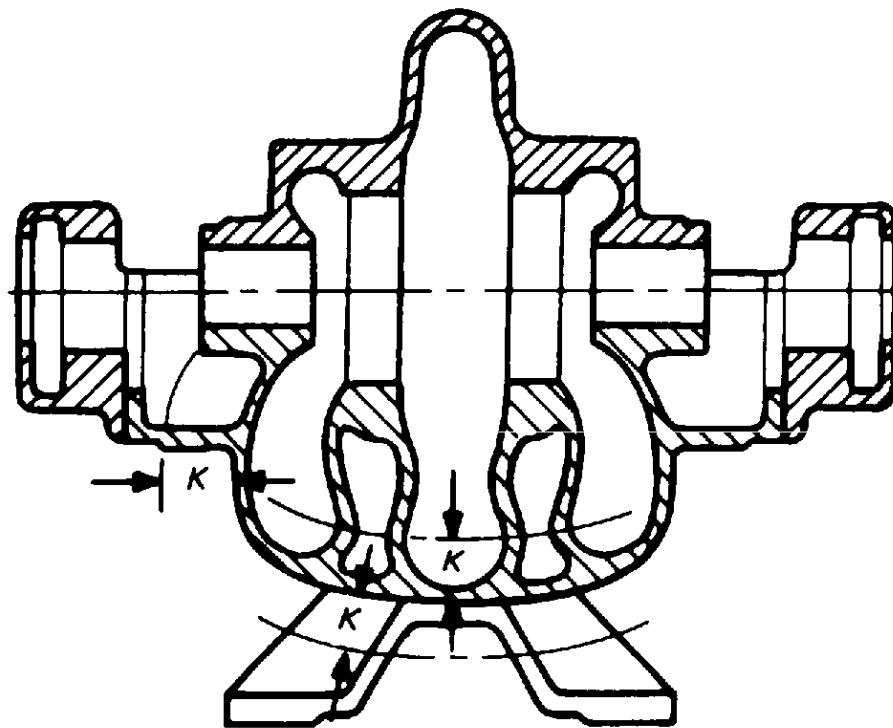


FIG. ND-3436(c)-1 EXTERNAL
AND INTERNAL ATTACHMENTS

FIG. ND-3436(c)-1 EXTERNAL AND INTERNAL ATTACHMENTS

ND-3434.2 Axially Split Configurations.

Bolting in axially split configurations shall be designed in accordance with the procedure given in ND-3441.7 for Type G pumps.

ND-3435 Piping

ND-3435.1 Piping Under External Pressure.

Piping located within the pressure retaining boundary of the pump shall be designed in accordance with ND-3640.

ND-3435.2 Piping Under Internal Pressure.

Piping identified with the pump and external to or forming a part of the pressure retaining boundary, such as auxiliary water connections, shall be designed in accordance with ND-3640.

ND-3436 Attachments

(a) External and internal attachments to pumps shall be designed so as not to cause excessive localized bending stresses or harmful thermal gradients in the pump. The effects of stress concentrations shall be considered.

(b) Attachments shall meet the requirements of ND-3135.

ND-3437 Pump Covers

Pump covers shall be designed in accordance with ND-3325 or ND-3326. Covers for which specific design rules are not given in ND-3325 or ND-3326 shall be designed by any method shown by analysis or experience to be satisfactory.

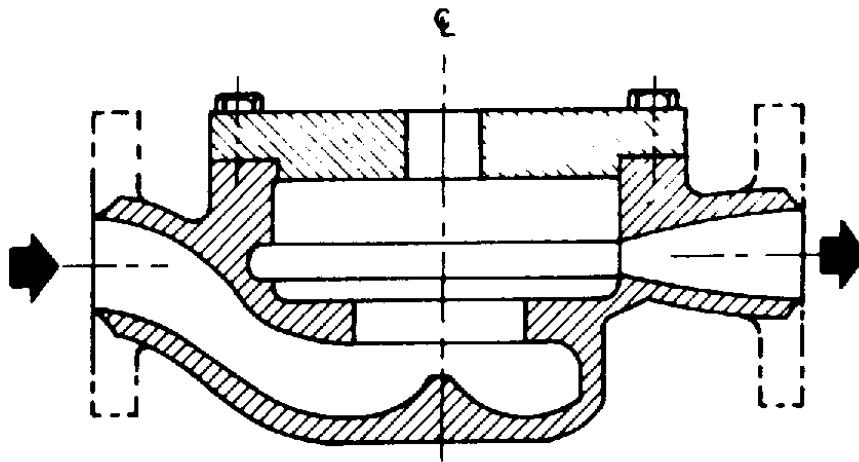


FIG. ND-3441.1-1 TYPE A PUMP

FIG. ND-3441.1-1 TYPE A PUMP

ND-3438 Supports

Pump supports shall be designed in accordance with the requirements of Subsection NF, unless included under the rules of ND-3411.1(j).

ND-3440 DESIGN OF SPECIFIC PUMP TYPES

ND-3441 Standard Pump Types

ND-3441.1 Design of Type A Pumps.

Type A pumps are those having single volutes and radially split casings with a single suction as illustrated in Fig. ND-3441.1-1 and ND-3441.1-2. Pumps with nozzle sizes NPS 4 discharge and smaller shall be constructed in accordance with ND-3441.1(a) through ND-3441.1(e). Larger pumps are permitted as stipulated in ND-3441.1(f).

(a) *Casing Wall Thickness.* Except where specifically indicated in these rules, no portion of the casing wall shall be thinner than the value of t which is determined as follows:

$$t = (PA)/S$$

or 0.25 in. (6 mm), whichever is greater, where

t	= minimum allowable wall thickness, in.
P	= Design Pressure, psig

Page 107

A	= scroll dimension, in., inside casing as shown in Fig. ND-3441.1(a)-1. If the value of dimension A exceeds 20 in., the formula shall not be used and (f) below applies.
S	= allowable stress, including casting factor, psi (ND-2571 and Tables 1A and 1B, Section II, Part D, Subpart 1)

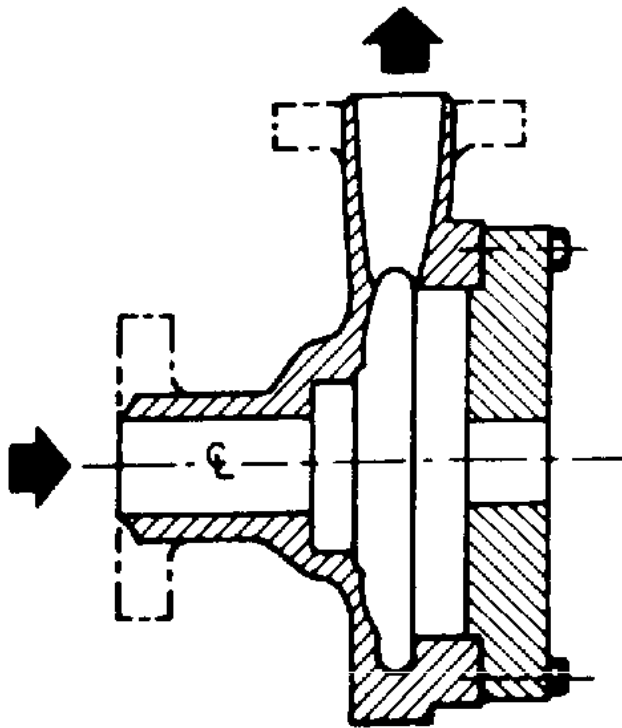


FIG. ND-3441.1-2 TYPE A PUMP

FIG. ND-3441.1-2 TYPE A PUMP

(b) *Cutwater Tip.* The cutwater tip radius shall not be less than $0.05t$.

(c) *Cutwater Fillets.* All cutwater fillets, including the tips, where they meet the casing wall, shall have a minimum radius of $0.10t$ or 0.25 in. (6 mm), whichever is greater.

(d) *Crotch Radius [Fig. ND-3441.1(a)-I].* The crotch radius shall not be less than $0.3t$.

(e) *Bottom of Casing.* That section of the pump casing within the diameter defined by dimension A in Fig. ND-3441.1(a)-1 on the inlet side of the casing, normally referred to as the bottom of the casing, shall have a wall thickness the greater of t from ND-3441.1(a) or t_b . The value of t_b shall be determined by methods of ND-3300 or Appendix A using the appropriate equations for the casing shape.

(f) Pumps with an "A" dimension greater than 20 in. or nozzles larger than NPS 4 discharge are permitted. Design of these larger pumps must be performed in accordance with Appendix II, Experimental Stress Analysis, or ND-3414. If the design is qualified by analysis, the analysis shall be certified in accordance with NCA-3551.1.

ND-3441.2 Design of Type B Pumps.

Type B pumps are those having single volutes and radially split casings with double suction as illustrated in Fig. ND-3441.2-1. Any design method that has been demonstrated to be satisfactory for the specified Design Conditions may be used.

ND-3441.3 Design of Type C Pumps.

Type C pumps are those having double volutes and radially split casings with a single suction as illustrated in Figs. ND-3441.3-1 and ND-3441.3-2. The splitter is considered a structural part of the casing. Casing design shall be in accordance with the requirements of this Subarticle and with those given in (a) through (e) below.

(a) *Casing Wall Thickness.* Except where specifically indicated in these rules, no portion of the casing wall shall be thinner than the value of t determined as follows:

$$t = (0.5PA)/S$$

where

t	= minimum allowable wall thickness, in.
P	= Design Pressure, psig
A	= scroll dimension, in., inside casing as shown in Fig. ND-3441.3-2
S	= allowable stress, including casting factor, psi (ND-2571 and Tables 1A and 1B, Section II, Part D, Subpart 1)

(b) *Splitter Wall Thickness*

(1) The splitter, which is considered a structural part of the casing, shall have a minimum wall thickness of $0.7t$ as determined above for the casing wall and shall extend from point B in Fig. ND-3441.3-2 sketch (a) through a minimum angle of 135 deg to point C. Beyond point C, the splitter wall may be reduced in thickness and tapered to blend with the cutwater tip radius.

(2) Cutwater tip and splitter tip radii shall not be less than $0.05t$.

(3) All cutwater and splitter fillets, including the tips, where they meet the casing wall, shall have a minimum radius of $0.10t$ or 0.25 in. (6 mm), whichever is greater.

(c) *Crotch Radius (Fig. ND-3441.3-2).* The crotch radius shall not be less than $0.3t$.

(d) *Bottom of Casing.* That section of the pump casing within the diameter defined by dimension A in Fig. ND-3441.3-2 on the inlet side of the casing, normally referred to as the bottom of the casing, shall have a wall thickness no less than the value of t determined in (a) above.

(e) *Alternative Rules for Casing Wall Thickness and Splitter Wall Thickness.* As an alternative to (a) and (b) above, it is permissible to use a smaller casing wall thickness and a larger splitter wall thickness when requirements of (1) through (3) below are met.

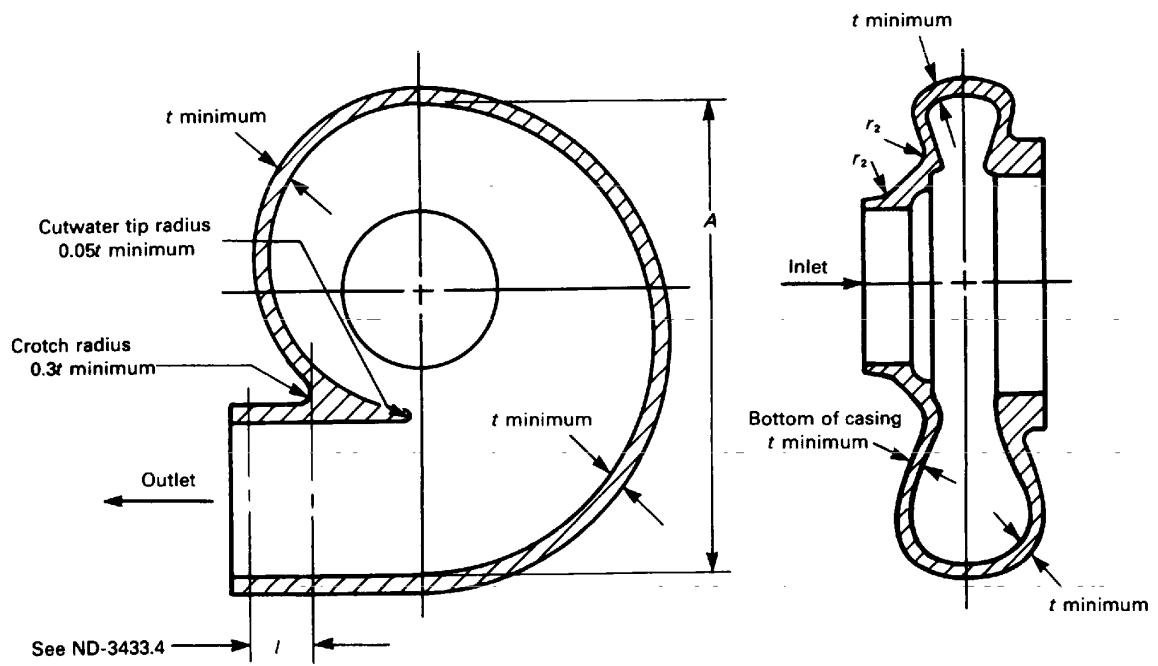


FIG. ND-3441.1(a)-1 TYPE A PUMP

FIG. ND-3441.1(a)-1 TYPE A PUMP

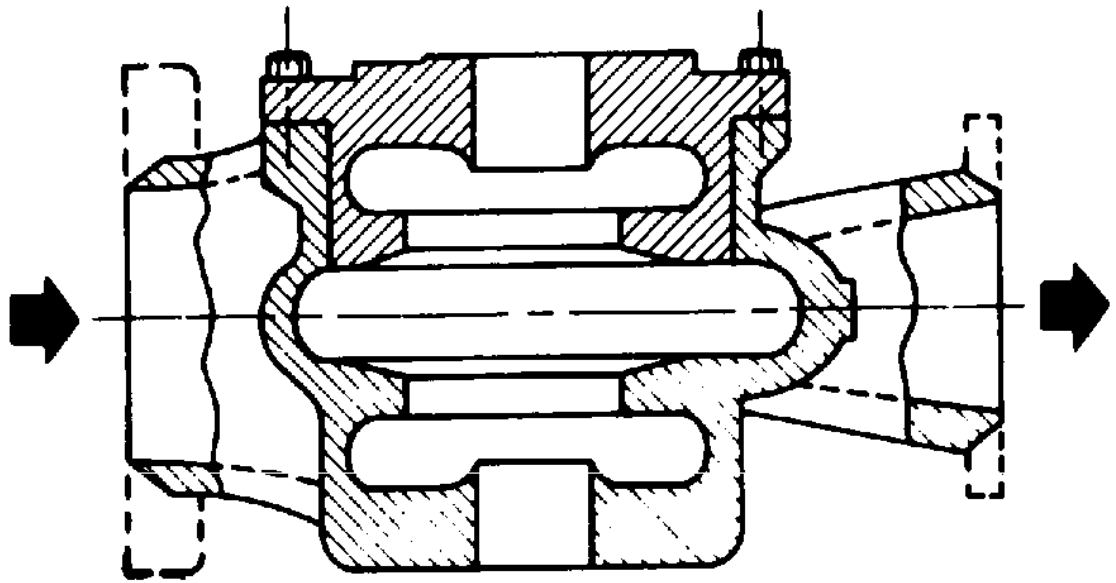


FIG. ND-3441.2-1 TYPE B PUMP

FIG. ND-3441.2-1 TYPE B PUMP

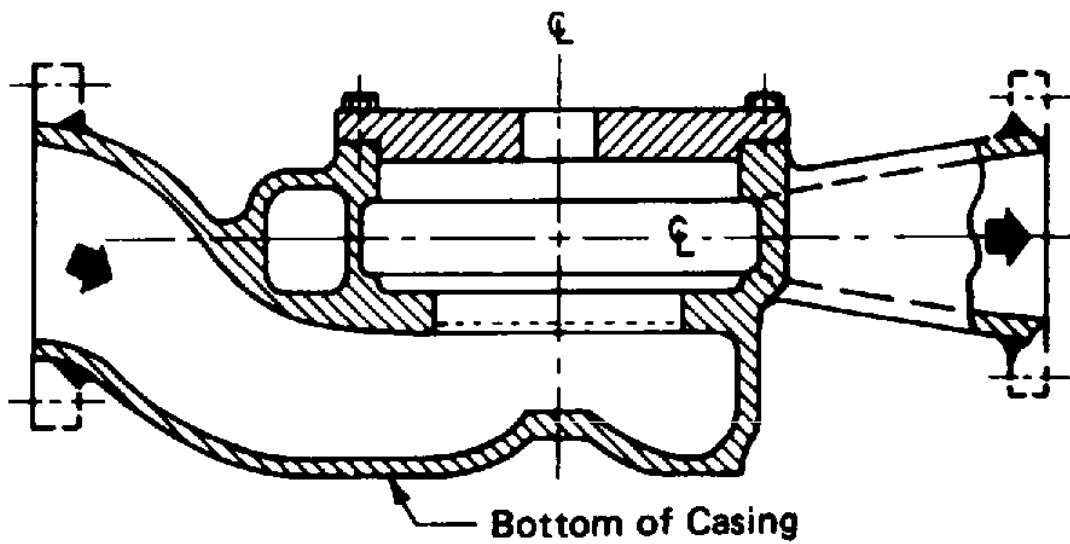


FIG. ND-3441.3-1 TYPE C PUMP

FIG. ND-3441.3-1 TYPE C PUMP

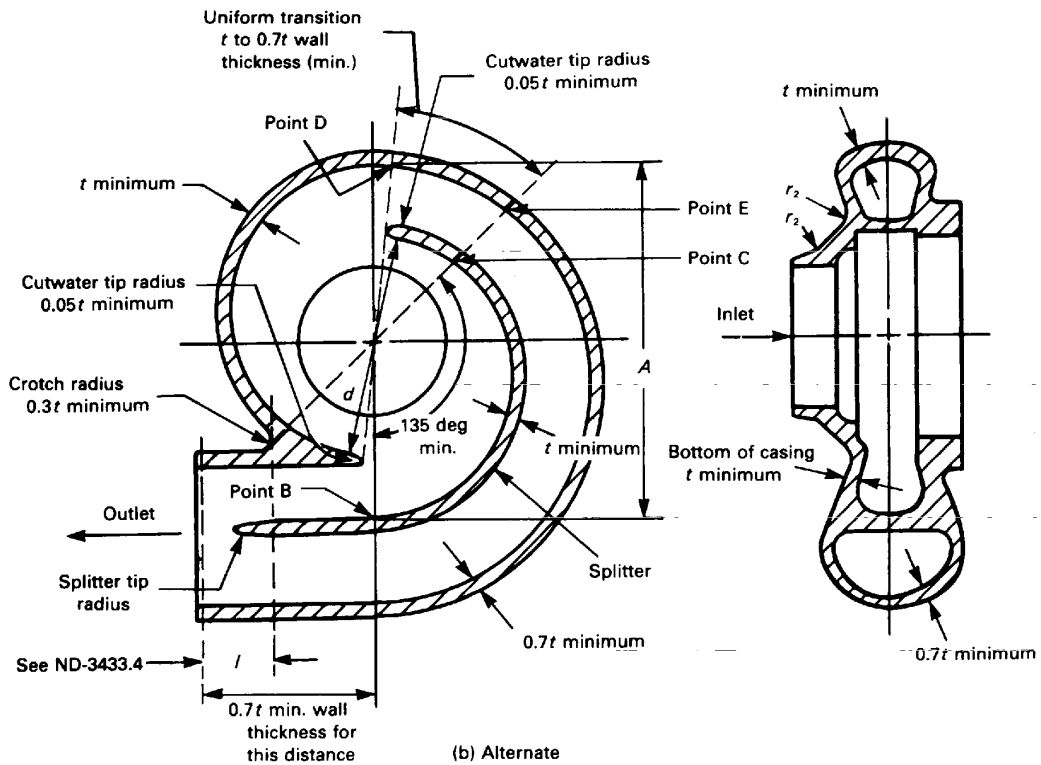
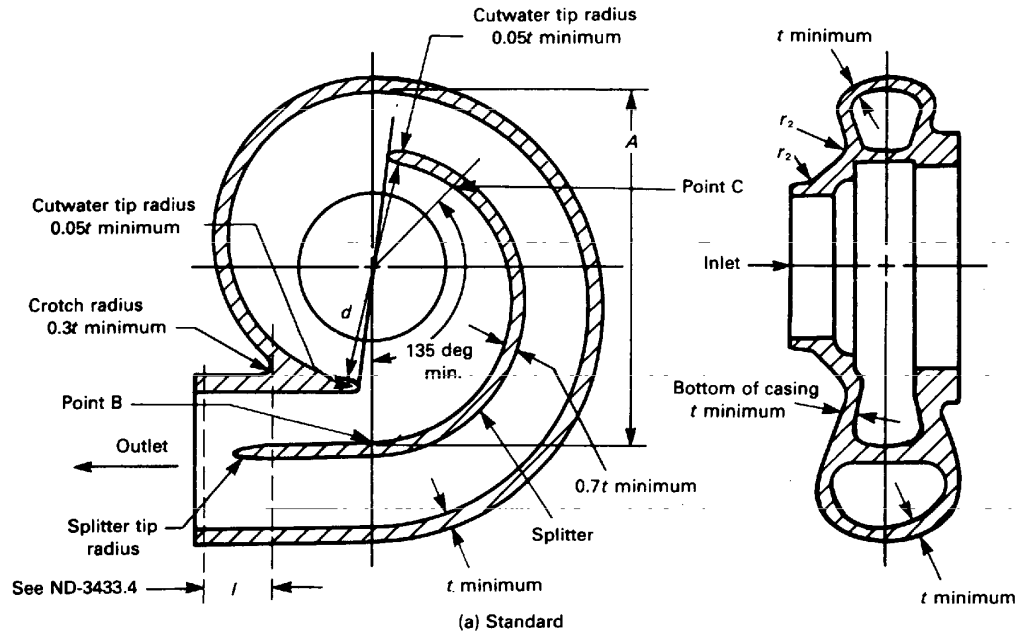


FIG. ND-3441.3-2 TYPE C PUMP

FIG. ND-3441.3-2 TYPE C PUMP

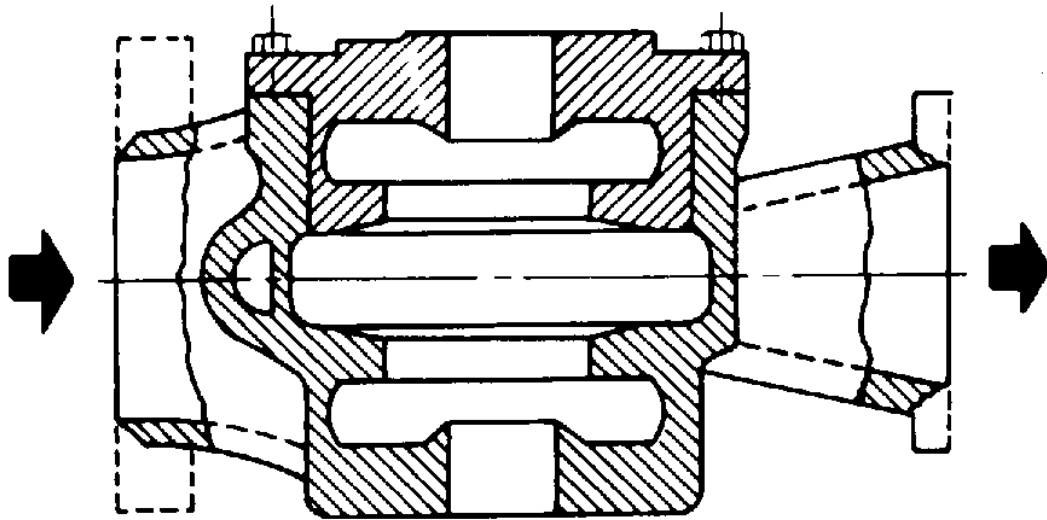


FIG. ND-3441.4(a)-1 TYPE D PUMP

FIG. ND-3441.4(a)-1 TYPE D PUMP

(1) The casing wall thickness, as determined by (a) above, shall be maintained at a minimum t , in., between the tangent point of the crotch radius to a point D radially opposite the splitter tip [Fig. ND-3441.3-2 sketch (b)]. The casing wall shall be decreased uniformly to point E from which point a minimum thickness of $0.7t$ shall be continued around the casing wall to a point on the discharge nozzle a distance l , in., from the crotch, where l is defined in Fig. ND-3433.4-1.

(2) The splitter wall thickness shall be as defined in (b) above, except that the splitter shall have a minimum thickness of t , in., instead of $0.7t$.

(3) The requirements of (b)(2) and (b)(3) above shall apply.

ND-3441.4 Design of Type D Pumps

(a) Type D pumps are those having double volutes and radially split casings, with double suction as illustrated in Fig. ND-3441.4(a)-1. Their design shall be in accordance with the applicable requirements of ND-3400.

(b) The requirements of ND-3441.3(a), (b), and (c), governing casing wall thickness, splitter wall thickness, and crotch radius, apply.

(c) In the casing portion between the cover and the casing wall, a wall thickness in excess of t may be required.

ND-3441.5 Design of Type E Pumps.

Type E pumps are those having volute type radially split casings and multivane diffusers which form a structural part of the casing as illustrated in Fig. ND-3441.5-1. The design shall be in accordance with the applicable requirements of ND-3400.

ND-3441.6 Design of Type F Pumps

(a) Type F pumps are those having radially split, axisymmetric casings with either tangential or radial outlets as illustrated in Fig. ND-3441.6(a)-1. The basic configuration of a Type F pump casing is a shell with a dished head attached at one end and a bolting flange at the other. The outlet may be either tangent to the side or normal to the center line of the casing. Variations of these inlet and outlet locations are permitted.

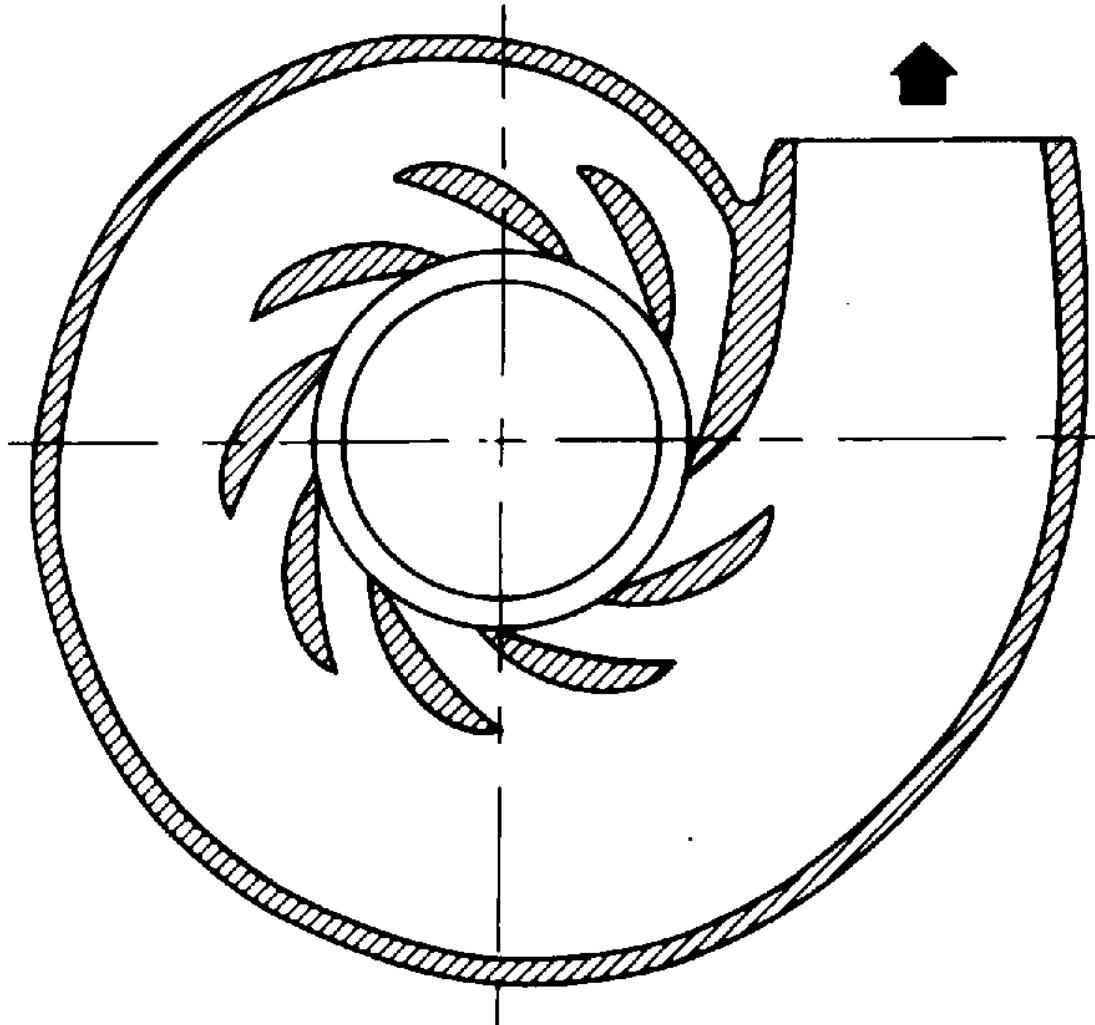


FIG. ND-3441.5-1 TYPE E PUMP

FIG ND-3441.5-1 TYPE E PUMP

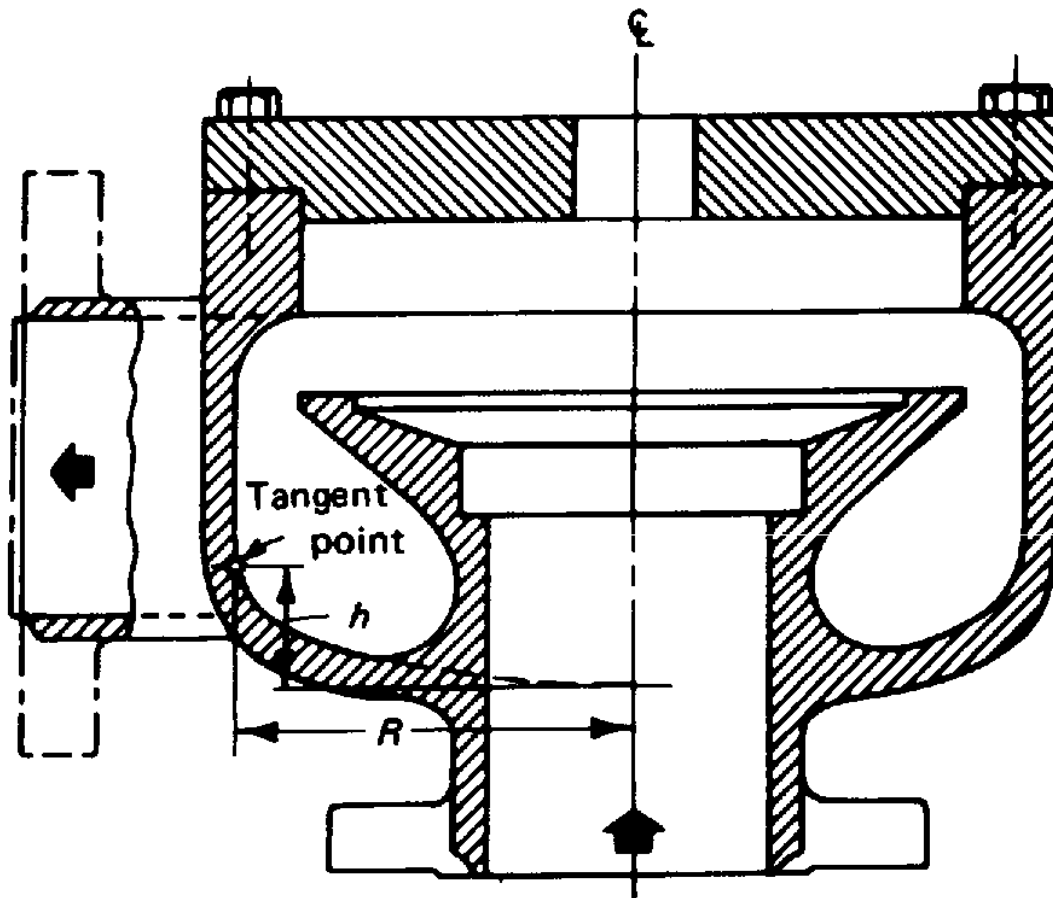


FIG. ND-3441.6(a)-1 TYPE F PUMP

FIG ND-3441.6(a)-1 TYPE F PUMP

(b) The design of Type F pumps shall be in accordance with the applicable requirements of ND-3400.

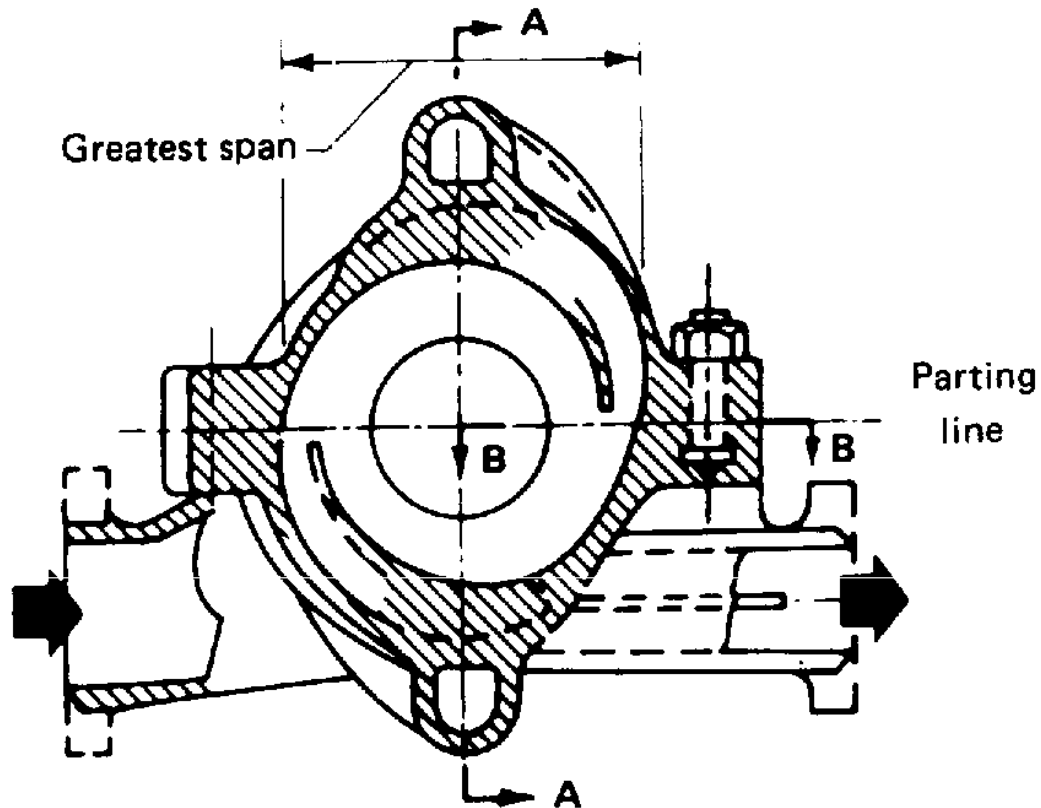


FIG. ND-3441.7(a)-1 AXIALLY SPLIT CASING, VOLUTE PUMP, TYPE G

FIG. ND-3441.7(a)-1 AXIALLY SPLIT CASING, VOLUTE PUMP, TYPE G

ND-3441.7 Design of Type G Pumps¹⁸

(a) Type G pumps are those having axially split, single or double volute casings [Figs. ND-3441.7(a)-1 and ND-3441.7(a)-2].

(b) Manufacturers proposing this design should thoroughly review nondestructive examination requirements for compatibility.

(c) An acceptable method for calculating the stress in the most highly stressed section of the pump case, such as the section with the greatest span, is given in (1) and (2) below. This method is not acceptable for those designs in which more than one bolt falls within a given section [Fig. ND-3441.7(c)-1, Section B-B].

(1) The following assumptions are made:

(a) assign one bolt to Section X , assign one-half bolt to Section Y and one-half bolt to Section Z Section Z is identical to Section Y ;

(b) the flange and bolts act together in bending;

(c) the maximum moment occurs at the bolt;

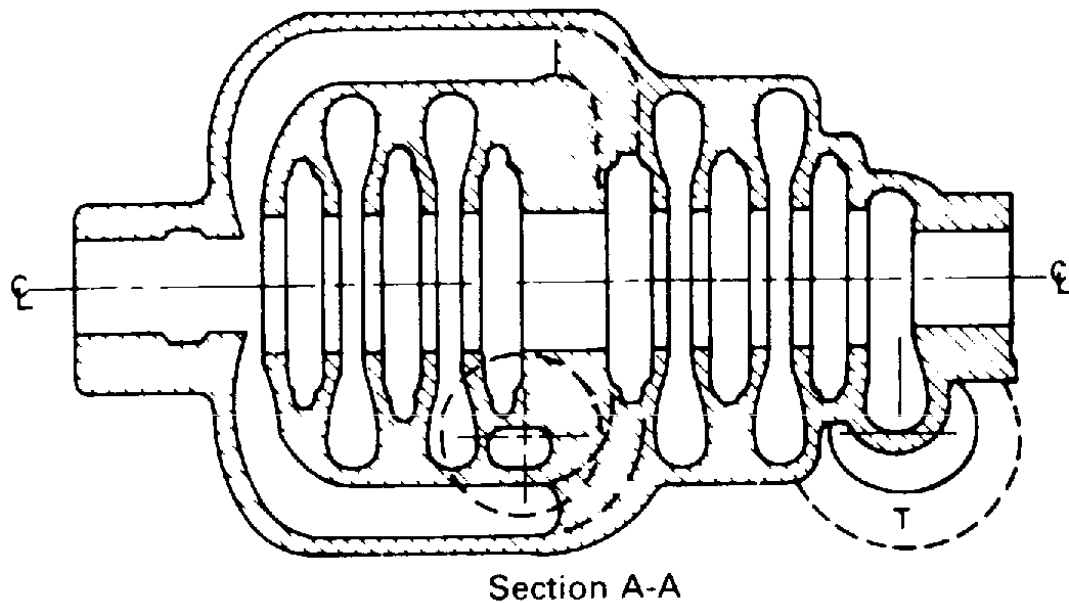
(d) the total moment is distributed between the flange and case in proportion to their moments of inertia.

(2) Typical sections are shown in Figs. ND-3441.7(c)(2)-1, ND-3441.7(c)(2)-2, and ND-3441.7(c)(2)-3. The procedure for the calculation is given in (a) through (o) below.

18 It is recognized that other acceptable procedures may exist which also constitute adequate design methods, and it is not the intention to rule out these alternative methods provided they can be shown to have been satisfactory by actual service experience.

(a) Establish Design Pressure P , psi. Establish dimensions A , B , C , F , R , t_c , t_f , w , and b from Fig. ND-3441.7(c)(2)-1, ND-3441.7(c)(2)-2, or ND-3441.7(c)(2)-3 and determine the following:

A_G	= effective gasket area, sq in.
D	= diameter of bolt hole, in.
G	= $B + 0.5t_c$, in.
R	= $C - (B + t_c)$, in.
w	= section width, in.
W	= load used in calculating preliminary bolt stress, lb
	= W_X , W_Y , W_Z
d	= bolt root diameter, in.
A_b	= bolt root area, sq in.
y	= gasket design seating stress, psi (Table XI-3221.1-1)
m	= gasket factor (Table XI-3221.1-1)
E	= modulus of elasticity of bolt at service temperature, psi
e	= unit thermal elongation of bolt, in./in.
DTF	= Design Temperature, °F
S_b	= allowable stress, bolt, psi
S_c	= allowable stress, case, psi



**FIG. ND-3441.7(a)-2 AXIALLY SPLIT
CASING, VOLUTE PUMP, TYPE G**

FIG. ND-3441.7(a)-2 AXIALLY SPLIT CASING, VOLUTE PUMP, TYPE G

(b) Determine the effective gasket area A_G sq in., for Sections X and Y :

$$A_G = [(A - F)w - (\pi D^2/4)]C \times K$$

For the factor K , use 0.20 if case face is crowned for greatest contact pressure at inner edge; for flat surfaces, use 0.50.

(c) Determine bolt load, lb, and preliminary bolt stress σ_{PRE} psi:

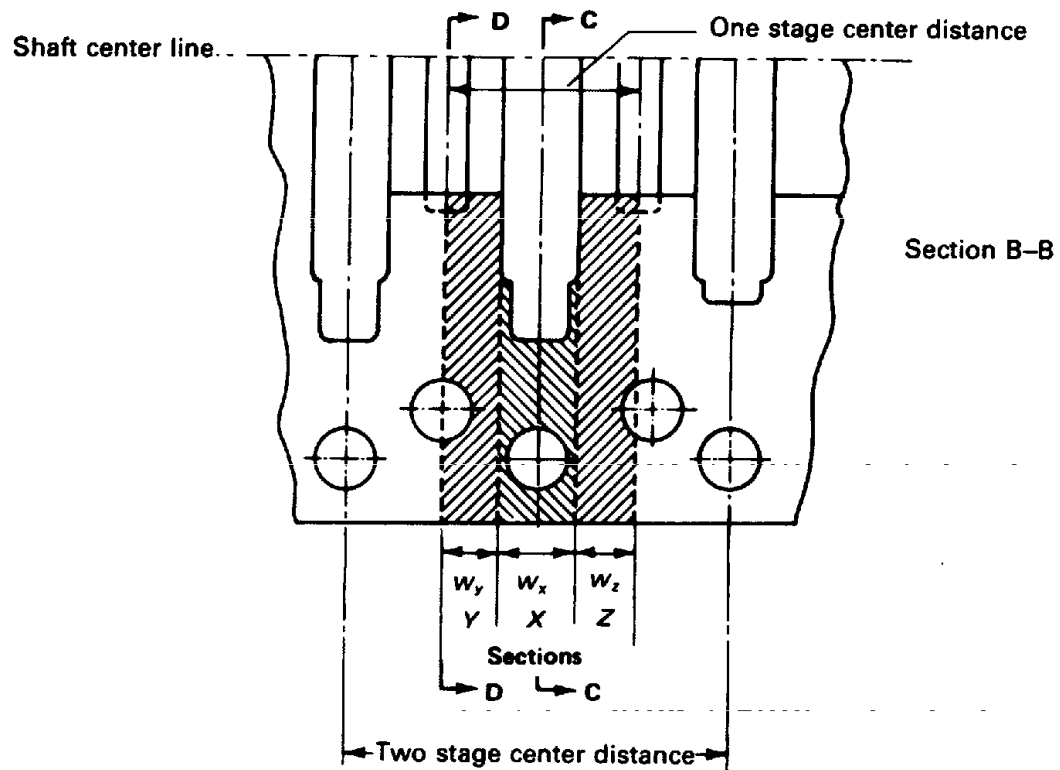
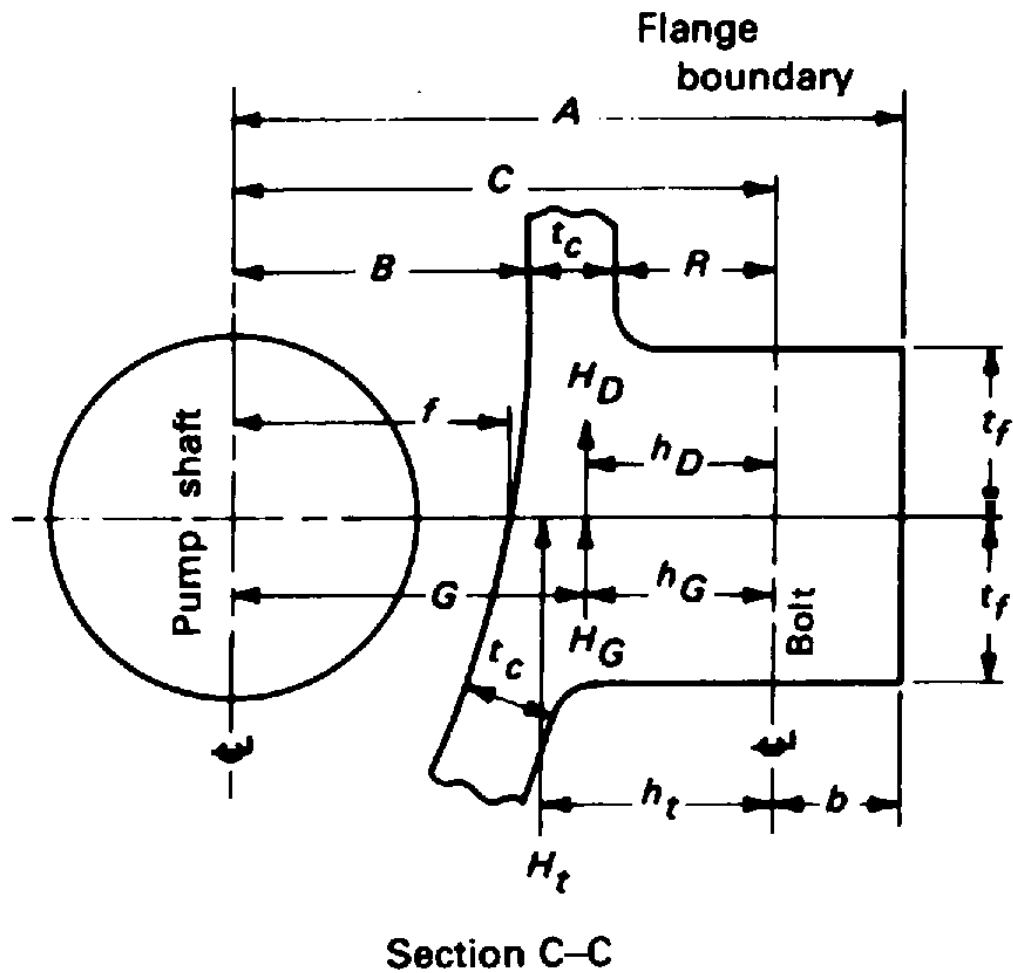


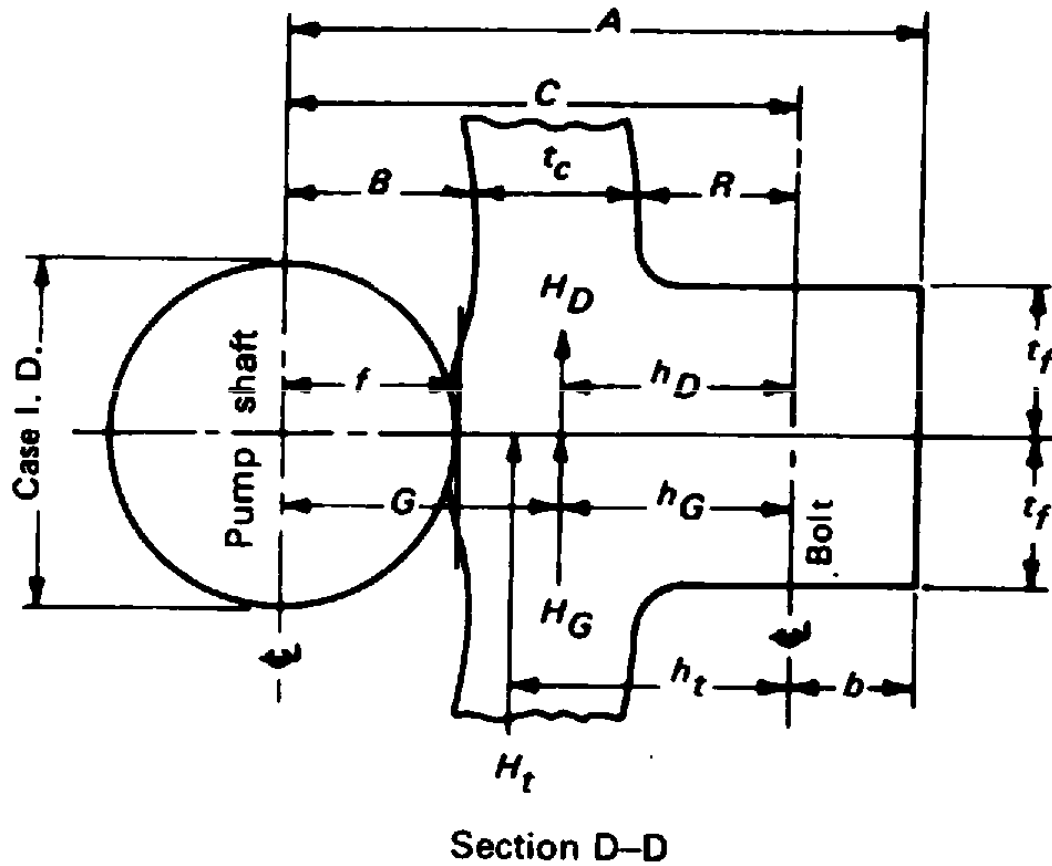
FIG. ND-3441.7(c)-1 AXIALLY SPLIT CASING, VOLUTE PUMP, TYPE G
Section B — B Typical Highly Stressed Sections of Pump Case

FIG. ND-3441.7(c)-1 AXIALLY SPLIT CASING, VOLUTE PUMP, TYPE G



**FIG. ND-3441.7(c)(2)-1 TYPICAL
SECTION OF TYPE G PUMP**

FIG. ND-3441.7(c)(2)-1 TYPICAL SECTION OF TYPE G PUMP



**FIG. ND-3441.7(c)(2)-2 TYPICAL
SECTION OF TYPE G PUMP**

FIG. ND-3441.7(c)(2)-2 TYPICAL SECTION OF TYPE G PUMP

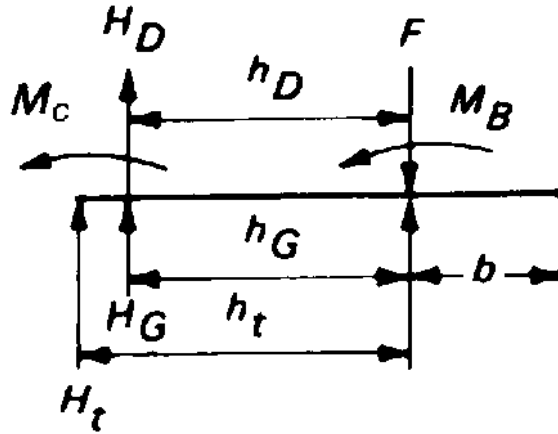


FIG. ND-3441.7(c)(2)-3 TYPICAL LOADS ON TYPE G PUMP

FIG. ND-3441.7(c)(2)-3 TYPICAL LOADS ON TYPE G PUMP

$$H = G \times w \times P$$

$$H_p = A_G \times m \times P$$

$$W_{m1} = H + H_p$$

$$W_{m2} = 0.5 A_G y$$

$$W = \text{greater of } W_{m1} \text{ or } W_{m2}$$

$$\sigma_{PRE} = W/A_b$$

(d) Determine the total load H_o lb:

$$H_D = B \times w \times P$$

$$H_G = H_p$$

$$H_T = H - H_D$$

$$H_o = H_D + H_G + H_T$$

(e) Determine the lever arms h_D , h_G and h_T , in.:

$$h_D = R + 0.5t_c$$

$$h_G = h_D$$

$$h_T = 0.5 (R + t_c + h_G)$$

(f) Determine the total moment M_o in.-lb:

$$M_D = H_D h_D$$

$$M_G = H_G h_G$$

$$M_T = H_T h_T$$

$$M_o = M_D + M_G + M_T$$

(g) Determine the moments of inertia, in.⁴, I_F (flange), I_B (bolt), I_C (case), and I_T (total):

$$I_F = [w(t_f)^3/12] - [D(t_p)^3/12]$$

$$I_B = 0.049d^4$$

$$I_C = w(t_c)^3/12$$

$$I_T = I_F + I_B + I_C$$

(h) Determine the moments, in.-lb, carried M_F (flange), M_B (bolt), and M_C (case):

$$M_F = (M_o I_F)/I_T$$

$$M_B = (M_o I_B)/I_T$$

$$M_C = (M_o I_C)/I_T$$

(i) Determine the resultant bolt load F_R lb:

$$F_R = [H_D(b + h_D) + H_G(b + h_G) + H_T(b + h_T) - M_C - M_B]/b$$

or

$$F_R = H_o + [(M_o - M_C - M_B)/b]$$

(j) Determine resultant bolt stresses, psi:

$$\sigma_{\text{Load}} = F_R/A_b$$

$$\sigma_{\text{Temp}} = eE$$

$$\sigma_{\text{Tensile}} = \sigma_{\text{Load}} + \sigma_{\text{Temp}}$$

$$\sigma_{\text{Bending}} = M_B d/2I_B$$

(k) Determine the shear and bending flange stresses σ_s' , psi, and σ_b' , psi, respectively:

$$\sigma_s' = H_o / wt_f$$

$$\sigma_b' = M_F t_f / 2I_F$$

(l) Determine the tensile and bending case stresses σ_t'' , psi, and σ_b'' , psi, respectively:

$$\sigma_t'' = H_D / wt_C$$

$$\sigma_b'' = M_C t_C / 2I_C$$

TERMS

(m) Use the following method for combining stresses in combined sections.

Let F_X load on Section X, lb

F_Y load on section Y, etc., lb

Let S_X stress in section X, psi

S_Y stress in section Y, etc., psi

Then the combined stress S_{COMB} is as follows:

$$S_{\text{COMB}} = (F_X + F_Y) / [(F_X/S_X) + (F_Y/S_Y)], \text{ etc.}$$

(n) Determine the maximum stresses using (1) through (4) below.

(1) To determine the preliminary bolt stress, establish the load W and stress σ_{PRE} for Section X and for Section (Y + Z):

$$\sigma_{\text{PRE}_{\text{COMB}}} = \frac{W_X + W_{(Y+Z)}}{\frac{W_X}{\sigma_{\text{PRE}_X}} + \frac{W_{(Y+Z)}}{\sigma_{\text{PRE}_{(Y+Z)}}}}$$

The allowable limit for this stress is S_b .

(2) To determine the resultant bolt stress, establish the load F_R and the stresses σ_t and σ_b for Section X and for Section $(Y+Z)$:

$$\sigma_{t_{\text{COMB}}} = \frac{F_{R_X} + F_{R_{(Y+Z)}}}{\frac{F_{R_X}}{\sigma_{t_X}} + \frac{F_{R_{(Y+Z)}}}{\sigma_{t_{(Y+Z)}}}}$$

The allowable limit for $\sigma_{t_{\text{COMB}}}$ is $2S_b$.

$$\sigma_{b\text{ COMB}} = \frac{F_{R_X} + F_{R_{(Y+Z)}}}{\frac{F_{R_X}}{\sigma_{b_X}} + \frac{F_{R_{(Y+Z)}}}{\sigma_{b_{(Y+Z)}}}}$$

The allowable limit for $\sigma_{b\text{ COMB}}$ is $3S_b$.

(3) To determine the flange stresses, establish the load H_o , the shear stress σ'_s , and the bending stress σ'_b for Section X and for Section (Y + Z):

$$\sigma'_{s\text{ COMB}} = \frac{\frac{H_{o_X} + H_{o_{(Y+Z)}}}{\sigma'_{s_X} + \frac{H_{o_{(Y+Z)}}}{\sigma'_{s_{(Y+Z)}}}}}{\sigma'_{b_X} + \frac{H_{o_{(Y+Z)}}}{\sigma'_{b_{(Y+Z)}}}} \sigma'_{b\text{ COMB}} = \frac{H_{o_X} + H_{o_{(Y+Z)}}}{\sigma'_{b_X} + \frac{H_{o_{(Y+Z)}}}{\sigma'_{b_{(Y+Z)}}}}$$

$$\sigma'_{s\text{ max}} = [(\sigma'_{s\text{ COMB}})^2 + (\sigma'_{b\text{ COMB}}/2)^2]^{1/2}$$

$$\sigma'_{n\text{ max}} = \sigma'_{s\text{ max}} + (\sigma'_{b\text{ COMB}}/2)$$

where $\sigma'_{n\text{ max}}$ is the maximum normal stress. The allowable limit for $\sigma'_{s\text{ max}}$ is S_c and the allowable limit for $\sigma'_{n\text{ max}}$ is $1.5S_c$.

TERM

(4) To determine the case stresses, establish the load H_D , the tensile stress σ_t'' , and the bending stress σ_b'' for Section X and for Section (Y + Z):

$$\sigma_t''_{\text{COMB}} = \frac{H_{D_X} + H_{D_{(Y+Z)}}}{\frac{H_{D_X}}{\sigma_t''_X} + \frac{H_{D_{(Y+Z)}}{\sigma_t''_{(Y+Z)}}}$$

$$\sigma_b''_{\text{COMB}} = \frac{H_{D_X} + H_{D_{(Y+Z)}}}{\frac{H_{D_X}}{\sigma_b''_X} + \frac{H_{D_{(Y+Z)}}{\sigma_b''_{(Y+Z)}}}$$

The allowable limit for $\sigma_t''_{\text{COMB}}$ is S_c . The total stress is $\sigma_t''_{\text{COMB}} + \sigma_b''_{\text{COMB}}$. The allowable limit for total stress is $1.5S_c$.

TERM

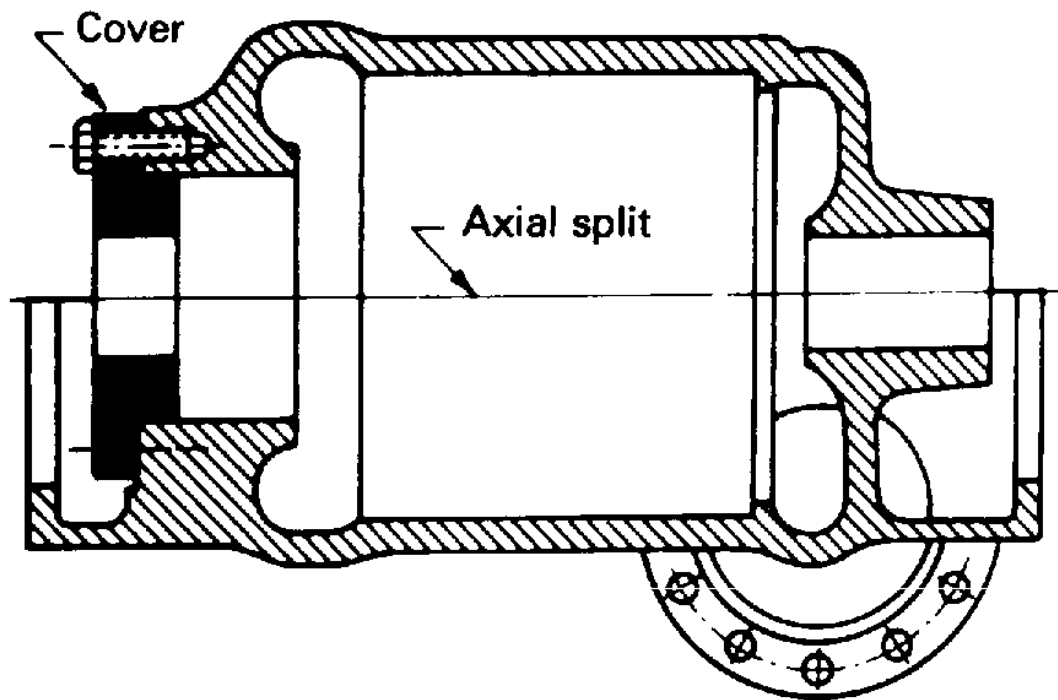
(o) The above procedure will generally show some bolt stresses in excess of the indicated allowable values. Under these circumstances it is permissible to average bolt stresses between adjacent bolts. Such averaged stresses shall not exceed the specified allowables.

ND-3441.8 Design of Type H Pumps.

Type H pumps are those having axially split, barrel type casings (Figs. ND-3441.8-1 and ND-3441.8-2) and radially split covers. The axially split casing shall be designed in accordance with the rules of ND-3441.7 for Type G

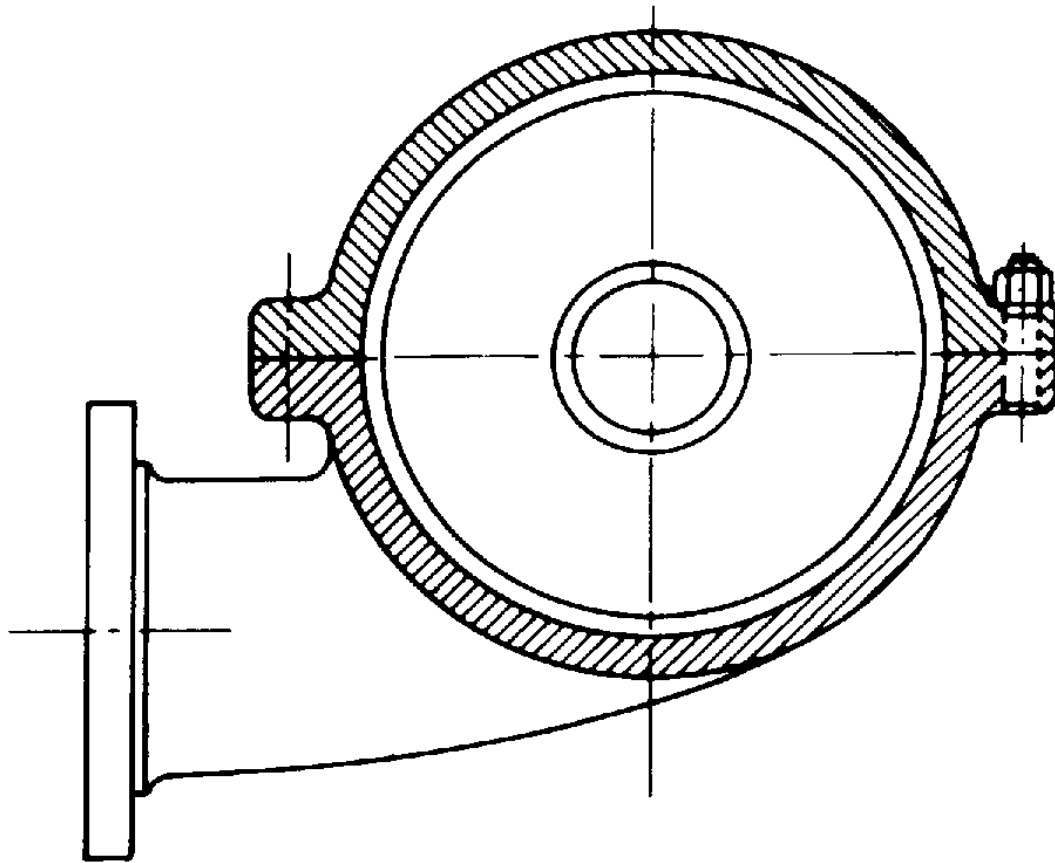
Page 115

pumps. The radially split cover shall be designed in accordance with the rules of ND-3437.



**FIG. ND-3441.8-1 LONGITUDINAL SECTION
THROUGH TYPE H PUMP**

FIG. ND-3441.8-1 LONGITUDINAL SECTION THROUGH TYPE H PUMP



**FIG. ND-3441.8-2 TRANSVERSE SECTION
THROUGH TYPE H PUMP**

FIG. ND-3441.8-2 TRANSVERSE SECTION THROUGH TYPE H PUMP

ND-3441.9 Design of Type K Pumps.

Type K pumps are vertical pumps having a radially split casing with one or more internal pump stages, as illustrated in Figs. ND-3441.9-1 and ND-3441.9-2. The basic configuration is a casing which forms the pressure boundary and consists of a barrel and a head joined by bolted flanges. There is an inner assembly consisting of internal chambers of the head, one or more bowls, column sections, and a suction bell, all joined by bolted flanges and arranged so that the external surfaces of these parts are subjected to inlet pressure. These pumps may be furnished with or without column(s) and with or without lateral restraints between the inner assembly and outer casing.

(a) *Flanged Joints.* Except for flanged joints conforming to (5), flanged joints may be analysed and the stresses evaluated by using methods given in Appendix XI if of the "RF" type and in accordance with Appendix L if of the "FF" type, as modified by (1) through (4) below or by (5) below.

(1) The Design Pressure to be used for the calculation of H in Appendix XI or Appendix L shall be replaced by the flange design pressure:

$$(1) P_{FD} = P + P_{eq}$$

where

P = Design or Service Condition Pressure as defined in NCA-2140, psi

P_{eq} = Equivalent pressure to account for the axial force and moments applied to the flange joint, psi

The equivalent pressure, P_{eq} , shall be determined from the seismic and external loads acting on the flanged joint using the equation:

$$P_{eq} = \frac{KM_f}{\pi G^3} + \frac{4F}{\pi G^2} \quad (2)$$

(2)

where

M_f = the resultant bending moment on the flange as taken from paragraph ND-3658, in.-lb_f

F = the axial load at the flange, lb_f

G = the diameter at the location of the gasket load reaction, in.

K = If the loads include dynamic loads the value of this coefficient shall be 8. If the loads are static the value shall be 16.

(2) Equations (3) and (4) in Appendix XI-3223 or Appendix L-3221 shall be used to establish minimum bolt area required using allowable stress values given in Tables 1A and 1B, Section II, Part D, Subpart 1.

(3) Equation (6) in Appendix XI-3240 for longitudinal hub stress shall be revised to include primary axial membrane stress as follows:

$$S_H = \frac{fM_o}{Lg_1^2B} + \frac{PB}{4g_o} \quad (3)$$

(3)

Where P is the Design or Service Pressure as defined in NCA-2140, psi. Other terms are defined in XI-3130.

(4) The allowable stress limits shall be:

S_H not greater than $1.5S$

S_R not greater than $1.5S$

Page 116

Page 117

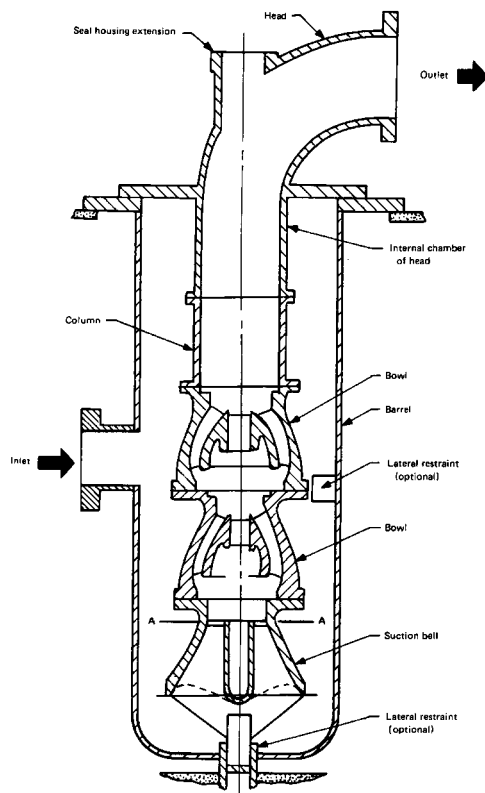


FIG. ND-3441.9-1 TYPE K PUMP

S_T not greater than $1.5S$

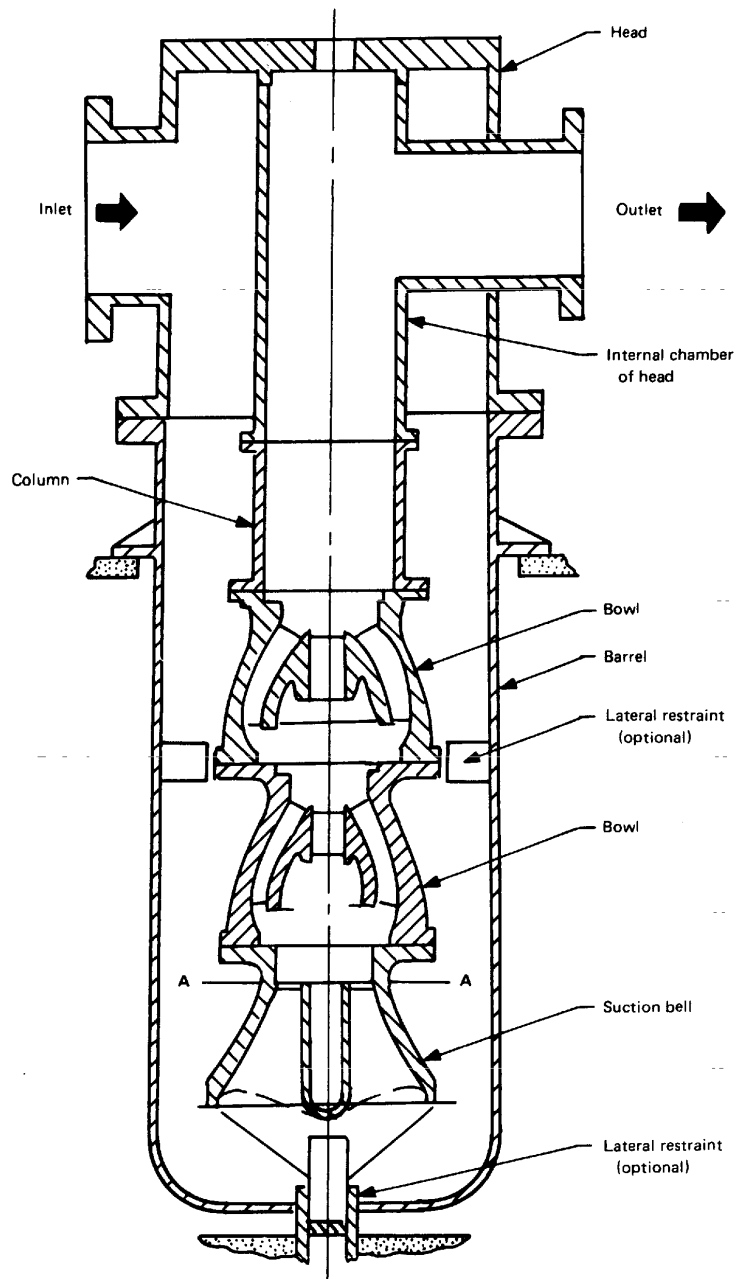


FIG. ND-3441.9-2 TYPE K PUMP

FIG. ND-3441.9-2 TYPE K PUMP

(5) If the flanged joint conforms to one of the standards listed in Table ND-3132-1 and if each P_{FD} as calculated by (1) is less than the rated pressure at the Design or Service Temperature utilized, the requirements of this subparagraph are satisfied.

(b) *Casing*. The barrel and head of the casing shall be designed in accordance with the requirements of ND-3400 and with those given in (1) and (2) below.

(1) *Barrel*. The Design Pressure for the barrel shall be the pump inlet pressure or as otherwise stated in the Design Specification (NCA-3250), but in no case shall it be less than the maximum pressure at the pump inlet under any Service Condition. The static pressure head shall be considered in the selection of the Design Pressure.

The inlet nozzle loads shall include the Design Pressure and piping moments. The equivalent pressure shall be determined using Eq. (1), with $F = 0$ in Eq. (2), as applied to the inlet geometry.

The barrel shall be designed in accordance with the requirements of ND-3320 for pressure vessels.

(2) *Head*

(a) The external walls of the head, which form the pressure boundary shall be designed for the pressures specified in (b) and (c) below. The Design Pressure for the internal chambers shall be as specified under the inner assembly rules.

(b) The Design Pressure P , for the portions of the head that form the pressure boundary between the outlet pressure and the atmosphere shall be the outlet pressure or as otherwise stated in the Design Specification, but in no case shall it be less than the maximum pressure at the pump outlet under any Service Condition.

The minimum thickness of the head waterway required for Design Pressure and for temperatures not exceeding those for various materials in Tables 1A and 1B, Section II, Part D, Subpart 1 shall be not less than that determined by the formula:

$$t_m = \frac{P D_o}{2(SE + Py)} + A \quad (4)$$

(4)

where

t_m	= minimum required wall thickness of the head waterway in its finished form, in.
D_o	= the outside diameter of the head waterway, in.
S	= the allowable stress for the material at the design temperature (Tables 1A and 1B, Section II, Part D, Subpart 1), psi
E	= the joint efficiency for the type of longitudinal joint used, as given in ND-3350 or casting quality factor as given in the

notes to Tables 1A and 1B, Section II, Part D, Subpart 1

= 0.4 for D_o/t_m greater or equal to 6.0

=

$$\frac{d}{d + D_o} \text{ for } \frac{D_o}{t_m} \text{ less than 6.0}$$

d = inside diameter of the head waterway, in.

A = corrosion or erosion allowance as specified by the Design Specification, in. If both surfaces are wetted, the corrosion allowance must be applied to both surfaces.

The above head waterway minimum thickness is in its finished form. If curved segments of pipe are used as the waterway, the minimum wall thickness after bending shall be not less than the required value.

The discharge nozzle loads shall include the Design Pressure and piping moments. The equivalent pressure shall be determined using Eq. (1), with $F = 0$ in Eq. (2), as applied to the head geometry.

(c) The Design Pressure for the portions of the head that form the pressure-containing boundary between the inlet pressure and the atmosphere shall be the inlet pressure or as otherwise stated in the Design Specification, but in no case shall it be less than the maximum pressure at the pump inlet under any Service Condition.

This portion of the head shall be designed in accordance with ND-3320 for pressure vessels.

(c) *Inner Assembly.* The inner assembly consists of those elements of the pump subjected to differential pressure within the pump. This assembly comprises the internal chambers of the head, the bowls and columns, and the upper flange of the suction bell.

Because of the installation and operation, pumped fluids within the inner assembly may transfer through the flanged connections back to the inlet fluid source. This fluid transfer does not effect the integrity of the overall pressure boundary but may result in a higher Design Pressure for the barrel and portions of the head and shall be considered in the determination of the barrel Design Pressure.

The Inner Assembly of Type K pumps shall be designed in accordance with the requirements of ND-3400 and with those given in (1) through (3) below. Alternatively, the configuration may be designed in accordance with Appendix II, Design by Experimental Stress Analysis, or Appendix XIII, Design by Stress Analysis.

(1) *Columns.* The Design Pressure for columns, P_c (psi), shall include the piping moments and axial loads. It shall be not less than the maximum differential

Page 119

pressure which can be developed across the wall of that column under any Service Condition. The weight of the pump bowls and impeller thrust shall be taken into consideration. P_c shall be determined using Eq. (1) and (2) but with "G" equal to the average column shell diameter.

The minimum thickness of the column shall be not less than that determined by the equation:

$$t_m = \frac{P_c D_o}{2(SE + P_y)} + A \quad (5)$$

(5) where the terms are as defined in ND-3441.9(b)(2)(b), but as applied to the column geometry and material.

(2) *Column Flanges.* Flanged joints in the column shall be designed in accordance with ND-3441.9(a) except that the design pressure shall be P_c . The equivalent pressure shall be determined using Eq. (1) as applied to the column geometry and shall be not less than the maximum differential pressure which can be developed across the wall of that column under any Service Condition. Unpacked flange joints are permitted.

(3) *Bowls.* The Design Pressure for the bowl(s), P_b shall include the piping moments. The equivalent pressure shall be determined using Eq. (1), with $F = 0$ in Eq. (2), as applied to the bowl geometry and shall be determined as the maximum differential pressure to which the bowl may be subjected under any Service Condition.

The design of the bowls shall be completed in accordance with (a) through (c) below for unribbed bowl geometries. For those bowl geometries which use external ribs to increase bowl and flange stiffness the design shall be completed using methods which have been proven in actual service. Unless special provisions are made to insure that interchangeability between bowls is prevented all bowls shall be designed to the same requirements.

(a) *Bowl Minimum Thickness.* The minimum thickness of the bowl shell, remote from discontinuities, shall be not less than that determined by:

$$t_m = \frac{P_b D_o}{2(SE + P_{by})} + A \quad (6)$$

(6)

where the terms are as defined in ND-3441.9(b)(2)(b) but as applied to the bowl geometry and material and:

D_o = the largest outside diameter of the bowl, taken at the suction end of the individual bowl assembly, (Fig. ND-3441.10-2), in.

The above minimum bowl thickness is applicable only to a location within the bowl which is remote from discontinuities and may have to be increased in order to satisfy the local evaluations of (b) and (c) below.

(b) *Vane/Shell Interaction.* Consideration shall be given to the restraining effect of the diffuser vanes on the radial expansion of the shell due to internal pressure. An acceptable method of accounting for this effect is presented below:

$$F_D = \frac{2 (2 - \mu) P_b A_D^2}{\frac{16 l_D t_D}{t_v} + \frac{t_D (\pi A_D)^3}{(n_v t_D)^3}} \quad (7)$$

(7)

where

F_D	= vane load/unit length, lb _f /in.
P_b	= the maximum internal bowl differential pressure, psi.
A_D	= the mean diameter of the vaned portion of the bowl as defined in Fig. ND-3441.10-2, in.
l_D	= the radial mean vane length as defined in Fig. ND-3441.10-2, in.
t_v	= the mean vane thickness, in.
t_D	= the shell thickness at the vane-shell intersection as defined in Fig. ND-3441.10-2, in.
n_v	= the number of vanes in the bowl waterway
μ	= Poisson's ratio

The local shell bending stress, σ_B , shall be less than 1.5 SE. Its value is determined by the equation:

$$\sigma_B = \frac{3 F_D \pi A_D}{n_v t_D^2} \quad (8)$$

(8)

The vane membrane stress, σ_v , shall be less than SE as determined by the equation:

$$\sigma_v = \frac{F_D}{t_v} \quad (9)$$

(9)

(c) *Bowl Flanges.* The flange joint between the individual bowl discharge flange and the next stage bowl inlet flange is usually such that the outlet flange rotational restraint is insufficient to restrict outlet flange rotation. Therefore, the prying action between flat faced flanges can be ignored and the outlet flange shall be analyzed in accordance with Appendix XI. This may not be true for ribbed flanges or the last stage bowl which attaches to the column assembly. If any of these joints have sufficient rigidity to support the prying action it shall be analyzed as an Appendix L flange. The analysis shall be in accordance with ND-3441.9(a) using Eq. (1), with $F = 0$ in Eq. (2). The definition

Page 120

of the outlet flange geometry for the analysis is shown in Fig. ND-3441.10-2.

The minimum radial distance between the bolt circle and the outside of the bowl or the inside rabbet fit shall be equal to or greater than one bolt diameter.

(4) *Suction Bell.* The Design Pressure for the suction bell, P_{sb} , shall be determined as the sum of the differential pressure developed at the first stage of the pump under any service condition plus an equivalent pressure to account for moments on the suction bell. The equivalent pressure shall be calculated using Eq. (1), with $F = 0$ in Eq. (2). The suction bell pressure, P_{sb} , is applied only to the suction bell flange. Below the suction bell flange (the section above line A-A in Figs. ND-3441.9-1 and ND-3441.9-2), the remaining portions of the bell are not considered subject to a differential pressure.

ND-3441.10 Design of Type L Pumps.

Type L pumps are vertical pumps of one or more stages, having a radially split casing as illustrated in Fig. ND-3441.10-1. The basic configuration consists of a head with an attached support plate, one or more bowls and column sections, and a suction bell, all joined by flanges. These pumps may be furnished with or without column. External restraint may be provided at various locations to restrain vibratory motions and resist external loads.

The configuration is such that the external surfaces of those parts above the support plate are subjected to atmospheric pressure. The parts below the support plate may be subjected to atmospheric pressure, or atmospheric pressure plus submerged head pressures. Because of the installation and operation, pumped fluids within the bowl and column assemblies may transfer through the flanged connections back to the fluid source. This fluid transfer does not effect the integrity of the overall pressure boundary.

Type L pumps shall be designed in accordance with the requirements of ND-3400 and with those given in (a) through (e) below. Alternatively, the configuration may be designed in accordance with Appendix II, Design by Experimental Stress Analysis, or Appendix XIII, Design by Stress Analysis.

(a) *Flanged Joints.* Except for flanged joints conforming to (5) below, flanged joints may be analysed and the stresses evaluated by using methods given in Appendix XI if of the "RF" type and in accordance with Appendix L if of the "FF" type, as modified by (1) through (4) below.

(1) The Design Pressure to be used for the calculation of H in Appendix XI or Appendix L shall be replaced by the flange design pressure:

$$(1) P_{FD} = P + P_{eq}$$

where

P	= Design or Service Condition Pressure as defined in NCA-2140, psi
P_{eq}	= Equivalent pressure to account for the moments applied to the flange joint, psi

The equivalent pressure P_{eq} shall be determined from the seismic and external loads acting on the flanged joint using the equation:

$$P_{eq} = \frac{KM_f}{\pi G^3} + \frac{PB}{\pi G^2} \quad (2)$$

(2)

where

M_f	= the resultant bending moment on the flange as taken from paragraph ND-3658, in.-lbf
F	= the axial load at the flange, lb
G	= the diameter at the location of the gasket load reaction, in.
K	= If the loads include dynamic loads the value of this coefficient shall be 8. If the loads are static the value shall be 16.

(2) Equations (3) and (4) in Appendix XI-3223 or Appendix L-3221 shall be used to establish minimum bolt area required using allowable stress values given in Tables 1A and 1B, Section II, Part D, Subpart 1.

(3) Equation (6) in Appendix XI-3240 for longitudinal hub stress shall be revised to include primary axial membrane stress as follows:

$$S_H = \frac{fM_o}{Lg_1^2B} + \frac{PB}{4g_o} \quad (3)$$

(3)

where P is the Design or Service Pressure as defined in NCA-2140, (psi). Other terms are defined in Appendix XI-3130.

(4) The allowable stress limits shall be:

S_H not greater than $1.5S$

S_R not greater than $1.5S$

S_T not greater than $1.5S$

(5) If the flanged joint conforms to one of the standards listed in Table ND-3132-1 and if each P_{FD} as calculated by Eq. (1) is less than the rated pressure at the Design or Service Temperature utilized, the requirements of this subparagraph are satisfied.

(b) *Head Waterway.* The Design Pressure P for portions of the head which form the pressure boundary between the outlet pressure and the atmosphere shall be the outlet pressure or as otherwise stated in the Design Specification. In no case shall it be less than the maximum pressure at the pump outlet under any

Page 121

Service Condition. The minimum thickness of the head waterway required for Design Pressure and for temperatures not exceeding those for various materials in Tables 1A and 1B, Section II, Part D, Subpart 1 shall be not less than that determined by the formula:

$$t_m = \frac{PD_o}{2(SE + Py)} + A \quad (4)$$

(4)

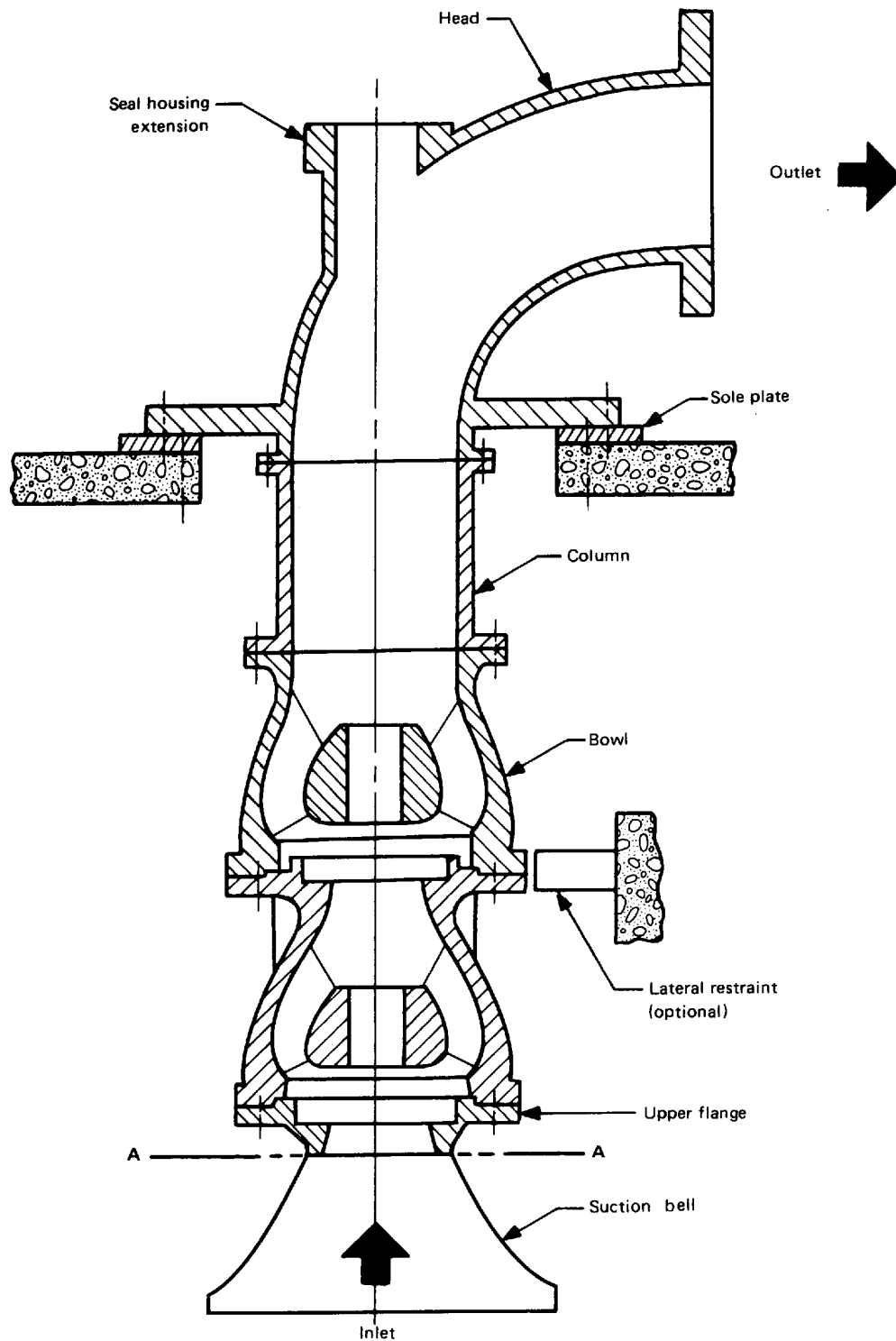


FIG. ND-3441.10-1 TYPE L PUMP

FIG. ND-3441.10-1 TYPE L PUMP

where

t_m	= minimum required wall thickness of the head waterway in its finished form, in.
D_o	= the outside diameter of the head waterway, in.
S	= the allowable stress for the material at the design temperature (Tables 1A and 1B, Section II, Part D, (Subpart 1), psi
E	= the joint efficiency for the type of longitudinal joint used, as given in ND-3350 or casting quality factor as given in the notes to Tables 1A and 1B, Section II, Part D, Subpart 1
y	= 0.4 for $D_o/t_m \geq 6.0$
y	=

$$\frac{d}{d + D_o} \text{ for } D_o/t_m < 6.0$$

d	= inside diameter of the head waterway, in.
A	= corrosion or erosion allowance as specified by the Design Specification, in. If both surfaces are wetted, the corrosion allowance must be applied to both surfaces.

The above head waterway minimum thickness is in its finished form. If curved segments of pipe are used as the waterway, the minimum wall thickness after bending shall be not less than the required value.

(c) *Column.* The Design Pressure for the column P_c shall include the effects of the piping moments and axial loads. It shall be not less than the maximum differential pressure which can be developed across the wall of that column under any Service Condition. The weight of the pump bowls and impeller thrust shall be taken into consideration. P_c shall be determined using Eq. (1) and (2) but with "G" equal to the average column shell diameter.

(1) *Column Thickness.* The minimum thickness of the column shall be not less than that determined by the equation:

$$t_m = \frac{P_c D_o}{2(SE + Py)} + A \quad (5)$$

(5) where the terms are as defined in (b) above, except as applied to the column geometry and material.

(2) *Column Flanges.* Flanged joints in the column shall be designed in accordance with ND-3441.10(a) except that the design pressure shall be P_c . The equivalent pressure shall be determined using Eq. (1) as applied to the column geometry and shall be not less than the maximum differential pressure which can be developed across the wall of that column under any Service Condition. Unpacked flange joints are permitted.

(d) *Bowls.* The Design Pressure for the bowl(s) P_b shall be determined as the maximum differential pressure to which the bowl may be subjected under any service condition.

The design of the bowls shall be completed in accordance with (1) through (3) below for unribbed bowl geometries. For those bowl geometries which use external ribs to increase bowl and flange stiffness, the design shall be completed using methods which have been proven in actual service. In both cases, the pump bowl experiencing the largest load shall be used in the design. Unless special provisions are made to insure that interchangeability between bowls is prevented, all bowls shall be designed to the same requirements.

(1) *Bowl Minimum Thickness.* The minimum thickness of the bowl shell, remote from discontinuities, shall be not less than that determined by:

$$t_m = \frac{P_b D_o}{2(SE + Py)} + A \quad (6)$$

(6)

where

D_o = the largest outside diameter of the bowl, taken at the suction end of the individual bowl assembly (Fig. ND-3441.10-2)

The above minimum bowl thickness is applicable only to a location within the bowl which is remote from discontinuities and may have to be increased in order to satisfy the local evaluations of (2) and (3) below.

(2) *Vane/Shell Interaction.* Consideration shall be given to the restraining effect of the diffuser vanes on the radial expansion of the shell due to internal pressure. An acceptable method of accounting for this effect is presented below.

$$F_D = \frac{2(2 - \mu) P_b A_D^2}{\frac{16l_D t_D}{t_v} + \frac{t_D (\pi A_D)^3}{(n_v t_d)^3}} \quad (7)$$

(7)

where

F_D

= vane load/unit length, lbf/in.

 P_b

= the maximum internal bowl differential pressure, psi

 A_D

= the mean diameter of the vaned portion of the bowl as defined in Fig. ND-3441.10-2, in. The section shall be taken at a portion of the bowl where the hub can be considered essentially solid.

Page 123

Page 124

 l_D

= the radial mean vane length as defined in Fig. ND-3441.10-2, in.

 t_v

= the mean vane thickness, in.

 t_D

= the shell thickness at the vane-shell intersection as defined in Fig. ND-3441.10-2, in.

 n_v

= the number of vanes in the bowl waterway

 μ

= Poisson's ratio

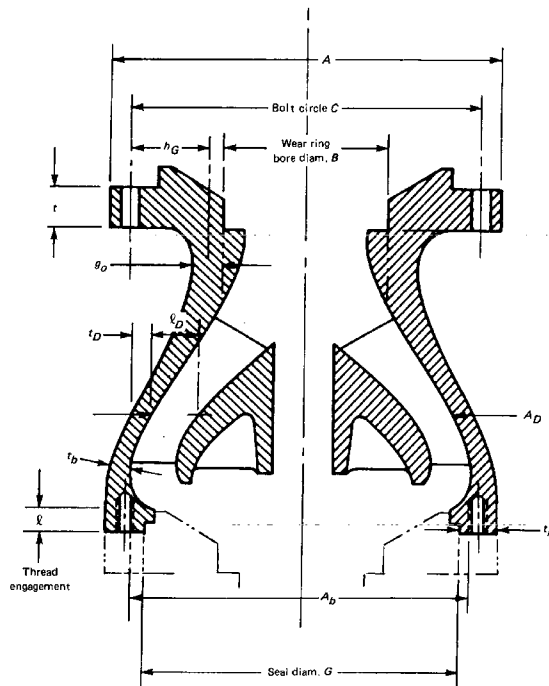


FIG. ND-3441.10-2 TYPE L PUMP BOWL

FIG. ND-3441.10-2 TYPE L PUMP BOWL

The local shell bending stress σ_v shall be less than 1.5 SE. Its value is determined by the equation:

$$\sigma_v = \frac{F_D}{t_v} \quad (8)$$

(8)

(3) *Bowl Flanges.* Flanged joints in the bowls shall be designed in accordance with ND-3441.10(a) except that the design pressure shall be P_b . The equivalent pressure shall be determined using Eq. (1), as applied to the bowl geometry and shall be not less than the maximum differential pressure which can be developed across the wall of that bowl under any Service Condition. Unpacked flange joints are permitted. The flange joint between the individual bowl discharge flange and the next stage bowl inlet flange is usually such that the outlet flange rotational restraint is insufficient to restrict outlet flange rotation. Therefore, the prying action between flat faced flanges can be ignored and the outlet flange shall be analyzed in accordance with Appendix XI. This may not be true for ribbed flanges or the last stage bowl which attaches to the column assembly. The definition of the outlet flange geometry for the analysis is shown in Fig. ND-3441.10-2.

The minimum radial distance between the bolt circle and the outside of the bowl or the inside rabbet fit shall be equal to or greater than one bolt nominal diameter.

(e) *Suction Bell.* The Design Pressure for the suction bell P_{sb} shall be determined as the sum of the differential pressure developed at the first stage of the pump under any service condition plus an equivalent pressure to account for moments on the suction bell. The equivalent pressure shall be calculated using Eq. (1), with $F = 0$ in Eq. (2), except using the geometry of the suction bell. The suction bell pressure, P_{sb} , is applied only to the suction bell flange. Below the suction bell flange (Section A-A of Fig. ND-3441.10-1), the remaining portion of the bell and any strainer basket which may be attached thereto are not considered subject to a differential pressure load.

ND-3442 Special Pump Types

ND-3442.1 Design of Type J Pumps (Centrifugal)

(a) Type J pumps are those that cannot logically be classified with any of the preceding types of centrifugal pumps.

(b) It is not planned to establish rules for Type J pumps, and any design method which has been demonstrated to be satisfactory for the specified Design Conditions may be used.

ND-3442.2 Design of Reciprocating Pumps.

See ND-3450.

ND-3450 DESIGN OF CLASS 3 RECIPROCATING PUMPS

ND-3451 Scope

(a) These rules cover the strength and pressure integrity of the structural parts of the liquid end [Fig. ND-3451(a)-1], whose failure would violate the pressure boundary. Such parts include:

- (1) liquid cylinder and valve chambers
- (2) valve covers
- (3) liquid cylinder heads
- (4) stuffing boxes
- (5) packing glands
- (6) manifolds
- (7) piping and nozzles normally identified with the pump furnished by the pump supplier
- (8) related bolting
- (9) external and internal integral attachments to the pressure retaining boundary

(b) These rules do not apply to the plunger or piston, nonstructural internals, including valves, valve seats, gaskets, packing, and cylinder mounting bolting. Hydrostatic testing of packing glands is not required.

ND-3452 Acceptability

The pressure boundary parts shall be capable of withstanding the specified Design Pressures, and the design shall be such that the requirements of ND-3100 are satisfied in addition to these rules.

ND-3453 Material and Stresses

Material and allowable stresses shall conform to the requirements of ND-2000.

Page 125

Page 126

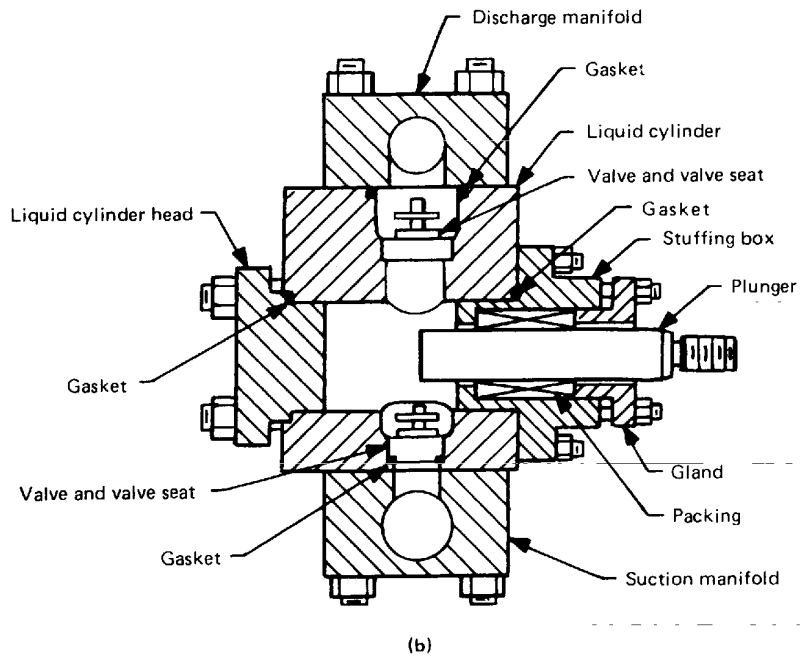
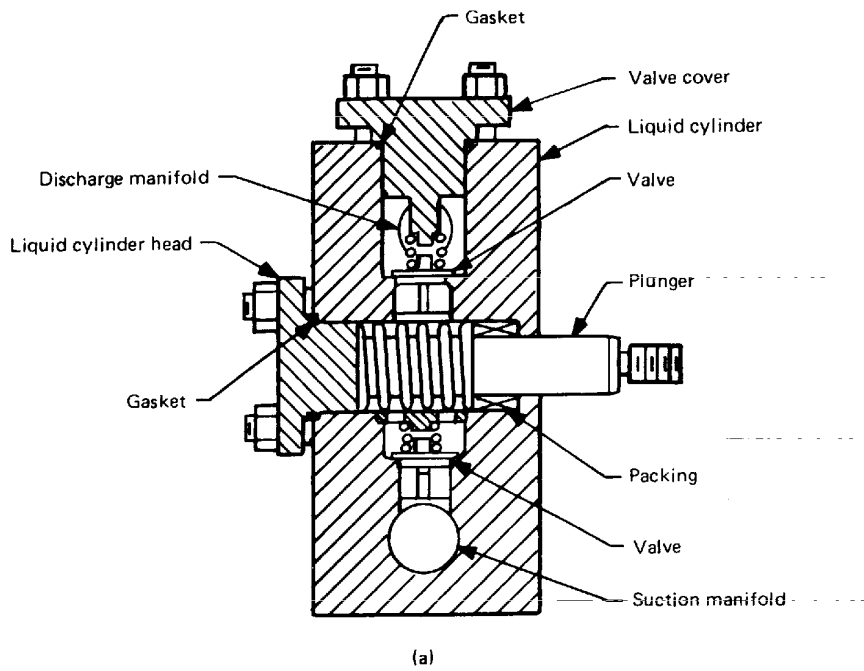


FIG. ND-3451(a)-1 HORIZONTAL SINGLE-ACTING POWER PUMP LIQUID ENDS

FIG. ND-3451(a)-1 HORIZONTAL SINGLE-ACTING POWER PUMP LIQUID ENDS

ND-3454 Design Requirements

ND-3454.1 Design of Welded Construction

(a) Design of welded construction shall be in accordance with ND-3350.

(b) Partial penetration welds, as shown in Fig. ND-4244(e)-1 sketch (c-3) and Fig. ND-4244(f)-1 sketches (a) and (b), are allowed for nozzles such as vent and drain connections and openings for instrumentation. Nozzles shall not exceed NPS 2 (DN 50). For such nozzles, all reinforcement shall be integral with the portion of the shell penetrated. Partial penetration welds shall be of sufficient size to develop the full strength of the nozzles.

ND-3454.2 Piping.

Piping located within the pressure retaining boundary of the pump, and identified with the pump, shall be designed in accordance with ND-3600.

ND-3454.3 Liquid End.

Any design method which has been demonstrated to be satisfactory for the specified design may be used.

ND-3454.4 Fatigue.

The liquid cylinder and pressure retaining bolting are exposed to significant fatigue loadings which shall be considered in the design. Any design method which has been demonstrated to be satisfactory for the specified design may be used.

ND-3454.5 Earthquake Loadings.

The effects of earthquake shall be considered in the design of pumps. The stresses resulting from these earthquake effects shall be included with the stresses resulting from pressure or other applied loads.

ND-3454.6 Corrosion.

In designs where corrosion of material is a factor, allowances shall be made.

ND-3454.7 Bolting.

Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with the procedure described in Appendix XI.

ND-3500 VALVE DESIGN

ND-3510 GENERAL REQUIREMENTS

ND-3511 Design Specification¹⁹

¹⁹

CAUTIONARY NOTE: Certain types of double seated valves have the capacity of trapping liquid in the body or bonnet cavity in the closed position. If such a cavity accumulates liquid and is in the closed position at a time when adjacent system piping is increasing in temperature, a substantial and uncontrolled increase in pressure in the body or bonnet cavity may result. Where such a condition is possible, it is the responsibility of the Owner or his designee to provide, or require to be provided, protection against harmful overpressure in such valves.

Design and Service Conditions (NCA-2142) shall be stipulated in the Design Specification (NCA-3250). The requirements of NCA-3254(a) for specifying the location of valve boundary jurisdiction may be considered to have been met by employing the minimum limits of ND-1131, unless the Design Specification extends the boundary of jurisdiction beyond these minimum limits. The requirements of NCA-3254(b) for specifying the boundary conditions are not applicable to valve end connections.

ND-3512 Standard Design Rules

ND-3512.1 Flanged and Butt Welded End Valves.

The design of valves with flanged and butt welded ends shall conform to the applicable requirements for Standard Class category valves of ANSI B16.34 except as provided in (a) and (b) below.

(a) Valves with flanged and butt welding ends may be designated as Class 75 in sizes larger than NPS 24, provided that the following additional requirements are met.

(1) The maximum rated pressure shall be 75 psi (517 kPa) for fluid temperatures from -20°F to 350°F (-29°C to 177°C).

(2) The minimum valve body wall thickness, exclusive of corrosion allowance, shall be in accordance with the following:

$$t_m = 0.4t_o + 0.2 \text{ for } d \leq 50 \text{ in.}$$

or

$$t_m = 0.008d + 0.2 \text{ for } d > 50 \text{ in.}$$

where

t_m = minimum body wall thickness, in.

t_o = minimum body wall thickness as tabulated in ANSI B16.34 for Class 150, in.

d = inside diameter, in.

(3) Flanges shall be designed in accordance with the requirements of Appendix XI, AWWA-C207 Class E (275 psi), MSS-SP-44, or API-605.

(4) The minimum hydrostatic shell test pressure shall be 125 psi (861 kPa) and shall be maintained for a minimum of 10 min.

(5) The minimum valve closure test pressure shall be 85 psi (586 kPa) and shall be maintained for a minimum of 10 min.

Page 127

(b) Valves with flanged ends in sizes larger than NPS 24 may be used, provided that the following additional requirements are met.

(1) For MSS-SP-44 the Pressure Class shall be limited to Class 600 and lower, and for API-605 the Pressure Class shall be limited to Class 150 and Class 300.

(2) The operating temperatures shall be limited to the range of -20°F to 650°F (-29°C to 343°C).

(3) Flanges are designed in accordance with the requirements of Appendix XI, MSS-SP-44, or API-605.

ND-3512.2 Socket Welded End and Nonwelded End Valves.

The design of valves with socket welded end connections and nonwelded piping end connections other than ANSI B16.5 flanges shall conform to the applicable requirements for Standard Class category butt welding valves of ANSI B16.34 except that the end connections shall conform to the applicable requirements of ND-3661 or ND-3671.

ND-3512.3 Wafer or Flangeless Valves.

The design of valves that can be bolted between flanges (i.e., butterfly valves) shall conform to the applicable requirements of Standard Class category valves of ANSI B16.34 and the requirements of (a) through (e) below.

(a) The design shall provide for bolt-up using all of the bolt holes and the bolt circle of the specified flange.

(b) Bolt holes parallel to the body run may be either threaded or unthreaded. Threaded holes may be blind holes suitable for use with bolt studs.

(c) The required minimum valve body wall thickness shall be measured from the valve inside circumference to either the valve outside circumference or the circumference of a circle inscribed about the inner tangents to the bolt holes, whichever is smaller.

(d) The inner ligament of either a through hole or a blind threaded hole in the vicinity of a stem penetration shall not be less than 25% of the required body neck thickness.

(e) The inner ligament for singular holes parallel to the body run shall not be less than 25% of the required valve body wall thickness. Such holes shall not be larger than $\frac{3}{8}$ in. (10 mm) diameter.

ND-3512.4 Design and Service Loadings.

The design requirements of ND-3512.1 and ND-3512.2 include pressure-temperature ratings for Design Loadings and Service Loadings for which Level A Limits are designated. When any Service Loadings are stipulated for which Level B, Level C, or Level D Limits are designated in the Design Specification, the requirements of ND-3520 shall be met.

ND-3512.5 Openings for Auxiliary Connections.

Openings for auxiliary connections, such as for drains, bypasses, and vents, shall meet the requirements of ANSI B16.34 and the applicable requirements of ND-3330.

ND-3513 Alternative Design Rules

For butt welding end valves and for socket welding end valves whose end connections conform to the requirements of ND-3661, the design requirements for Special Class category valves of ANSI B16.34 may be used in place of ND-3512 when permitted by the Design Specification, provided that the following requirements are met.

(a) The nondestructive examination requirements of ANSI B16.34, Special Class, shall be met for all sizes of butt welding and socket welding end valves in accordance with the examination methods and acceptance standards of ND-2500.

(b) When any Service Loadings are stipulated for which Level B, Level C, or Level D Limits are designated in the Design Specification, the requirements of ND-3520 shall be met.

(c) Openings for auxiliary connections, such as for drains, bypasses, and vents, shall meet the requirements of ANSI B16.34 and the applicable reinforcement requirements of ND-3330.

ND-3515 Acceptability of Metal Bellows and Metal Diaphragm Stem Sealed Valves

Valves using metal bellows or metal diaphragm stem seals shall be constructed in accordance with the rules of this Subarticle, based on the assumption that the bellows or diaphragms do not retain pressure and Design Pressure is imposed on a required backup stem seal such as packing. The bellows or diaphragms need not be constructed in accordance with the requirements of this Section.

ND-3516 Acceptability of Elastomer Diaphragm Valves

Valves using elastomer diaphragms, wherein the diaphragm performs the function of a disc or plug, shall be constructed in accordance with ND-3500. This is based on the assumptions that the diaphragms do not retain pressure, design pressure is imposed on the backup stem seal, and the following additional requirements are met.

(a) Design temperature shall not exceed 350°F (177°C).

(b) Valve size and Pressure Class shall not exceed NPS 12 (DN 300) for Class 150 and NPS 4 (DN 100) for Class 300.

(c) A backup stem seal shall be provided.

(d) Diaphragms shall meet the requirements of MSS SP-100.

ND-3520 LEVEL B, C, AND D SERVICE LIMITS

ND-3521 Design Requirements

(a) When the piping system in which the valve is located is designed to the requirements of ND-3600, the valve body is considered adequate to withstand piping end loads provided that conditions (1) and (2) below are satisfied. In lieu of (1) and (2), the design procedure of NB-3545.2 is acceptable.

(1) The section modulus and metal area at a plane normal to the flow passage through the region at the valve body crotch, that is, in the plane A-A of Fig. ND-3521-1, shall be not less than 110% of the section modulus and metal area of the piping connected to the valve body inlet and outlet nozzles.

(2) The allowable stress for valve body material is equal to or greater than the allowable stress of the connected piping material. If the valve body material allowable stress is less than that of the connected piping material, the valve section modulus and metal area shall be not less than 110% of the section modulus and metal area of the connected piping multiplied by the ratio $S_{\text{pipe}}/S_{\text{valve}}$.

(b) The maximum internal pressure resulting from Service Loadings for which Level B, Level C, or Level D Limits are designated shall not exceed the tabulated factors in Table ND-3521-1 times the Design Pressure or the rated pressure at the applicable service temperature. If these pressure limits are met, loadings for the stress limits in Table ND-3521-1 are considered to be satisfied.

(c) Where valves are provided with operators having extended structures and these structures are essential to maintaining pressure integrity, an analysis, when required by the Design Specification, shall be performed based on static forces resulting from equivalent earth quake accelerations acting at the centers of gravity of the extended masses. The valve bodies shall conform to the stress limits listed in ND-3522. Classical bending and direct stress equations, where free body diagrams determine a simple stress distribution that is in equilibrium with the applied loads, may be used.

TABLE ND-3521-1
LEVEL A, LEVEL B, LEVEL C, AND LEVEL D
SERVICE LIMITS

Service Limit	Stress [Note (1)] Limits [Notes (2)–(5)]	$P_{\max}$ [Note (6)]
Level A	$\sigma_m \leq 1.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5S$	1.0
Level B	$\sigma_m \leq 1.1S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65S$	1.1
Level C	$\sigma_m \leq 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$	1.2
Level D	$\sigma_m \leq 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$	1.5

NOTES:

- (1) Stress means the maximum normal stress.
- (2) A casting quality factor of 1 shall be assumed in satisfying these stress limits.
- (3) These requirements for the acceptability of valve design are not intended to assure the functional adequacy of the valve.
- (4) Design requirements listed in this table are not applicable to valve disks, stems, seat rings, or other parts of the valves which are contained within the confines of the body and bonnet.
- (5) These rules do not apply to safety relief valves.
- (6) The maximum pressure shall not exceed the tabulated factors listed under $P_{\max}$ times the Design Pressure or times the rated pressure at the applicable service temperature.

TABLE ND-3521-1 LEVEL A, LEVEL B, LEVEL C, AND LEVEL D SERVICE LIMITS

ND-3522 Stress and Pressure Limits

Level B, C, and D Service Limits are specified in Table ND-3521-1. The symbols used in Table ND-3521-1 are defined as follows:

σ_m	= general membrane stress, psi. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.
σ_L	= local membrane stress, psi. This stress is the same as σ_m , except that it includes the effect of discontinuities.
σ_b	= bending stress, psi. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.
S	= allowable stress value given in Tables 1A and 1B, Section II, Part D, Subpart 1, psi. The allowable stress shall correspond to the highest metal temperature at the section under consideration during the loading under consideration.

Page 129

Page 130

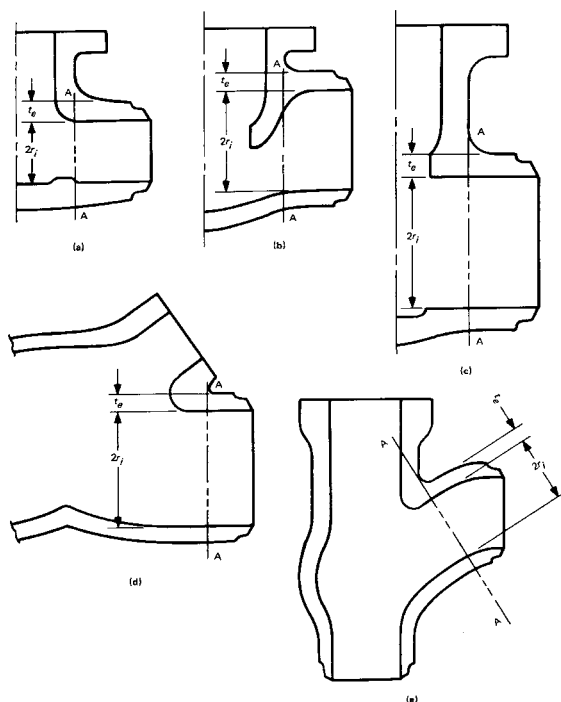


FIG. ND-3521-1 TYPICAL SECTIONS OF VALVE BODIES

FIG. ND-3521-1 TYPICAL SECTION OF VALVE BODIES

ND-3530 GENERAL RULES

ND-3531 Hydrostatic Tests

The following requirements apply to valves designated to either ND-3512 or ND-3513.

ND-3531.1 Shell Hydrostatic Test.

A shell hydrostatic test shall be made using either water or air in accordance with the requirements of ANSI B16.34. Stem seal leakage during this test is permissible. Hydrostatic tests for metal bellows of metal diaphragm stem sealed valves shall include hydrostatic testing of the valve body, bonnet, body-to-bonnet joint, and either the bellows or diaphragm or the required backup stem seal. End closure seals for retaining fluid at test pressure in welding end valves may be positioned in the welding end transitions as defined in ANSI B16.34 in reasonable proximity to the end plane of the valve so as to ensure safe application of the test pressure.

ND-3531.2 Valve Closure Test.

After the shell hydrostatic test, a valve closure test shall be performed in accordance with ANSI B16.34 except that all valve sizes shall be subjected to a test differential pressure across the valve disk not less than 110% of the 100°F (38°C) pressure rating. During this test, seat leakage value is defined by the Design Specification.

ND-3531.3 Time at Pressure.

The duration of the shell hydrostatic test shall meet the requirements of ND-6223. The duration of the valve closure test shall be the greater of either 1 in./in. of minimum wall thickness t_m or the testing time requirement of ANSI B16.34, but not less than 1 min.

ND-3531.4 Exemptions to the Valve Closure Test

(a) For valves that are designed for Service Conditions that have the pressure differential across the closure member limited to values less than the 100°F (38°C) pressure rating, or that have closure members or actuating devices (direct, mechanical, fluid, or electrical) that would be subject to damage at high differential pressures, the test pressure may be reduced to 110% of the maximum specified differential pressure in the closed position. This exception shall be identified in the Design Specification, and this maximum specified differential pressure shall be noted on the valve name plate and the N Certificate Holder's Data Report Form.

(b) For valves designed for nonisolation service, the primary function of which is to modulate flow, and which by their design are prevented from providing full closure, the valve closure test defined in ND-3531.2 above is not required. This exception shall be identified in the Design Specification and noted on the valve nameplate and the N Certificate Holder's Data Report Form.

ND-3590 PRESSURE RELIEF VALVE DESIGN

ND-3591 Acceptability

ND-3591.1 General Requirements.

The rules of this Subsubarticle constitute the requirements for the design acceptability of spring-loaded pressure relief valves. The design rules for pilot operated and power actuated pressure relief valves are covered by ND-3500. The rules of this Subsubarticle cover the pressure retaining integrity of the valve inlet and outlet connections, nozzle, disk, body structure, bonnet (yoke), and body-to-bonnet (yoke) bolting. The rules of this Subsubarticle also cover other items such as the spring, spindle (stem), spring washers, and set pressure adjusting screw. The rules of this Subsubarticle do not apply to guides, control rings, bearings, set screws, and other nonpressure-retaining items. Figures ND-3591.1-1 and ND-3591.1-2 are illustrations of typical pressure relief valves.

ND-3591.2 Definitions.

The definitions for pressure relief valve terms used in this Subsubarticle are given in the American National Standard ANSI B95.1-1977, Terminology for Pressure Relief Devices, and also in ND-7000. Pressure relief valves characteristically have multipressure zones within the valve, that is, a primary pressure zone and a secondary pressure zone as illustrated by Figs. ND-3591.1-1 and ND-3591.1-2.

ND-3591.3 Acceptability of Small Pressure Relief Valves.

Pressure relief valves having inlet piping connections NPS 2 and under shall comply with the wall thickness requirements of ND-3595.1. Other elements of the valve shall be designed to ensure pressure integrity, in accordance with appropriate design practices based on successful experience in comparable service conditions.

ND-3591.4 Acceptability of Large Pressure Relief Valves.

The design shall be such that the requirements of this Subsubarticle are met.

ND-3592 Design Considerations

ND-3592.1 Design Conditions.

The general design requirements of ND-3100 are applicable with consideration for the design conditions of the primary and secondary pressure zones. In case of conflict between ND-3100 and ND-3590, the requirements of ND-3590

Page 131

Page 132

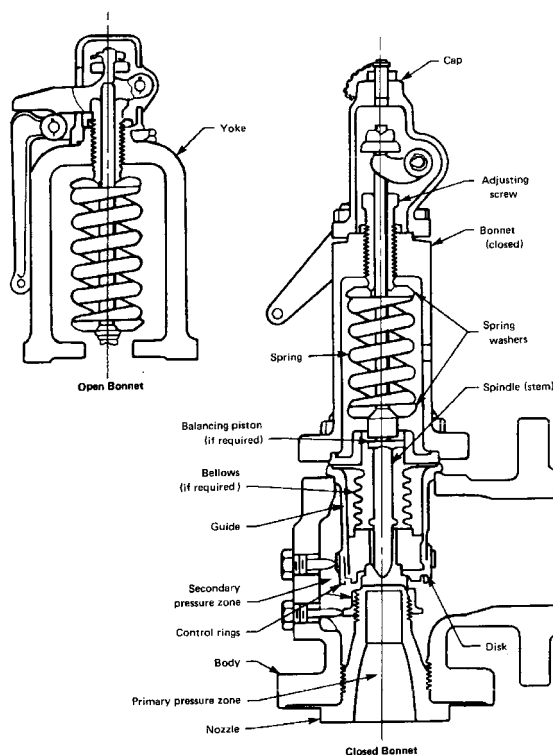


FIG. ND-3591.1-1 TYPICAL PRESSURE RELIEF DEVICES

shall apply. Mechanical loads for both the closed and open (full discharge) positions shall be considered in conjunction with the service conditions. In addition, the requirements of ND-7000 shall be met.

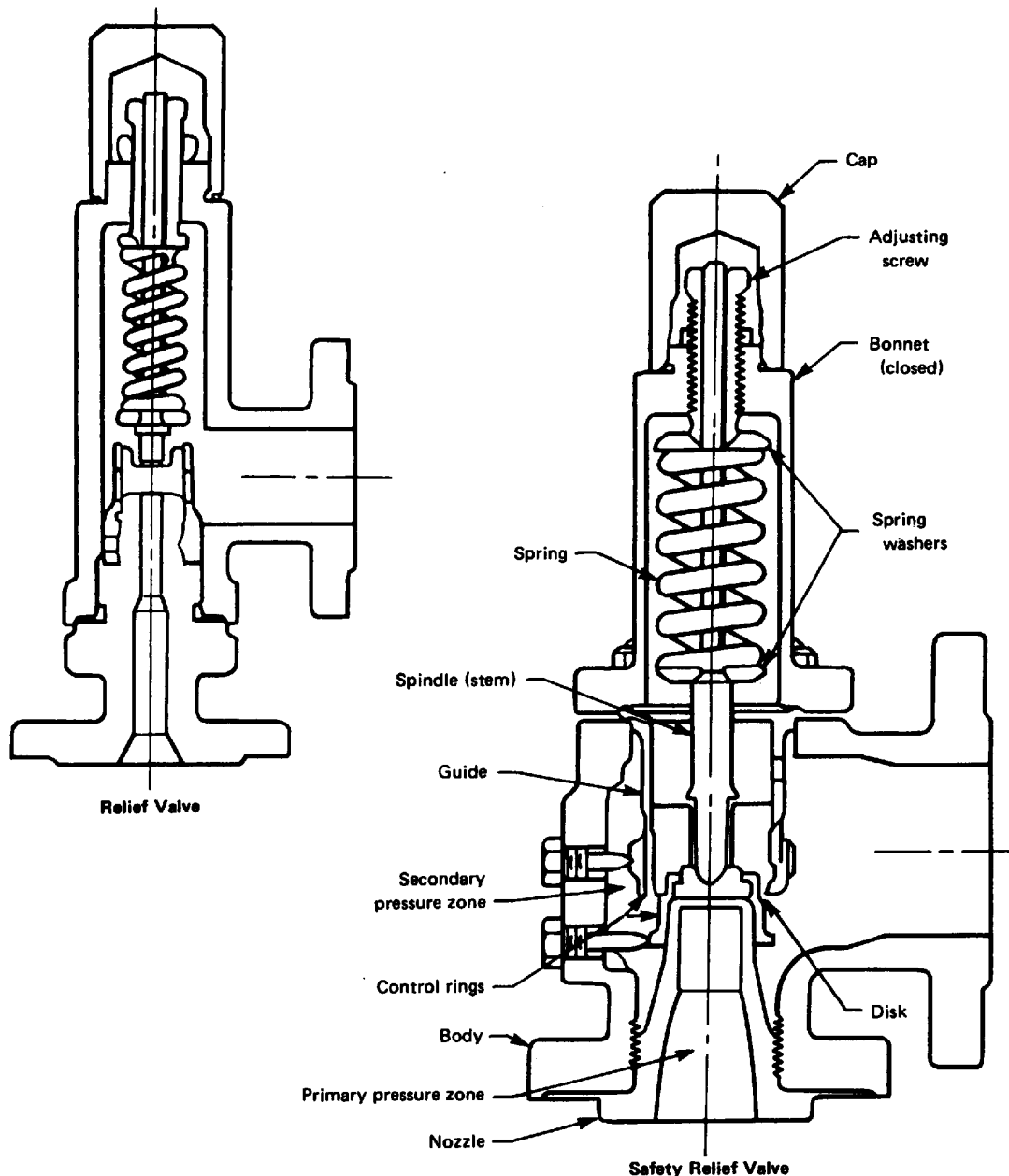


FIG. ND-3591.1-2 TYPICAL PRESSURE RELIEF DEVICES

FIG. ND-3591.1-2 TYPICAL PRESSURE RELIEF DEVICES

ND-3592.2 Stress Limits For Specified Service Loadings

(a) *Level A Service Loadings.* Stress limits for Level A service loadings for the valve shall be as follows.

(1) The general membrane stress shall not exceed S .

(2) The general membrane stress plus bending stress shall not exceed $1.5S$.

(3) Substantiation by analysis of localized stresses associated with contact loading of bearing or seating surfaces is not required.

(4) The values of S shall be in accordance with Tables 1A, 1B, and 3, Section II, Part D, Subpart 1.

(b) *Level B, C, and D Service Loadings.* Stress limits for Level B, C, and D service loadings are specified in Table ND-3592.2(b)-1. The symbols used in Table ND-3592.2(b)-1 are defined in ND-3522.

ND-3593 Special Rules

ND-3593.1 Hydrostatic Test.

Pressure relief valve shell hydrostatic tests shall be made in accordance with ND-3531.1 and ND-3531.3 except that the inlet (primary pressure containing) portion of the pressure relief valve shall be shell tested at a pressure at least equal to 1.5 times the set pressure marked on the valve. For closed system application, the outlet portion of the pressure relief valve shall be shell tested to 1.5 times the design secondary pressure (ND-7111).

ND-3593.2 Marking.

In addition to marking required by NCA-8220 and ND-7000, the secondary design pressure shall be marked on the valve or valve name plate.

ND-3594 Design Requirements for Level B, C, and D Service Loadings

(a) When the piping system in which the valve is located is designed to the requirements of ND-3600, the valve body may be considered adequate to withstand piping end loads, provided that conditions (1) and (2) below are satisfied.

(1) The section modulus and metal area at a plane normal to the flow passage through the region at the valve inlet and outlet (Figs. ND-3591.1-1 and ND-3591.1-2) shall be not less than 110% of the section modulus and metal area of the piping connected (or joined) to the valve inlet and outlet.

**TABLE ND-3592.2(b)-1
CLASS 3 PRESSURE RELIEF DEVICES:
LEVEL B, C, AND D SERVICE LOADINGS**

Service Loadings	Stress Limits
Level B	$\sigma_m \leq 1.1 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65 S$
Level C	$\sigma_m \leq 1.5 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8 S$
Level D	$\sigma_m \leq 2.0 S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4 S$

GENERAL NOTES:

- (a) A casting quality factor is not required to satisfy these limits.
- (b) These requirements for the acceptability of valve design are not intended to ensure the functional adequacy of the valve. However, the designer is cautioned that the requirements of ND-7000 relative to set pressure, lift, blowdown, and closure shall be met.
- (c) Design requirements listed in this Table are applicable to those portions of the valves which are pressure retaining or affect pressure retaining items of these valves.

TABLE ND-3592.2(b)-1 CLASS 3 PRESSURE RELIEF DEVICES: LEVEL B, C, AND D SERVICE LOADINGS

(2) The allowable stress for valve body material shall be equal to or greater than the allowable stress of the connected piping material. If the valve body material allowable stress is less than that of the connected piping material, the valve section modulus and metal area shall be not less than 110% of the section modulus and metal area of the connecting pipe multiplied by the ratio $S_{\text{pipe}}/S_{\text{valve}}$.

(b) The pressure retaining portions of pressure relief valves shall conform to the stress limits listed in Table ND-3592.2(b)-1 for those service loadings stipulated as Level B, C, or D.

(c) Pressure relief valves have extended structures, and these structures are essential to maintaining pressure integrity. An

analysis, when required by the Design Specification, shall be performed based on static forces resulting from equivalent earthquake accelerations acting at the centers of gravity of the extended masses. Classical bending and direct stress equations, where free body diagrams determine a simple stress distribution that is in equilibrium with the applied loads, may be used.

ND-3595 Design of Pressure Relief Valve Parts

ND-3595.1 Body.

Minimum wall thicknesses of valve bodies shall conform to the applicable requirements for Standard Class category valves of ANSI B16.34, taking into account the dimensional and pressure conditions of the primary and secondary zones. Minimum wall thickness adjacent to the inlet nozzle and for a distance

Page 134

equal to that minimum wall thickness from the plane of the back face of the inlet flange shall be that required for Standard Class category valves of ANSI B16.34 for the inlet flange size and pressure class. Minimum wall thicknesses elsewhere in the secondary zone shall be determined by the requirements for Standard Class category valves of ANSI B16.34 for the outlet flange size and pressure class, including such other rules and considerations of ANSI B16.34 as may be applicable. In valve design where the outlet flange is an extension of the bonnet, the bonnet design shall conform to these rules. Where the inlet flange geometry involves inside contours encroaching on the metal section boundary represented by dimension B in Tables 9, 12, 15, 18, 21, 24, or 27 in ANSI B16.5, adequacy of the design shall be proven by stress calculation in accordance with ND-3658. Additional metal thickness needed for operating stresses, shapes other than circular, stress concentrations, and adequate structural strength of the crotch area(s) of the neck(s) of the valve for bending stresses and installation stress that may be imposed on the valve must be determined by the manufacturer.

ND-3595.2 Bonnet (Yoke).

The bonnet (yoke) may be analyzed using classic bending and direct stress formulae, with appropriate free body diagrams. The general membrane stress and the general membrane stress plus bending stress shall not exceed the stress limits of ND-3592.2.

ND-3595.3 Nozzle.

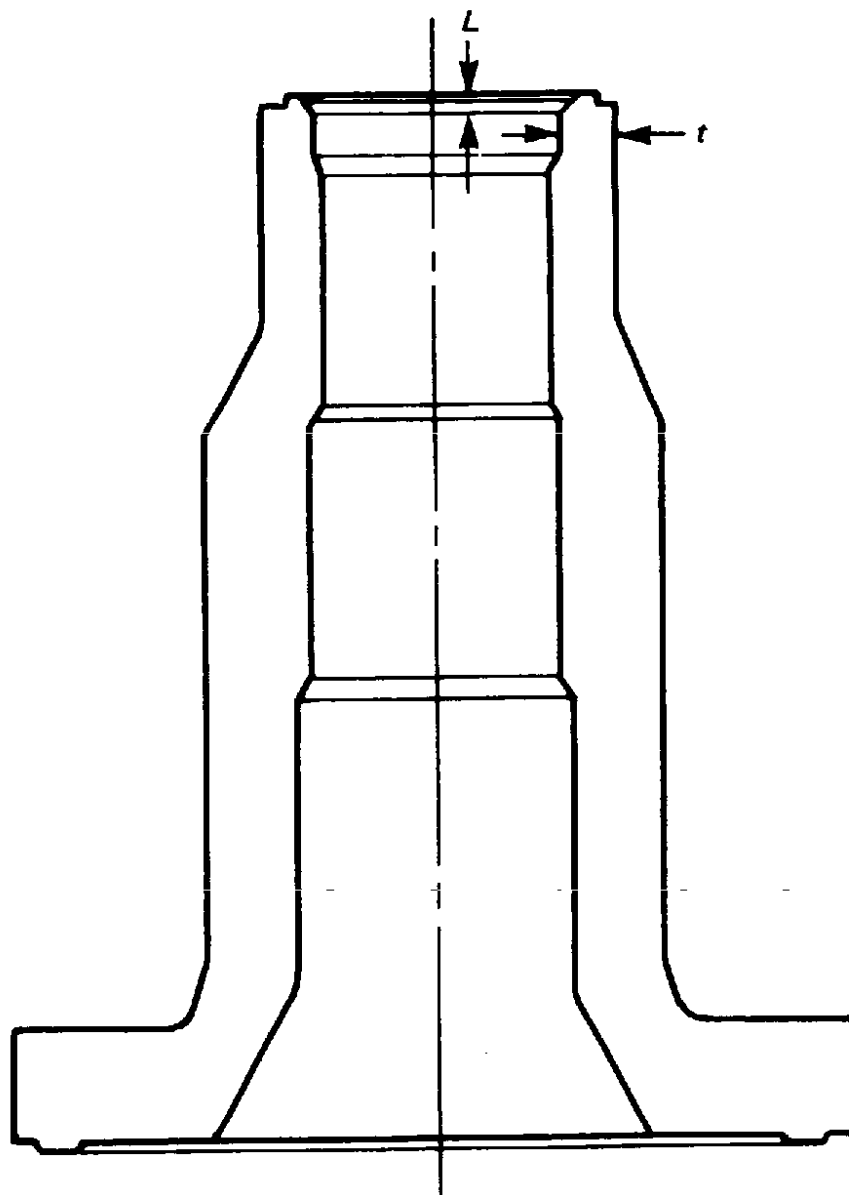
The minimum wall thickness of the nozzle shall be determined from the limit on general membrane stress. Alternatively, the rules of NB-3594.3 may be used. These requirements are not applicable to the transition region to the seat contacting area of the nozzle defined by L in Fig. ND-3595.3-1, provided the dimension L is less than the nominal wall thickness t .

ND-3595.4 Body-to-Bonnet Joint.

For valves having inlet piping connections NPS 2 and less, body-to-bonnet connections may be threaded. The thread shear stress, considering all loadings, shall not exceed 0.6 times the allowable stress S . The body-to-bonnet bolting shall be designed to resist the hydrostatic end force of the rated maximum secondary Design Pressure combined with the total spring load to full lift, and to maintain sufficient compression for a tight joint on the gasket or joint contact surface. The bolt stresses for these loadings shall not exceed the allowable stress values of Table 3, Section II, Part D, Subpart 1.

ND-3595.5 Disk.

The stress evaluation shall be made for the condition which results in the maximum stress in the disk. The bending stress shall not exceed the stress limits of ND-3592.2.



t = nozzle wall thickness, in.
 L = length of seal transition region, in.
 $L \leq t$

FIG. ND-3595.3-1 VALVE NOZZLE

FIG. ND-3595.3-1 VALVE NOZZLE

ND-3595.6 Spring Washer.

The shear stress shall not exceed 0.6S. The bending stress shall not exceed the stress limits of ND-3592.2.

ND-3595.7 Spindle (Stem).

The general membrane stress shall not exceed the stress limits of ND-3592.2.

ND-3595.8 Adjusting Screw.

The adjusting screw shall be analyzed for thread stress in accordance with the method of ANSI B1.1 and this stress shall not exceed 0.6S. The general membrane stress of the adjusting screw shall not exceed the stress limits of ND-3592.2, based on the root diameter of the thread.

ND-3595.9 Spring.

The valve spring shall be designed so that the full lift spring compression shall be no greater than 80% of the nominal solid deflection. The permanent set of the spring (defined as the difference between the free height and the height measured a minimum of 10 min after the spring has been

Page 135

compressed solid three additional times after presetting at room temperature) shall not exceed 1.0% of the free height.

ND-3596 Design Reports

ND-3596.1 General Requirements.

The manufacturer shall certify compliance with the requirements of this Subsubarticle in accordance with the provisions of NCA-3570.

ND-3600 PIPING DESIGN

ND-3610 GENERAL REQUIREMENTS

ND-3611 Acceptability

The requirements for acceptability of a piping system are given in the following subparagraphs.

[98]

ND-3611.1 Allowable Stress Values.

Allowable stress values to be used for the design of piping systems are given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1.

[98]

[98]

ND-3611.2 Stress Limits

(a) *Design and Service.* Loadings shall be specified in the Design Specification.

(b) *Design Loadings.* The sum of stresses due to design internal pressure, weight, and other sustained loads shall meet the requirements of Eq. (8), ND-3652.

(c) *Service Loadings.* The following Service Limits shall apply to Service Loadings as designated in the Design Specification.

(1) *Level A and B Service Limits.* For Service Loadings for which Level A and B Service Limits are designated in the Design Specification, the requirements of ND-3653 shall be met. When Level B Limits apply, the peak pressure $P_{\max}$ alone shall not exceed 1.1 times the pressure P_a calculated in accordance with Eq. (5), ND-3641.1.

(2) *Level C Service Limits.* For Service Loadings for which Level C Service Limits are designated in the Design Specification, the sum of stresses shall meet the requirements of ND-3654.

(3) *Level D Service Limits.* For Service Loadings for which Level D Service Limits are designated in the Design Specification, the sum of stresses due to internal pressure, live and dead load, and those due to occasional loads shall meet the requirements of ND-3655.

(4) *Test Conditions.* Testing shall be in accordance with ND-6000. Occasional loads shall not be considered as acting at time of test.

(d) *External Pressure Stress.* Piping subject to external pressure shall meet the requirements of ND-3641.2.

(e) *Allowable Stress Range for Expansion Stresses.* The allowable stress range S_A is given by Eq. (1):

$$(1) S_A = f(1.25 S_c + 0.25 S_h)$$

where

S_c = basic material allowable stress at minimum (cold) temperature, psi

S_h = basic material allowable stress at maximum (hot) temperature, psi

f = stress range reduction factor for cyclic conditions for total number N of full temperature cycles over total number of years during which system is expected to be in service, from Table ND-3611.2(e)-1

(1) In determining the basic material allowable stresses S_c and S_h , joint efficiencies need not be applied.

(2) Stress reduction factors apply essentially to noncorrosive service and to corrosion resistant materials, where employed to minimize the reduction in cyclic life caused by corrosive action.

(3) If the range of temperature change varies, equivalent full temperature cycles may be computed as follows:

$$(2) N = N_E + r_1^5 N_1 + r_2^5 N_2 + \dots + r_n^5 N_n$$

where

N_E = number of cycles at full temperature change ΔT_E for which expansion stress S_E has been calculated

$N_1, N_2, \dots, N_n$ = number of cycles at lesser temperature changes, $\Delta T_1, \Delta T_2, \dots, \Delta T_n$

$r_1, r_2, \dots, r_n$ = $(\Delta T_1)/(\Delta T_E), (\Delta T_2)/(\Delta T_E), \dots, (\Delta T_n)/(\Delta T_E)$

= the ratio of any lesser temperature cycles for which the expansion stress S_E has been calculated

(f) *Allowable Stress for Nonrepeated Stresses.* The allowable stress due to any single nonrepeated anchor movement (such as predicted building settlement) calculated in accordance with Eq. (10a) of ND-3653.2(b) shall be $3.0S_c$.

[98]

**TABLE ND-3611.2(e)-1
STRESS RANGE REDUCTION FACTORS**

Number of Equivalent Full Temperature Cycles <i>N</i>	<i>f</i>
7,000 and less	1.0
7,000 to 14,000	0.9
14,000 to 22,000	0.8
22,000 to 45,000	0.7
45,000 to 100,000	0.6
100,000 and over	0.5

TABLE ND-3611.2(e)-1 STRESS RANGE REDUCTION FACTORS

ND-3612 Pressure-Temperature Ratings for Piping Products

ND-3612.1 Piping Products Having Specific Ratings

(a) Pressure-temperature ratings for certain piping products have been established and are contained in some of the standards listed in Table ND-3132-1. The pressure ratings at the corresponding temperatures given in the standards listed in Table ND-3132-1 shall not be exceeded, and piping products shall not be used at temperatures in excess of those given in Tables 1A and 1B Section II, Part D, Subpart 1 for the materials of which the products are made.

(b) Where piping products have established pressure-temperature ratings which do not extend to the upper material temperature limits permitted by this Subsection, the pressure-temperature ratings between those established and the upper material temperature limit may be determined in accordance with the rules of this Subsection.

ND-3612.2 Piping Products Not Having Specific Ratings.

Should it be desired to use methods of manufacture or design of piping products not covered by this Subsection, it is intended that the manufacturer shall comply with the requirements of ND-3640 and ND-3690 and other applicable requirements of this Subsection for the Design Loadings involved. The manufacturer's recommended pressure ratings shall not be exceeded.

ND-3612.4 Considerations for Local Conditions and Transients

(a) Where piping systems operating at different pressures are connected by a valve or valves, the valve or valves shall

be designed for the higher pressure system requirements of pressure and temperature. The lower pressure system shall be designed in accordance with (1), (2), or (3) below.

(1) The requirements of the higher pressure system shall be met.

(2) Pressure relief devices or safety valves shall be included to protect the lower pressure system in accordance with ND-7311 and ND-7321.

(3) Assure compliance with all the conditions of (a) through (e) below.

(a) Redundant check or remote actuated valves shall be used in series at the interconnection, or a check in series with a remote actuated valve.

(b) When mechanical or electrical controls are provided, redundant and diverse controls shall be installed which will prevent the interconnecting valves from opening when the pressure in the high pressure system exceeds the Design Pressure of the low pressure system.

(c) Means shall be provided such that operability of all components, controls, and interlocks can be verified by test.

(d) Means shall be provided to assure that the leakage rate of the interconnecting valves does not exceed the relieving capacity of the relief devices on the low pressure system.

(e) Adequate consideration shall be given to the control of fluid pressure caused by heating of the fluid trapped between two valves.

The low pressure system relieving capacity may be determined in accordance with ND-7311 and ND-7321, on the basis of the interconnecting valve being closed but leaking at a specified rate, when (a) through (e) above are met. The pressure relief devices or safety valves shall adjoin or be as close as possible to the interconnecting valve and shall relieve preferably to a system where the relieved effluent may be contained. The design of the overpressure protection system shall be based on pressure transients that are specified in the Design Specification, and all other applicable requirements of ND-7000 shall be met.

(b) Where pressure reducing valves are used and one or more pressure relief devices or safety valves are provided, bypass valves may be provided around the pressure reducing valves. The combined relieving capacity of the pressure relief devices, safety valves, and relief piping shall be such that the lower pressure system service pressure will not exceed the lower pressure system Design Pressure by more than 10% if the pressure reducing valve fails in the open position and the bypass valve is open at the same time. If the pressure reducing valve and its bypass valve are mechanically or electrically interlocked so that only one may be open at any time, the high pressure system is at a pressure higher than the Design Pressure of the

Page 137

low pressure system, the relieving capacity of the pressure relief devices, safety valves, and relief piping shall be at least equal to the maximum capacity of the larger of the two valves. The interlocks shall be redundant and diverse.

(c) Exhaust and pump suction lines for any service and pressure shall have relief valves of a suitable size, unless the lines and attached equipment are designed for the maximum pressure and temperature to which they may be accidentally or otherwise subjected.

(d) The effluent from relief devices may be discharged outside the containment only if provisions are made for the disposal of the effluent.

(e) Drip lines from steam headers, mains, separators, or other equipment operating at different pressures shall not discharge through the same trap. Where several traps discharge into a single header that is or may be under pressure, a stop valve and a check valve shall be provided in the discharge line from each trap. The Design Pressure of trap discharge piping shall not be less than the maximum discharge pressure to which it may be subjected. Trap discharge piping shall be designed for the same pressure as the trap inlet piping, unless the discharge piping is vented to a system operated under lower pressure and has no intervening stop valves.

(f) Blowdown, dump, and drain piping from water spaces of a steam generation system shall be designed for saturated steam at the pressures and temperatures given below.

Vessel Pressure, psi	Design Pressure, psi	Design Temperature, °F
600 and below	250	410
601 to 900	400	450
901 to 1500	600	490
1501 and above	900	535

These requirements for blowdown, dump, and drain piping apply to the entire system beyond the blowdown valves to the blowdown tank or other points where the pressure is reduced to approximately atmospheric and cannot be increased by closing a valve. Where pressures can be increased because of calculated pressure drop or otherwise, this shall be taken into account in the design. Such piping shall be designed for the maximum pressure to which it may be subjected.

(g) Pump discharge piping shall be designed for the maximum pressure exerted by the pump at any load and for the highest corresponding temperature actually existing.

**TABLE ND-3613.4-1
WELD JOINT EFFICIENCY FACTOR**

Type of Longitudinal Joint	Weld Joint Efficiency Factor <i>E</i>
Arc Weld	
Single butt weld	0.80
Double butt weld	0.90
Single or double butt weld with 100% radiography per ND-2560 for joints welded with filler metal or otherwise examined by ultrasonic methods per ND-2550 for joints welded without filler metal, as applicable	1.00
Electric resistance weld	0.85

TABLE ND-3613.4-1 WELD JOINT EFFICIENCY FACTOR

(h) When a fluid passes through heat exchangers in series, the Design Temperature of the piping in each section of the system shall conform to the most severe temperature condition expected to be produced by heat exchangers in that section.

ND-3613 Allowances

ND-3613.1 Corrosion or Erosion.

When corrosion or erosion is expected, the wall thickness of the piping shall be increased over that required by other design requirements. This allowance shall be consistent with the specified design life of the piping.

ND-3613.2 Threading and Grooving.

The calculated minimum thickness of piping that is to be threaded or grooved shall be increased by an allowance equal to the depth of the cut.

ND-3613.3 Mechanical Strength.

When necessary to prevent damage, collapse, or buckling of pipe due to superimposed loads from supports or other causes, the wall thickness of the pipe shall be increased, or, if this is impractical or would cause excessive local stresses, the superimposed loads or other causes shall be reduced or eliminated by other design methods.

ND-3613.4 Pressure Design Weld Joint Efficiency for Butt Welds.

Longitudinal weld joint efficiency factors for pressure design for butt welds as listed in Table ND-3613.4-1 shall be applied to the allowable stress values given in Tables 1A and 1B, Section II, Part D, Subpart 1.

ND-3613.5 Steel Casting Quality Factors.

The quality factors for castings required in Tables 1A and 1B,

Page 138

Section II, Part D, Subpart 1 apply to castings which are designed using the stresses contained in this Subsection. The minimum examination required for these castings is that stipulated in the applicable material specification and in ND-2570. Castings satisfying these minimum requirements shall be designed with a quality factor of 1.00.

ND-3620 DESIGN CONSIDERATIONS

ND-3621 Design and Service Loadings

The provisions of ND-3110 shall apply, except as modified in this Subarticle.

ND-3621.1 Cooling Effects on Pressure.

When the cooling of a fluid may reduce the pressure in the piping to below atmospheric, the piping shall be designed to withstand the external pressure or provision shall be made to break the vacuum.

ND-3621.2 Fluid Expansion Effects.

When the expansion of a fluid may increase the pressure, the piping system shall be designed to withstand the increased pressure or provision shall be made to relieve the excess pressure.

ND-3622 Dynamic Effects

ND-3622.1 Impact.

Impact forces caused by either external or internal loads shall be considered in the piping design.

ND-3622.2 Reversing Dynamic Loads.

Reversing dynamic loads are those loads which cycle about a mean value and include building filtered loads, earthquake, and the reflected waves in a piping system due to flow transients resulting from sudden opening or closure of valves (see Fig. ND-3622-1). A reversing dynamic load shall be treated as a nonreversing dynamic load in applying the rules of ND-3600 when either of the following conditions exist:

- (a) The frequency ratio of the dynamic dominant load driving frequency to the lowest piping system natural frequency is less than 0.5.
- (b) The number of reversing dynamic load cycles, exclusive of earthquake, exceed 20.

ND-3622.3 Vibration.

Piping shall be arranged and supported so that vibration will be minimized. The designer shall be responsible, by design and by observation under startup or initial service conditions, for ensuring that vibration of piping systems is within acceptable levels.

ND-3622.4 Exposed Piping.

Exposed piping shall be designed to withstand wind loadings, using meteorological data to determine wind forces. When State, Province, or Municipal ordinances covering the design of building structures are in effect and specify wind loadings, these values shall be considered the minimum design values. However, it is not necessary to consider earthquake and wind loadings to be acting concurrently.

ND-3622.5 Nonreversing Dynamic Loads.

Nonreversing dynamic loads are those loads which do not cycle about a mean value and include the initial thrust force due to sudden opening or closure of valves and waterhammer resulting from entrapped water in two-phase flow systems (see Fig. ND-3622-1).

ND-3623 Weight Effects

Piping systems shall be supported to provide for the effects of live and dead weights, as defined in the following subparagraphs, and they shall be arranged or properly restrained to prevent undue strains on equipment.

ND-3623.1 Live Weight.

The live weight shall consist of the weight of the fluid being handled or of the fluid used for testing or cleaning, whichever is greater.

ND-3623.2 Dead Weight.

The dead weight shall consist of the weight of the piping, insulation, and other loads permanently imposed upon the piping.

ND-3624 Thermal Expansion and Contraction Loads

ND-3624.1 General Requirements

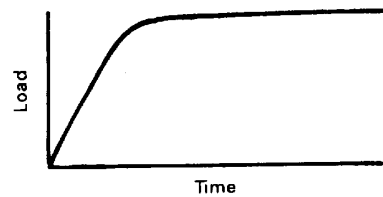
- (a) The design of piping systems shall take account of the forces and moments resulting from thermal expansion and contraction and from the effects of expansion joints.
- (b) Thermal expansion and contraction shall be provided for, preferably by pipe bends, elbows, offsets, or changes in direction of the piping.
- (c) Hangers and supports shall permit expansion and contraction of the piping between anchors.

ND-3624.2 Expansion Joints.

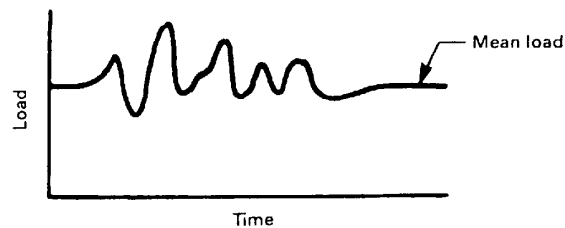
Expansion joints of the corrugated, slip sleeve, ball, or swivel types may be used if they conform to the requirements of ND-3649.1 through ND-3649.4, their structural and working parts are designed for the maximum pressure and temperature of the piping system, and their design prevents the complete disengagement of working parts while in service.

Page 139

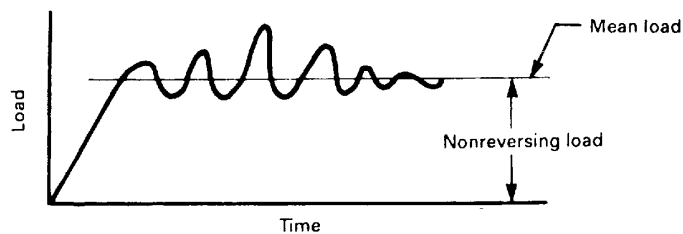
Page 140



**(a) Nonreversing Dynamic Load
(Relief/Safety Valve Open End Discharge)**



**(b) Reversing Dynamic Load
(Earthquake Load Cycling About Normal Operating Condition)**



**(c) Nonreversing Followed By Reversing
(Initial Water Slug Followed By Reflected Pressure Pulses)**

FIG. ND-3622-1 EXAMPLES OF REVERSING AND NONREVERSING DYNAMIC LOADS

ND-3640 PRESSURE DESIGN OF PIPING PRODUCTS

ND-3641 Straight Pipe

[98]

ND-3641.1 Straight Pipe Under Internal Pressure.

The minimum thickness of pipe wall required for Design Pressures and for temperatures not exceeding those for the various materials listed in Tables 1A and 1B, Section II, Part D, Subpart 1, including allowances for mechanical strength, shall not be less than that determined by Eq. (3) as follows:

$$t_m = \frac{PD_o}{2(SE + Py)} + A \quad (3)$$

$$t_m = \frac{Pd + 2SEA + 2yPA}{2(SE + Py - P)} \quad (4)$$

(3 - 4)

where

t_m

= minimum required wall thickness, in. If pipe is ordered by its nominal wall thickness, the manufacturing tolerance on wall thickness must be taken into account. After the minimum pipe wall thickness t_m is determined by Eq. (4), this minimum thickness shall be increased by an amount sufficient to provide the manufacturing tolerance allowed in the applicable pipe specification or required by the process. The next heavier commercial wall thickness shall then be selected from standard thickness schedules such as contained in ANSI B36.10 or from manufacturers' schedules for other than standard thickness.

P

= internal Design Pressure, psi

D_o

= outside diameter of pipe, in. For design calculations, the outside diameter of pipe as given in tables of standards and specifications shall be used in obtaining the value of t_m . When calculating the allowable pressure of pipe on hand or in stock,

the actual measured outside diameter and actual measured minimum wall thickness at the thinner end of the pipe may be used to calculate this pressure.

d

= inside diameter of pipe, in. In using Eq.(4) the value of d is for the maximum possible inside diameter allowable under the purchase specification.

S

= maximum allowable stress for the material at the Design Temperature, psi (Section II, Part D, Subpart 1, Tables 1A and 1B)

E

= joint efficiency for the type of longitudinal joint used, as given in Table ND-3613.4-1, or casting quality factor determined in accordance with ND-3613.5

A

= additional thickness, in.:

(a) to compensate for material removed or wall thinning due to threading or grooving, required to make a mechanical joint. The values of A listed in Table ND-3641.1(a)-1 are minimum values for material removed in threading.

(b) to provide for mechanical strength of the pipe. Small diameter, thin wall pipe or tubing is susceptible to mechanical damage due to erection, operation, and maintenance procedures. Accordingly, appropriate means must be employed to protect such piping against these types of loads if they are not considered as Design Loads. Increased wall thickness is one way of contributing to resistance against mechanical damage.

(c) to provide for corrosion or erosion. Since corrosion and erosion vary widely from installation to installation, it is the responsibility of designers to determine the proper amounts which must be added for either or both of these conditions.

**TABLE ND-3641.1(a)-1
VALUES OF A**

Type of Pipe	A , in.
Threaded steel and nonferrous pipe: 3/4 in. nominal and smaller	0.065
1 in. nominal and larger	Depth of thread
Grooved steel and nonferrous pipe	Depth of groove plus 1/64 in.

TABLE ND-3641.1(a)-1 VALUES OF A

The allowable working pressure of pipe may be determined from the following equation:

$$P_a = \frac{2SEt}{D_o - 2yt} \quad (5)$$

(5)

where

t	= the specified or actual wall thickness minus, as appropriate, material removed in threading, corrosion or erosion allowance, material manufacturing tolerances, bending allowance (NB-3642.1), material to be removed by counterboring, in.
P_a	= the calculated maximum allowable internal pressure, psi, for straight pipe which shall at least equal the Design Pressure. P_a may be used for piping products with pressure ratings equal to that of straight pipe (see ANSI B16.9). For standard flanged joints, the rated pressure shall be used instead of P_a . For other piping products where the pressure rating may be less than that of the pipe [for example, flanged joints designed to Appendix XI and reinforced branch connections (ND-3643) where part of the required reinforcement is in the run pipe], the Design Pressure shall be used instead of P_a . P_a may be rounded out to the next higher unit of 10.
y	= a coefficient having a value of 0.4, except that for pipe with a D_o/t_m ratio less than 6, the value of y shall be taken as:

$$y = \frac{d}{d + D_o} \quad (6)$$

(6)
[98]

ND-3641.2 Straight Pipe Under External Pressure.

For determining wall thickness and stiffening requirements for straight pipe under external pressure, the procedures outlined in ND-3133 shall be followed.

ND-3642 Curved Segments of Pipe

ND-3642.1 Pipe Bends.

Pipe bends shall be subject to the limitations in (a), (b), and (c) below.

(a) The minimum wall thickness after bending shall not be less than the minimum wall thickness required for straight pipe.

(b) The ovality shall meet the requirements of ND-4223.2.

(c) The information in Table ND-3642.1(c)-1 is given to guide the designer when ordering pipe.²⁰

²⁰ The minimum thicknesses of straight pipe shown in Table nd-3642.1(c)-1 should be sufficient to allow the pipe to meet the minimum wall thicknesses requirements of ND-3641 after having been

**TABLE ND-3642.1(c)-1
MINIMUM THICKNESS FOR BENDING**

Radius of Bends	Minimum Thickness Recommended Prior to Bending [Note (1)]
6 pipe diameters or greater	$1.06t_m$
5 pipe diameters	$1.08t_m$
4 pipe diameters	$1.16t_m$
3 pipe diameters	$1.25t_m$

NOTE:

(1) t_m is determined by Eq. (3) or (4) of ND-3641.1.

TABLE ND-3642.1(c)-1 MINIMUM THICKNESS FOR BENDING

ND-3642.2 Elbows.

Flanged elbows manufactured in accordance with the standards listed in Table ND-3132-1 shall be considered suitable for use at the pressure-temperature ratings specified by such standards. In the case of standards under which butt welding elbows are made to a nominal wall thickness, the elbows shall be considered suitable for use with pipe of the same nominal thickness and of the same material.

ND-3643 Intersections

[98]

ND-3643.1 General Requirements

(a) ND-3643 gives acceptable rules governing the design of branch connections to sustain internal and external pressure in cases where the axes of the branch and the run intersect, the angle between the axes of the branch and of the run is between 45 deg and 90 deg, inclusive, and no allowance is required for corrosion or erosion.

(b) Branch connections in which the smaller angle between the axes of the branch and the run is less than 45 deg impose special design and fabrication problems. The rules given for angles between 45 deg and 90 deg, inclusive, may be used as a guide, but sufficient additional strength must be provided to assure safe service. Such branch connections shall be designed to meet the requirements of ND-3649.

(c) Branch connections in piping may be made by using one of the products or methods given in (1) through (4) below:

(1) flanged, butt welding, socket welding, or screwed fittings made in accordance with the applicable standards listed in Table ND-3132-1;

(2) welding outlet fittings, such as cast or forged nozzles; couplings including ANSI B16.11 couplings, to a maximum nominal size of 3 in.; and adaptors or similar items having butt welding, socket welding, threaded, or flanged ends for attachment of the branch

Page 142

pipe. Such outlet fittings shall be attached to the main pipe:

(a) by the full penetration weld; or

(b) for right angle branch connections, by a fillet weld or partial penetration weld as shown in Fig. ND-3643.2(b)-2, sketch (e) or (f), provided the requirements of (1) through (4), as follows, are met:

(1) the nominal size of the branch shall not exceed 2 in. or one-quarter of the nominal size of the run, whichever is less;

(2) the minimum size of the weld, $x_{\min}$, shall not be less than $1\frac{1}{4}$ times the fitting wall thickness in the reinforcement zone;

(3) the groove angle, θ , shall be equal to or greater than 45 deg;

(4) except for attaching ANSI B16.11 couplings, the requirements of ND-3643.3 shall be met.

(3) extruded outlets at right angles to the run pipe, in accordance with ND-3643.4, where the attachment of the branch pipe is by butt welding;

(4) by attaching the branch pipe directly to the run pipe by welding or threading as stipulated in (a), (b), or (c) below:

(a) right angle branch connections may be made by attaching the branch pipe to the run pipe by socket welding, provided the requirements of (1) through (5) below are met:

(1) the nominal size of branch does not exceed 2 in. (51 mm) or one-fourth the nominal size of the run, whichever is less;

(2) the depth of the socket in the run is at least equal to that shown in ANSI B16.11 with a minimum shoulder of $\frac{1}{16}$ in. (1.6 mm) between the bottom of the socket and the inside diameter of the run pipe; weld metal may be deposited on the run pipe to provide the required socket depth and to provide any reinforcement required;

(3) a minimum of $\frac{1}{16}$ in. (1.6 mm) clearance shall be provided between the bottom of the socket and the end of the inserted pipe;

(4) the size of the fillet weld shall not be less than $1\frac{1}{4}$ times the nominal branch wall thickness;

(5) the requirements of ND-3643.3 shall be met.

(b) right angle branch connections may be made by attaching the branch pipe directly to the run by threading within the provisions of ND-3671.3 and provided the requirements of (1) and (2) below are met:

(1) the nominal size of the branch does not exceed 2 in. or one-fourth the nominal size of the run, whichever is less;

(2) minimum thread engagement shall be six full threads for $\frac{1}{2}$ in. and $\frac{3}{4}$ in. (DN 15 and DN 20) branches; seven for 1 in., $1\frac{1}{4}$ in. and $1\frac{1}{2}$ in. (DN 15, DN 32, and DN 40) branches; and eight for 2 in. branches; weld metal may be deposited on the run pipe to provide sufficient thickness for required thread engagement;

(5) branch connections may be made by attaching the branch pipe directly to the run pipe:

(a) by a full penetration weld as shown in Fig. ND-3643.2(b)-1, with or without pad or saddle reinforcement as shown in Fig. ND-3643.3(c)(1)-1 or Fig. ND-3643.3(c)(1)-2, provided the requirements of ND-3643.3 are met; or

(b) for right angle branch connections, by a fillet weld or partial penetration weld as shown in Fig. ND-3643.2(b)-2,

sketches (a) through (d), provided the requirements of (1) through (4), as follows, are met:

- (1) the nominal size of the branch shall not exceed 2 in. (DN 50) or one-quarter of the nominal size of the run, whichever is less;
- (2) the minimum size of the weld, $x_{\min}$, shall not be less than $1\frac{1}{4}$ times the nominal branch wall thickness;
- (3) the groove angle, θ , shall be equal to or greater than 45 deg;
- (4) the requirements of ND-3643.3 shall be met.

[98]

ND-3643.2 Branch Connections Not Requiring Reinforcement.

Reinforcement need not be provided if the branch connection is made in accordance with the requirements of (a) through (c) below:

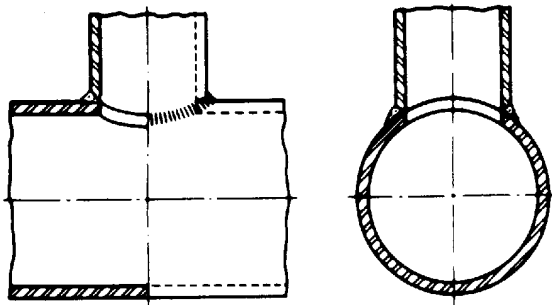
(a) by the use of a fitting manufactured in accordance with one of the standards listed in Table ND-3132-1 and used within the limits of pressure-temperature ratings specified in such standards, a butt welding fitting made in accordance with ANSI B16.9 shall be of nominal thickness not less than the nominal thickness required for the adjoining pipe;

(b) by welding a coupling or half coupling directly to the run pipe, provided the nominal diameter of the branch does not exceed 2 in. pipe size (DN 50) or one-fourth the nominal diameter of the run, whichever is less; the wall thickness of the coupling is not less than that of the branch pipe; the coupling is joined to the run pipe by one of the methods shown in Fig. ND-3643.2(b)-1 sketch (c)(1) or Fig. ND-3643.2(b)-2 sketch (e); and in no case is the thickness of the coupling less than extra heavy or 3000 lb nominal rating;

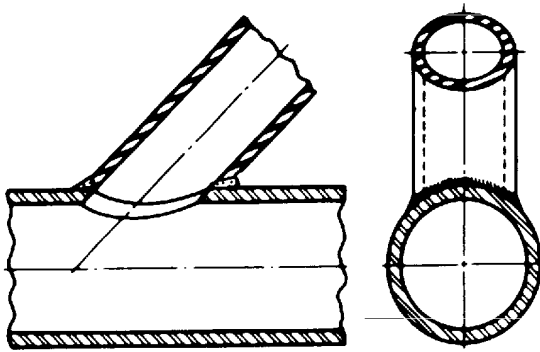
(c) by using an extruded outlet, provided the nominal diameter of the branch does not exceed 2 in. pipe size (DN 50) or one-fourth the nominal diameter of the pipe, whichever is less, and the minimum wall thickness

Page 143

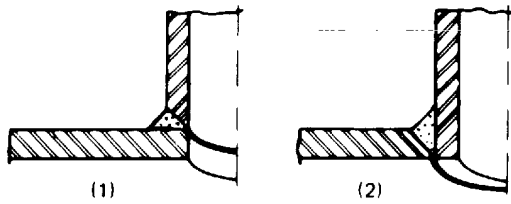
at the abutting end of the outlet is not less than required for the branch pipe wall.



(a) Typical Welded Branch Connection Without Additional Reinforcement



(b) Typical Welded Angular Branch Connection Without Additional Reinforcement



(c) Typical Branch Connections Made Using a Full Penetration Weld

FIG. ND-3643.2(b)-1 TYPICAL WELDED BRANCH CONNECTIONS

FIG. ND-3643.2(b)-1 TYPICAL WELDED BRANCH CONNECTIONS

ND-3643.3 Branch Connections Requiring Reinforcement

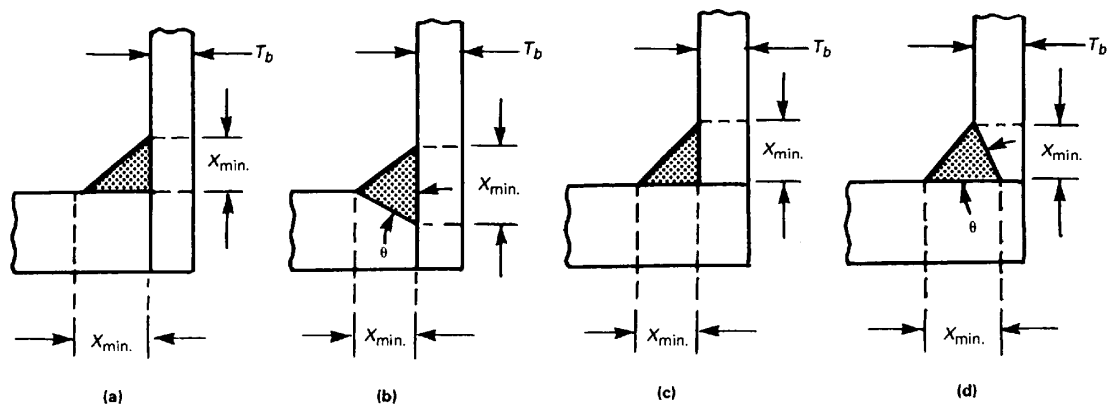
(a) Calculations shall be made to determine the adequacy of reinforcement in branch connections except as exempted in ND-3643.2.

(b) A branch connection may be made by extruding an integrally reinforced outlet on the run pipe. The reinforcement requirements shall be in accordance with ND-3643.4.

(c) A branch connection may be made by welding a pipe or fitting directly to the run pipe with or without added reinforcement, provided the pipe or fitting, deposited weldment, and other reinforcing devices meet the requirements of this subparagraph. This subparagraph gives rules covering the design of branch connections to sustain internal pressure in cases where the angle between the axes of the branch and of the run ranges from 45 deg to 90 deg. ND-3643.5 gives rules governing the design of connections to sustain external pressure.

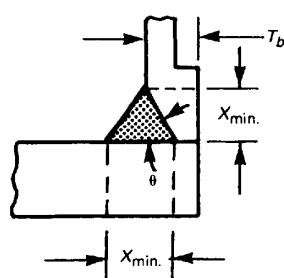
(1) *Nomenclature.* Figures ND-3643.3(c)(1)-1 and ND-3643.3(c)(1)-2 illustrate the notations used in the pressure-temperature design conditions of branch connections, which are as follows:

α	= angle between axes of branch and run, deg
b	= subscript referring to branch
D_o	= outside diameter of pipe, in.
d_1	= inside diameter of branch for right angle connections, in.; for connections at angles between 45 deg and 90 deg, $d_1 = (D_{ob} - 2T_b)/\sin \alpha$
d_2	= half width of reinforcing zone, in. = the greater of d_1 or $T_b + T_h + (d_1/2)$ but in no case more than D_{ob}
h	= subscript referring to run or header
L	= height of reinforcement zone outside of run or reinforcement, in. = $2.5T_b$
t_e	= thickness of attached reinforcing pad or height of the largest 60 deg right triangle supported by the run and branch outside diameter projected surfaces and lying completely within the area of integral reinforcement, in. [Fig. ND-3643.3(c)(1)-2]
T	= nominal, actual by measurement, or minimum wall thickness of pipe, in., permissible under purchase specification
t_m	= required minimum wall thickness, in., of pipe for pressure and temperature design conditions as determined by use of Eq. (3) or (4), ND-3641.1



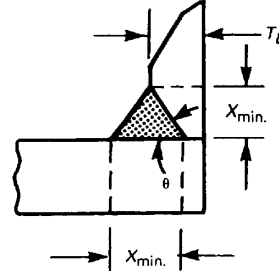
T_b = Nominal branch pipe wall thickness
 $X_{min} = 1\frac{1}{4} T_b$
 θ = Partial penetration weld groove angle ≥ 45 deg

ANSI B16.11 Coupling



(e)

Welded Outlet Fitting



(f)

T_b = Fitting wall thickness in the reinforcement zone
 (when the fitting is tapered in the reinforcement zone, use average wall thickness)
 $X_{min} = 1\frac{1}{4} T_b$
 θ = Partial penetration weld groove angle ≥ 45 deg

FIG. ND-3643.2(b)-2 TYPICAL RIGHT ANGLE BRANCH CONNECTIONS MADE USING A FILLET WELD OR A PARTIAL PENETRATION WELD

FIG. ND-3643.2(b)-2 TYPICAL RIGHT ANGLE BRANCH CONNECTIONS MADE USING A FILLET WELD OR A PARTIAL PENETRATION WELD

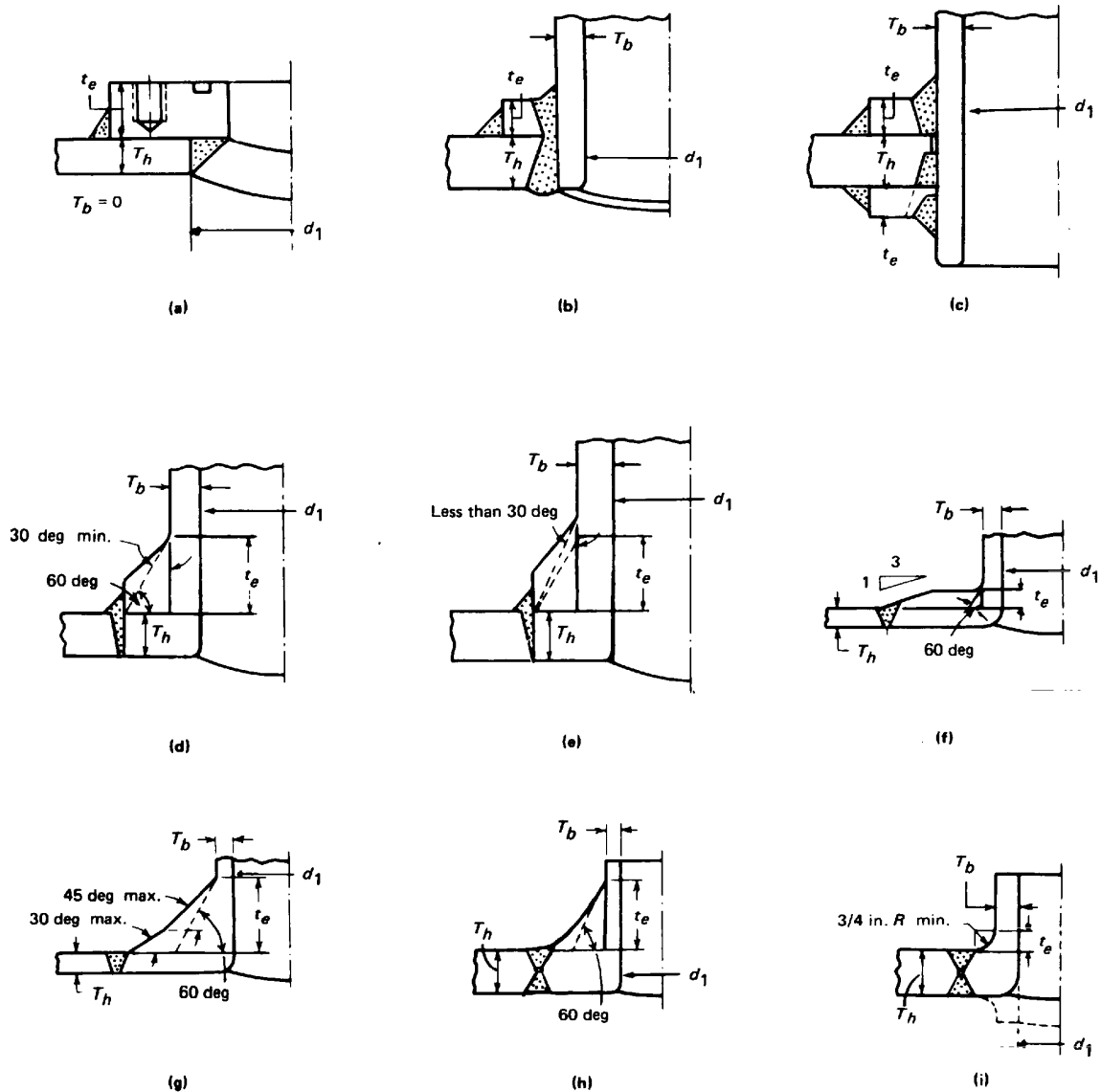


FIG. ND-3643.3(c)(1)-2 SOME REPRESENTATIVE CONFIGURATIONS DESCRIBING THE t_e REINFORCEMENT DIMENSION

FIG. ND-3643.3(c)(1)-2 SOME REPRESENTATIVE CONFIGURATIONS DESCRIBING THE t_e REINFORCEMENT DIMENSION

(2) *Requirements.* A pipe having a branch connection is weakened by the opening that must be made in it and, unless the wall thickness of the pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide additional reinforcement. The amount of reinforcement required shall be determined in accordance with ND-3643.3(c)(3) through (c)(7), ND-3643.4, or ND-3643.5.

(3) *Reinforcement Area.* The required reinforcement area in sq in. for branch connections shall be the quantity $1.07(t)(d)(2 - \sin \alpha)$.

(a) For right angle connections, the required reinforcement becomes $1.07(t_{mh})(d_1)$.

(b) The required reinforcement must be within the limits of the reinforcement zone as defined in ND-3643.3(c)(5).

(4) *Area Contributing to Reinforcement.* Metal needed to meet reinforcement required by ND-3643.3(c) must be within the limits of reinforcement zone determined in ND-3643.3(c)(5) and may include the following.

A_1 = area provided by excess pipe wall in the run, sq in.

$$= (2d_2 - d_1) [(T_h - \text{mill tolerance on } T_h) - t_{mh}]$$

A_2 = area provided by excess pipe wall in the branch for a distance L above the run, sq in.

$= 2L/\sin \alpha [(T_b - \text{mill tolerance on } T_b) - t_{mb}]$. In areas A_1 and A_2 , mill tolerance becomes zero when the minimum wall is specified instead of nominal wall.

A_3 = area provided by deposited weld metal beyond the outside diameter of the run and branch, sq in.

A_4 = area provided by reinforcement, sq in.

When the reinforcement area is composed of material with lower allowable stress than that of the run pipe, such reinforcement areas shall be increased by the inverse ratio of allowable stresses. No adjustment shall be made in reinforcement area for use of materials that have higher allowable stresses than the materials of the run pipe. Such reinforcement areas shall be decreased by the ratio of allowable stresses prior to any combination of areas to meet the reinforcement requirements of ND-3643.3(c).

(5) *Reinforcement Zone.* The reinforcement zone is a parallelogram, the length of which shall extend a distance d_2 on each side of the center line of the branch pipe and the width of which shall start at the inside surface of the run pipe and extend to a distance $(L + t_e)$ or $2.5T_p$ whichever is less, from the outside surface of the run pipe, when measured in the plane of the branch connection.

(6) *Reinforcement of Multiple Openings*

(a) When any two or more adjacent openings are so closely spaced that their reinforcement zones overlap, the two or more openings shall be reinforced in accordance with ND-3643.3(c)(3) with a combined reinforcement that has a strength equal to the combined strength of the reinforcement which would be required for the separate openings. No portion of the cross section shall be considered as applying to more than one opening or be evaluated more than once in a combined area.

(b) When more than two adjacent openings are to be provided with a combined reinforcement, the minimum distance between centers of any two of these openings should preferably be at least $1\frac{1}{2}$ times their average diameter and the area of reinforcement between them shall be at least equal to 50% of the total required for these two openings.

(7) *Rings, Pads, and Saddles*

(a) Reinforcement provided in the form of rings, pads, or saddles shall not be appreciably narrower at the side than at the crotch.

(b) A vent hole shall be provided at the ring, pad, or saddle to provide venting during welding and heat treatment.

(c) Rings, pads, or saddles may be made in more than one piece, provided the joints between pieces have full thickness welds and each piece is provided with a vent hole.

(d) Where saddles or pads are being employed for reinforcement, the potential for increased strain at the attachment welds which may occur as a result of rapid changes in differential metal temperatures between the saddle or pad and the run should be considered in the design evaluation.

ND-3643.4 Special Requirements for Extruded Outlets.

The definitions, limitations, nomenclature, and requirements of (a) through (h) below are specifically applicable to extruded outlets.

(a) *Definition.* An extruded outlet header is a header in which the extruded lip at the outlet has a height above the surface of the run which is equal to or greater than the radius of the curvature of the external contoured portion of the outlet $h_o \geq r_o$ [Fig. ND-3643.4(a)-1].

(b) *Cases to Which Rules Are Applicable.* These rules apply only to cases where the axis of the outlet intersects and is perpendicular to the axis of the run.

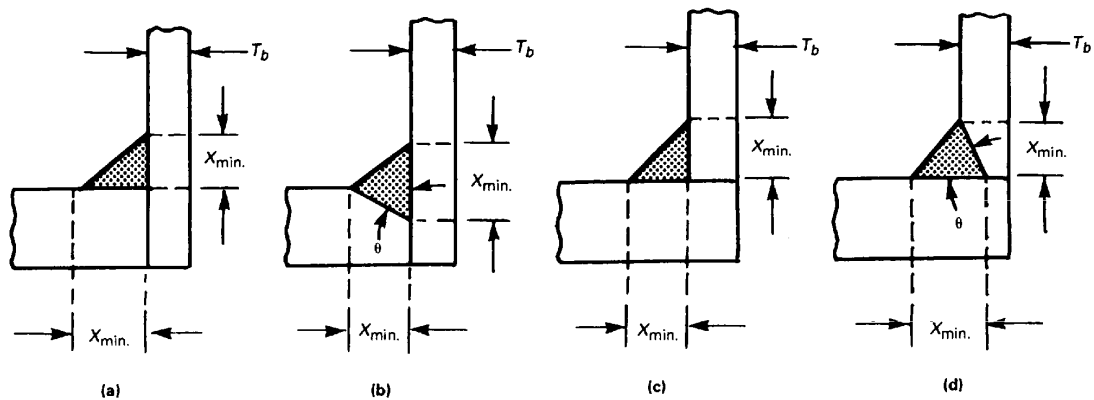
(c) *Nomenclature.* The notation used herein is illustrated in Fig. ND-3643.4(a)-1.

d	= outside diameter of branch pipe, in.
d_c	= corroded internal diameter of branch pipe, in.
D	= outside diameter of run, in.

Page 148

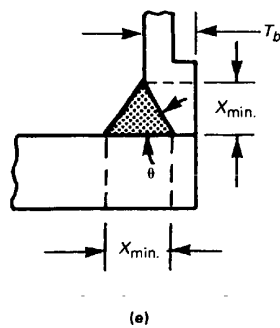
Page 149

D_c	= corroded internal diameter of run, in.
D_o	= corroded internal diameter of extruded outlet measured at the level of the outside surface of the run, in.
h_o	= height of the extruded lip, in.; this must be equal to or greater than r_o except as permitted in ND-3643.4(d)(4)
L	= height of reinforcement zone, in. $= 0.7 \sqrt{dT_o}$
t_b	= required thickness of branch pipe according to wall thickness Eq. (3) or (4), ND-3641.1, not including any thickness for corrosion, in.
T_b	= actual thickness of branch wall, not including the corrosion allowance, in.
t_r	= required thickness of the run according to Eq. (3) or (4), ND-3641.1, not including any allowance for corrosion, in.
T_r	= actual thickness of run wall, not including the corrosion allowance, in.
T_o	= corroded finished thickness of extruded outlet measured at a height equal to r_o above the outside surface of the run, in.
r_l	= half width of reinforcement zone, in. $= D_o$
r_o	= radius of curvature of external contoured portion of outlet measured in the plane containing the axes of the run and branch, in.; this is subject to the limitations given in (d) below

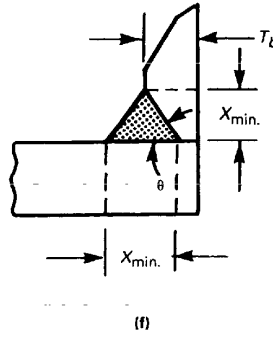


T_b = Nominal branch pipe wall thickness
 $X_{min} = 1\frac{1}{4} T_b$
 θ = Partial penetration weld groove angle ≥ 45 deg

ANSI B16.11 Coupling



Welded Outlet Fitting



T_b = Fitting wall thickness in the reinforcement zone
 (when the fitting is tapered in the reinforcement zone, use average wall thickness)
 $X_{min} = 1\frac{1}{4} T_b$
 θ = Partial penetration weld groove angle ≥ 45 deg

FIG. ND-3643.2(b)-2 TYPICAL RIGHT ANGLE BRANCH CONNECTIONS MADE USING A FILLET WELD OR A PARTIAL PENETRATION WELD

FIG. ND-3643.4(a)-1 REINFORCED EXTRUDED OUTLETS

(d) Radii

(1) The minimum radius shall not be less than $0.05d$, except that on branch diameters larger than 30 in. it need not exceed $1\frac{1}{2}$ in. (38 mm).

(2) The maximum radius for outlet pipe sizes 6 in. nominal (DN 150) and larger shall not exceed $0.10d + 0.50$ in. For outlet pipe sizes less than 6 in. nominal (DN 150), this dimension shall be not greater than $1\frac{1}{4}$ in. (32 mm).

(3) When the external contour contains more than one radius, the radius of any arc sector of approximately 45 deg

shall meet the requirements of (1) and (2) above.

(4) Machining shall not be employed in order to meet the above requirements.

(e) *Required Area*. The required area is defined as:

$$A = K(t_r)(D_o)$$

where K shall be taken as follows:

(1) for d/D greater than 0.60, $K = 1.00$

(2) for d/D greater than 0.15 and not exceeding 0.60, $K = 0.6 + 2d/3D$

(3) for d/D equal to or less than 0.15, $K = 0.70$

(f) *Reinforcement Area*. The reinforcement area shall be the sum of areas $A_1 + A_2 + A_3$ as defined in (1), (2), and (3) below.

(1) Area A_1 is the area lying within the reinforcement zone resulting from any excess thickness available in the run wall:

$$A_1 = D_o(T_r - t_r)$$

(2) Area A_2 is the area lying within the reinforcement zone resulting from any excess thickness available in the branch pipe wall:

$$A_2 = 2L(T_b - t_b)$$

(3) Area A_3 is the area lying within the reinforcement zone resulting from excess thickness available in the extruded outlet lip:

$$A_3 = 2r_o(T_o - T_b)$$

(g) *Reinforcement of Multiple Openings*. When any two or more adjacent openings are so closely spaced that the reinforcement zones overlap, the two or more openings shall be reinforced in accordance with ND-3643.4, with a combined reinforcement that has a strength equal to the combined strength of the reinforcement that would be required for separate openings. No portion of the cross section shall be considered as applying to more than one opening or be evaluated more than once in a combined area.

(h) *Marking*. In addition to the above, the Certificate Holder shall be responsible for establishing and marking on the section containing extruded outlets, the Design Pressure and Temperature, and the Certificate Holder's name or trademark.

ND-3643.5 Branch Connections Subject to External Pressure

(a) The reinforcement area in sq in. required for branch connections subject to external pressure shall be $0.54(t_{mh})(d_1)(2 - \sin \alpha)$. See ND-3643.3(c)(1).

(b) Procedures established for connections subject to internal pressure shall apply for connections subject to external pressure.

ND-3643.6 Reinforcement of Other Designs.

The adequacy of designs to which the reinforcement requirements of ND-3643 cannot be applied shall be proven by burst or proof tests (ND-3649) on scale models or on full-size structures, or by calculations previously substantiated by successful service of similar design.

ND-3644 Miters

Mitered joints may be used in piping systems under the conditions stipulated in (a) through (e) below.

(a) The thickness of a segment of a miter shall be determined in accordance with ND-3641.1. The required thickness thus determined does not allow for the discontinuity stresses which exist at the junction between segments. The discontinuity stresses are reduced for a given miter as the number of segments is increased. These discontinuity stresses may be neglected for miters in nonflammable, nontoxic, noncyclic services with incompressible fluids at pressures of 100 psi (690 kPa) and under, and for gaseous vents to atmosphere. Miters to be used in other services or at higher pressures shall meet the requirements of ND-3649.

(b) The number of full pressure or thermal cycles shall not exceed 7000 during the expected lifetime of the piping system.

(c) The angle θ in Fig. ND-3673.2(b)-1 shall not be more than $22\frac{1}{2}$ deg.

(d) The center line distance between adjacent miters shall be in accordance with Fig. ND-3673.2(b)-1.

(e) Full penetration welds shall be used in joining miter segments.

ND-3645 Attachments

(a) External and internal attachments to piping shall be designed so as not to cause flattening of the pipe, excessive localized bending stresses, or harmful thermal gradients in the pipe wall. It is important that such attachments be designed to minimize stress concentrations in applications where the number of stress cycles, due either to pressure or thermal effect, is relatively large for the expected life of the equipment.

(b) Attachments shall meet the requirements of ND-3135.

ND-3646 Closures

(a) Closures in piping systems shall be made by use of closure fittings, such as blind flanges or threaded or welded plugs or caps, either manufactured in accordance with standards listed in Table ND-3132-1 and used within the specified pressure-temperature ratings, or made in accordance with (b) below.

(b) Closures not manufactured in accordance with the standards listed in Table ND-3132-1 may be made in accordance with the rules contained in ND-3300 using the equation:

$$t_m = t + A$$

where

t_m	= minimum required thickness, in.
t	= pressure design thickness, calculated for the given closure shape and direction of loading using appropriate equations and procedures in ND-3000, in.
A	= sum of mechanical allowances (ND-3613), in.

(c) Connections to closures may be made by welding, extruding, or threading. Connections to the closure shall be in accordance with the limitations provided in ND-3643 for branch connections. If the size of the opening is greater than one-half the inside diameter of the closure, the opening shall be designed as a reducer in accordance with ND-3648.

(d) Other openings in closures shall be reinforced in accordance with the requirements of reinforcement for a branch connection. The total cross-sectional area required for reinforcement in any plane passing through the center of the opening and normal to the surface of the closure shall not be less than the quantity of $d_5^2 t$, where

d_5	= diameter of the finished opening, in.
t	= pressure design thickness for the closure, in.

ND-3647 Pressure Design of Flanged Joints and Blanks

ND-3647.1

ND-3647.1 Flanged Joints

(a) Flanged joints manufactured in accordance with the standards listed in Table ND-3132-1, as limited by ND-3612.1, shall be considered as meeting the requirements of ND-3640.

(b) Flanged joints not included in Table ND-3132-1 shall be designed in accordance with XI-3000.

ND-3647.2 Permanent Blanks.

The minimum required thickness of permanent blanks (Fig. ND-3647.2-1) shall be calculated from the following equations:

$$t_m = t + A$$

where

t_m	= the minimum required thickness, in.
t	= the pressure design thickness calculated from the equation below, in.
A	= the sum of the mechanical allowances, in. (ND-3613)

$$t = d_6 \left(\frac{3P}{16S} \right)^{1/2}$$

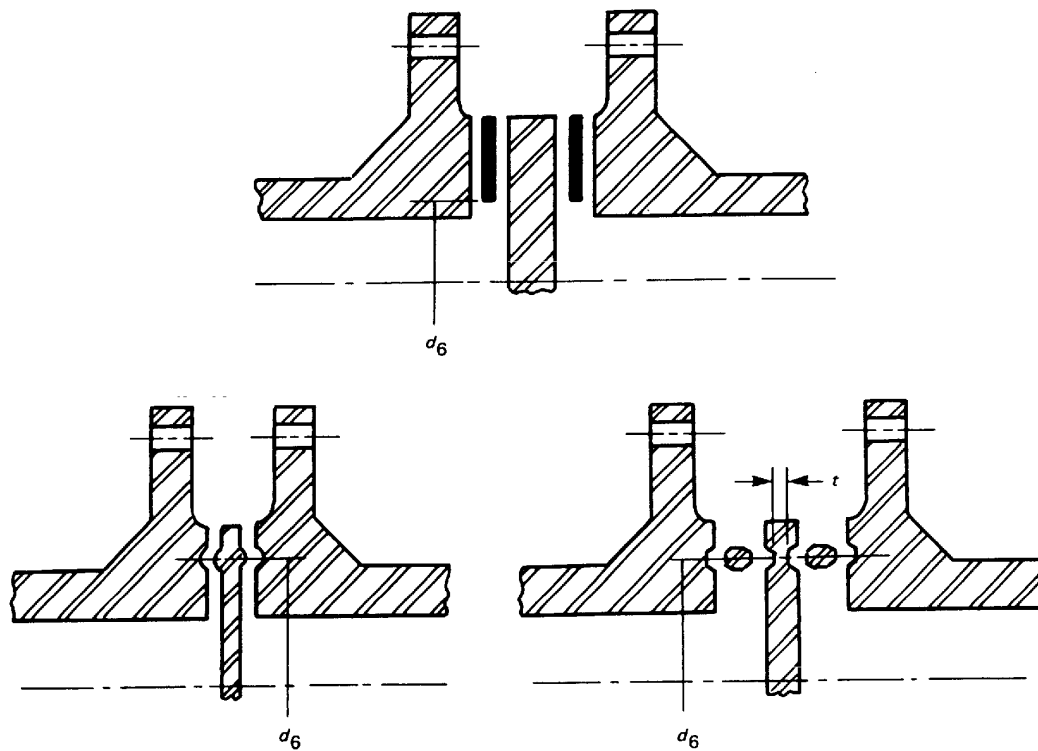


FIG. ND-3647.2-1 TYPES OF PERMANENT BLANKS

FIG. ND-3647.2-1 TYPES OF PERMANENT BLANKS

where

d_g

= the inside diameter of the gasket for raised or flat face flanges or the pitch diameter of the gasket for retained gasketed flanges, in.

P

= Design Pressure, psi

S

= the allowable stress in accordance with Tables 1A, 1B, and 3, Section II, Part D, Subpart 1, psi.

ND-3647.3 Temporary Blanks.

Blanks to be used for test purposes only shall have a minimum thickness not less than the pressure design thickness t calculated as in ND-3647.2, except that P shall not be less than the test pressure and the allowable stress S may be taken as 95% of the specified minimum yield strength of the blank material (Section II, Part D, Subpart 1, Tables 1A and 1B).

ND-3647.4 Flanges.

Flanges shall be integral or be attached to pipe by welding, brazing, threading, or other means within the applicable standards specified in Table ND-3132-1.

ND-3647.5 Gaskets

(a) Gaskets shall be made of materials which are not injuriously affected by the fluid or by temperatures within the Design Temperature range.

(b) Only metallic or asbestos metallic gaskets may be used on flat or raised face flanges if the expected normal service pressure exceeds 720 psi (4960 kPa) or the temperature exceeds 750°F (399°C). However, compressed sheet asbestos confined gaskets are not limited as to pressures, provided the gasket material is suitable for the temperatures.

(c) The use of metal or metal asbestos gaskets is not limited as to pressure, provided the gasket materials are suitable for the fluid Design Temperature.

ND-3647.6 Bolting

(a) Bolts, stud bolts, nuts, and washers shall comply with applicable standards and specifications listed in Table ND-3132-1. Unless otherwise specified, bolting

Page 152

shall be in accordance with the latest edition of ANSI B16.5. Bolts and stud bolts shall extend completely through the nuts.

(b) Studs shall be threaded full length or shall be machined down to the root diameter of the thread in the unthreaded portion, provided that the threaded portions are at least $1\frac{1}{2}$ diameters in length. Studs greater than 8 diameters in length may have an unthreaded portion which has the nominal diameter of the thread, provided the following requirements are met:

(1) the threaded portions shall be at least $1\frac{1}{2}$ diameters in length;

(2) the stud shall be machined down to the root diameter of the thread for a minimum distance of 0.5 diameters adjacent to the threaded portion; and

(3) a suitable transition shall be provided between the root diameter and unthreaded portions.

(c) Carbon steel bolts shall be ANSI Standard square or heavy hexagon head bolts and shall have ANSI Standard heavy semifinished hexagon nuts.

(d) Alloy steel stud bolts shall have ANSI Standard heavy hexagon nuts. Headed alloy bolts are not recommended.

(e) It is recommended that all alloy bolts or stud bolts and accompanying nuts be threaded in accordance with ANSI B1.1 Class 2A external threads and Class 2B internal threads.

ND-3648 Reducers

Reducer fittings manufactured in accordance with the standards listed in Table ND-3132-1 shall be considered suitable for use. Where butt welding reducers are made to a nominal pipe thickness, the reducers shall be considered suitable for use with pipe of the same nominal thickness.

ND-3649 Pressure Design of Other Pressure Retaining Piping Products

Other pressure retaining piping products manufactured in accordance with the standards listed in Table ND-3132-1 shall be considered suitable for use in piping systems at the specified pressure-temperature ratings. Pressure retaining piping products not covered by the standards listed in Table ND-3132-1 and for which design equations or procedures are not given in this Subsection may be used where the design of similarly shaped, proportioned, and sized components has been proven satisfactory by successful performance under comparable service conditions. Where such satisfactory service experience exists, interpolation may be made to other sized piping products with a geometrically similar shape. In the absence of such service experience, the pressure design shall be based on an analysis consistent with the general design philosophy of this Subsection and substantiated by at least one of the following:

(a) proof tests as described in ANSI B16.9;

(b) experimental stress analysis (Appendix II).

ND-3649.1 Expansion Joints - General Requirements.

Expansion joints of the bellows, sliding, ball, or swivel type may be used to provide flexibility for piping systems. The design of the piping systems and the design, material, fabrication, examination, and testing of the expansion joints shall conform to this Subsection and shall comply with the requirements of (a) through (e) below.

(a) Piping system layout, anchorage, guiding, and support shall be such as to avoid the imposition of motions or forces on the expansion joints other than those for the absorption of which they are both suitable and intended. Bellows expansion joints are normally not designed for absorbing torsion. Sliding expansion joints are normally not designed for absorbing bending. In sliding and bellows expansion joints used for absorbing axial motion, the hydrostatic end force caused by fluid pressure and the forces caused by either friction resistance or spring force, or both, should be resisted by rigid end anchors, cross connections of the section ends, or other means. Where reaction to hydrostatic end forces acts on pipe, guides shall be provided to prevent buckling in any direction. For bellows expansion joints, the pipe guiding and anchorage shall conform to EJMA Standards.²¹

(b) The expansion joints shall be installed in such locations as to be accessible for scheduled inspection and maintenance and for removal and replacement either directly or by other suitable means.

(c) Expansion joints employing mechanical seals shall be sufficiently leak-tight to satisfy safety requirements. The system designer shall specify the leak-tightness criteria for this purpose.

(d) Material shall conform to the requirements of ND-2000, except that no sheet material in the quenched, aged, or air-hardened condition shall be used for the flexible elements of a bellows joint. If heat treatment is required, it shall be performed either after welding the element into a complete cylinder or after all forming of the bellows is completed, the only welding permissible after such treatment being that required to connect the element to pipe or end flanges.

²¹ Expansion Joint Manufacturers Association, 331 Madison Avenue, New York, NY 10017.

(e) All welded joints shall comply with the requirements of ND-4800.

ND-3649.2 Bellows Expansion Joints.

Expansion joints of the bellows type may be used to provide flexibility for piping systems. The design, material, fabrication, examination, and testing of the expansion joints shall conform to this Subsection and the requirements of (a) through (f) below.

(a) The piping system layout, anchorage, guiding, and support shall be such as to avoid the imposition of motions or forces on the bellows other than those for which they have been designed.

(b) In all systems containing bellows, the hydrostatic end force caused by pressure and the bellows spring force shall be accommodated by or resisted by rigid anchors, cross connections of the expansion joint ends, or other means. Where bellows are used in straight pipe sections to absorb axial motion and where the hydrostatic end force of the bellows acts on the pipe as a column, guides must be provided to prevent buckling of the pipe in any direction. The pipe guiding and anchorage shall conform to the requirements of the Design Specification for the attached piping.

(c) The expansion joints shall be installed in such locations as to be accessible for scheduled inspection, where applicable.

(d) The joints shall be provided with bars or other suitable members for maintaining the proper face-to-face dimension during shipment and installation. Bellows shall not be extended or compressed to make up deficiencies in length or offset to accommodate connected piping which is not properly aligned, unless such misalignments have been specified by the system designer.

(e) The expansion joints shall be marked to show the direction of flow, if applicable, and shall be installed in accordance with this marking.

(f) Unless otherwise stated in the Design Specification, internal sleeves shall be provided when flow velocities exceed the following values:

Air, Steam, and Other Gases

Up to 6 in. (152 mm) diameter - 4 ft/sec/in. of diameter;

6 in. (152 mm) diameter and over - 25 ft/sec.

Water and Other Liquids

Up to 6 in. (152 mm) diameter - 2 ft/sec/in. of diameter;

6 in. (152 mm) diameter and over - 10 ft/sec.

ND-3649.3 Bellows Expansion Joint Material.

Pressure retaining material in the expansion joint shall conform to the requirements of ND-2000.

ND-3649.4 Bellows Expansion Joint Design.

Bellows may be of the unreinforced or reinforced convoluted type or of the toroidal type. The design shall conform to the requirements of ND-3000 and to those of (a) through (j) below.

(a) The circumferential membrane stresses in both the bellows and reinforcing member, due to pressure, shall not exceed the allowable stresses given in Section II, Part D, Subpart 1, Tables 1A and 1B.

(b) The sum of the bellows meridional membrane and bending stresses due to internal pressure shall not exceed a value which results in a permanent decrease in the spaces between adjacent convolutions of 7% after a pressure test of $1\frac{1}{2}$ times the Design Pressure, adjusted for temperature.

(c) The ratio of the internal pressure at which the bellows will become unstable (squirm) to the equivalent cold service pressure shall exceed 2.25. By definition, squirm shall be considered to have occurred if under internal pressure an initially symmetrical bellows deforms, resulting in a lack of parallelism or uneven spacing of adjacent convolutions at any point on the circumference. Unless otherwise specified, this deformation shall be construed as unacceptable squirm when the ratio of the maximum convolution pitch under internal pressure to the convolution pitch before application of pressure exceeds 1.15 for unreinforced and 1.20 for reinforced bellows. In the case of universal expansion joints, which consist of two bellows joined by a cylindrical section, compliance with these criteria shall be satisfied by the entire assembly. No external restraints on the bellows shall be employed during squirm testing other than those which will exist after installation.

(1) For single joints used in axial or lateral motion, the squirm test may be performed with the bellows fixed in the straight position at the maximum length expected in service; for rotation and universal joints, the bellows shall be held at the maximum design rotation angle or offset movement. In the case of single joints subjected to rotation movement or universal joints subjected to lateral offset movement, an instability condition as previously defined may or may not appear. Instead, movement of the convolutions may occur due to the superposition of the lateral internal pressure component on the applied rotation. In such cases, that portion of the bellows deformation due to the design rotation angle or offset movement shall not be included in the deformation used to define squirm.

Page 154

(2) In the case of squirm tests, the equivalent cold service pressure is defined as the Design Pressure multiplied by the ratio E_c/E_h , where E_c and E_h are defined as the modulus of elasticity of the bellows material at room temperature and normal service temperature, respectively.

(d) The combination of meridional membrane and bending stresses S in the bellows due to internal pressure and deflection, multiplied by a stress factor K_s ,²² shall not exceed the value defined by the following equation:

$$K_s S \leq S_f$$

where

$$K_s = (K_{sc})(K_{ss}), \text{ but not less than } 1.25$$

$$K_{sc} = \text{factor for differences in design fatigue curves at}$$

	temperatures greater than 100°F (38°C)
	$= 2S_c / (S_c + S_h)$
K_{ss}	= factor for the statistical variation in test results
	= 1.470 - 0.044 times the number of replicate tests
S	= total combined meridional membrane and bending stress due to pressure and deflection, psi. The calculation of the individual stress components and their combination must be determined by the same method as used for determining S_f . In the case of single joints subjected to rotation movement and universal joints subjected to lateral offset movement, the increase in deflection stress caused by the lateral internal pressure component shall be included in determining the combined stress.
S_f	= total combined stress to failure at design cyclic life (number of cycles to failure) obtained from plots of stress versus cyclic life based on data from fatigue tests of a series of bellows at a given temperature (usually room temperature) evaluated by a best-fit continuous curve or series of curves, psi. The S_f plot shall be parallel to the best-fit curve and shall lie below all of the data points.
S_c	= basic material allowable stress value at room temperature from Section II, Part D, Subpart 1, Tables 1A and 1B, psi
S_h	= basic material allowable stress value at normal service temperature from Section II, Part D, Subpart 1, Tables 1A and 1B, psi

(e) Compliance with (a) through (d) above shall be demonstrated by any one of the procedures of (1), (2), or (3) below.

22 See Appendix II, II-1520(g).

(1) Calculation of the individual stresses, their combination, and their relation to fatigue life may be performed by any analytical method based on elastic shell theory. The resulting equations shall be substantiated by correlation with actual tests of a consistent series of bellows of the same basic design (unreinforced, reinforced, and toroidal bellows are considered as separate designs) by each manufacturer in order to demonstrate predictability of rupture pressure, meridional yielding, squirm, and cyclic life. A minimum of five burst tests on bellows of varying sizes, with not less than three convolutions, shall be conducted to verify that the analytical method will adequately satisfy (a) and (b) above. No specimen shall rupture at less than four times its equivalent cold pressure rating. A minimum of ten squirm tests on bellows of varying diameters and number of convolutions shall be conducted to verify that the analytical method will adequately satisfy (c) above. Since column instability is most likely to occur in bellows less than 20 in. (508 mm) diameter, where the convoluted bellows length is greater than its diameter, the test specimens shall reflect these considerations. In the case of universal expansion joints, two additional tests shall be conducted to verify that the analytical method will adequately satisfy (c) above. The cyclic life versus the combined stress plot used in evaluating ND-3649.4(d) shall be obtained from the results of at least 25 fatigue tests on bellows of varying diameters, thicknesses, and convolution profiles. These curves may be used for diameter and convolution profiles other than those tested, provided that a variation in these dimensions has been included in the correlation with test data. Each group of five such tests on varying bellows may be considered the equivalent of one replicate test in determining K_s .

(2) Individual expansion joint designs may be shown to comply by the testing of duplicate bellows. At least two test specimens are required, one to demonstrate pressure capacity in accordance with (a), (b), and (c) above and the second to demonstrate fatigue life in accordance with (d) above. In the case of rupture and fatigue tests, the specimens need not possess a duplicate number of convolutions provided the number of convolutions is not less than three and the

diameter, thickness, depth, and pitch of the specimen are identical to the part to be furnished; squirm test specimens shall possess the total number of convolutions.

(a) Any or all of the above tests of (e)(1) or (e)(2) may be conducted at room temperature, provided that cold service pressure is defined as the Design Pressure multiplied by the ratio of S_c/S_h for rupture specimens and E_c/E_h for squirm specimens.

Page 155

(b) The fatigue life of the test specimen shall exceed $K_s^{4.3}$ times the number of design cycles specified for the most significant cyclic movements. This test shall include the effect of internal pressure. If lateral and rotation movements are specified, these may be converted to equivalent axial motion for cyclic testing; the convolution deflection produced by the lateral component of the internal pressure force during the squirm test for single rotation joints and universal joints shall be added to the mechanical deflections in determining fatigue life. Where accelerated fatigue testing is employed, the deflection and number of cycles required shall be in accordance with Appendix II. Cumulative fatigue requirements can be satisfied in accordance with ND-3649.4(g) without additional testing by assuming that the slope of the fatigue curve is 4.3 and that the curve passes through the test point.

(3) An individual design may be shown to comply by a design analysis in accordance with NC-3200. The stresses at every point in the bellows shall be determined by either elastic shell theory or by a plastic analysis, where applicable. Where an elastic analysis is employed, the stress intensity values of Tables 2A and 2B, Section II, Part D, Subpart 1, and fatigue curves of Figs. I-9.0 may be used to evaluate the design.

(a) The stability requirements of ND-3649.4(c) may be demonstrated by either:

(1) elastic stability calculations, provided that the ratio of the internal pressure at which the bellows is predicted to become unstable to the equivalent cold service pressure exceeds 10; or

(2) the pressure test of ND-6230, provided that the test is conducted at $2\frac{1}{4}$ times the equivalent cold design pressure, and single rotation and universal joints are held at their design rotation angle or offset movement during the test, and the requirements of ND-3649.4(b) are not exceeded by such a test.

(f) The Certificate Holder's Data Report shall state which of the above procedures was utilized to verify the design.

(g) If there are two or more types of stress cycles which produce significant stresses, their cumulative effect shall be evaluated as stipulated in Steps 1 through 5 below.

Step 1: Designate the specified number of times each stress cycle of types 1, 2, ..., n will be repeated during the life of the component as $n_1, n_2, \dots, n_n$ respectively.

NOTE: In determining $n_1, n_2, \dots, n_n$ consideration shall be given to the superposition of cycles of various origins which produce a total stress difference $S_1, S_2, \dots, S_n$ greater than the stress difference of the individual cycles. For example, if one type of stress cycle produces 1,000 cycles of stress difference variation from 0 to +60,000 psi and another type of stress cycle produces 10,000 cycles of a stress difference variation from 0 to -50,000 psi, the two types of cycles to be considered are defined by the following parameters:

Type 1 Cycle: n_1	= 1,000,
S_1	= (60,000 + 50,000)
	= 110,000 psi, and
Type 2 Cycle: n_2	= 9,000,
S_2	= (50,000 + 0) = 50,000 psi

Step 2: For each value $S_1, S_2, \dots, S_n$ use the applicable design fatigue curve and corresponding method of analysis to determine the maximum number of stress cycles which would be allowable if this type of cycle were the only one acting. Call these values $N_1, N_2, \dots, N_n$. The fatigue curve used may be either the S_f lot defined in ND-3649.4(d) or the curve consistent with ND-3649.4(e)(2) or (3). If the fatigue curve has been developed based on a total stress difference,

then the full value of $S_1, S_2, \dots, S_n$ of Step 1 must be used to determine N ; however, if the curve is based on an alternating stress, then the values of $S_1, S_2, \dots, S_n$ shall be reduced by a factor of 2, in which case $S_1, S_2, \dots, S_n$ become the alternating stresses.

Step 3: For each type of stress cycle, calculate the usage factors $U_1, U_2, \dots, U_n$ from $U_1 = n_1/N_1, U_2 = n_2/N_2, \dots, U_n = n_n/N_n$.

Step 4: Calculate the cumulative usage factor U from $U = U_1 + U_2 + \dots + U_n$.

Step 5: The cumulative usage factor U shall not exceed 1.0.

(h) The Certificate Holder shall submit a report which demonstrates compliance with ND-3649.

(i) Where necessary to carry the pressure, the cylindrical ends of the bellows may be reinforced by suitable collars. The design method used to assure that the stresses generated will not cause premature failure of the bellows material or weldment shall include the attachment weld between the bellows and end connections.

(j) The spring rates of the expansion joint assembly shall be provided by the Certificate Holder. The spring rates of a bellows can be defined by several methods due to the hysteresis loop which can occur during deflection; a restoring force may be required to return the bellows to the original neutral position after deflection. When applicable, the Design Specification shall state the maximum allowable force that can be imposed

Page 156

on the connecting parts or shall require the Certificate Holder to determine the maximum force necessary to deflect the bellows a given distance, such as the maximum movement to be absorbed.

ND-3650 ANALYSIS OF PIPING SYSTEMS

ND-3651 General Requirements²³

(a) The design of the complete piping system shall be analyzed between anchors for the effects of thermal expansion, weight, and other sustained and occasional loads. The system design shall meet the limits of ND-3650. The pressure portion of Eqs. (8) and (9) may be replaced with the expression:

$$S_{LP} = B_1 \frac{2Pd^2}{D_o^2 - d^2}$$

The pressure portion of Eq. (11) may be replaced by the expression:

$$S_{LP} = \frac{Pd^2}{D_o^2 - d^2}$$

where the terms are the same as in ND-3652, except:

P	= P or $P_{\max}$, psi
d	= nominal inside diameter of pipe, in.

(b) When evaluating stresses in the vicinity of expansion joints, consideration must be given to actual cross-sectional areas that exist at the expansion joint.

(c) For analysis of flanged joints, see ND-3658.

ND-3652 Consideration of Design Conditions

The effects of pressure, weight, and other sustained mechanical loads must meet the requirements of Eq. (8):

$$S_{SL} = B_1 \frac{PD_o}{2t_n} + B_2 \frac{M_A}{Z} \leq 1.5S_h \quad (8)$$

(8)

B_1, B_2	= primary stress indices for the specific product under investigation [Fig. ND-3673.2(b)-1]
P	= internal Design Pressure, psi
D_o	= outside diameter of pipe, in.
t_n	= nominal wall thickness, in.
M_A	= resultant moment loading on cross section due to weight and other sustained loads, in.-lb (ND-3653.3)
Z	= section modulus of pipe, in. ³

S_h

= basic material allowable stress at Design Temperature, psi

23 The pressure term in Eqs. (8), (9), and (11) may not apply for bellows and expansion joints.

ND-3653 Consideration of Levels A and B Service Limits

ND-3653.1 Occasional Loads.²⁴

The effects of pressure, weight, other sustained loads, and occasional loads, including nonreversing dynamic loads, for which Level B Service Limits are designated, must meet the requirements of Eq. (9):

$$S_{OL} = B_1 \frac{P_{\max} D_o}{2t_n} + B_2 \left(\frac{M_A + M_B}{Z} \right) \leq 1.8S_h \quad (9)$$

(9)

but not greater than $1.5S_y$. Terms are the same as in ND-3652, except:

 $P_{\max}$

= peak pressure, psi

 M_B

= resultant moment loading on cross section due to nonreversing dynamic loads.

 S_y

= material yield strength at temperature consistent with the loading under consideration, psi

 S_h

= material allowable stress at temperature consistent with the loading under consideration, psi

ND-3653.2 Thermal Expansion.

For Service Loadings for which Level A and B Service Limits are designated, the requirements of either Eq. (10), or Eq. (11), and Eq. (11a) must be met.

(a) The effects of thermal expansion must meet the requirements of Eq. (10):

$$S_E = \frac{iM_C}{Z} \leq S_A \quad (10)$$

(10)

Terms are the same as in ND-3652, except:

M_C

= range of resultant moments due to thermal expansion, in.-lb;
also include moment effects of anchor displacements due to
nonreversing dynamic loads if anchor displacement effects
were omitted from Eq. (9) (ND-3653.1)

S_A

= allowable stress range for expansion stresses (ND-3611.2),
psi

i

= stress intensification factor (ND-3673.2)

(b) The effects of any single nonrepeated anchor movements shall meet the requirements of Eq. (10a):

24 Design Pressure may be used if the Design Specification states that peak pressure and earthquake need not be taken as acting concurrently.

Page 157

$$\frac{iM_D}{Z} \leq 3.0S_c \quad (10a)$$

(10a)

Terms are the same as in ND-3653.2(a), except:

M_D

= resultant moment due to any single nonrepeated anchor
movement (e.g., predicted building settlement), in.-lb.

S_c

= basic material allowable stress at ambient temperature, psi

(c) The effects of pressure, weight, other sustained loads, and thermal expansion shall meet the requirements of Eq. (11):

$$S_{TE} = \frac{PD_o}{4t_n} + 0.75i\left(\frac{M_A}{Z}\right) + i\left(\frac{M_C}{Z}\right) \leq (S_h + S_A) \quad (11)$$

(11)

Terms are the same as in ND-3652 and ND-3653.2(a), except 0.75i shall not be less than 1.0.

(d) The effects of reversing dynamic loads must meet the requirements of Eq. (11a):

$$S_R = \frac{iM_R}{Z} \leq 3.0S_A \quad (11a)$$

(11a)

Terms same as in NC-3653.2(a), except:

M_R

= range of resultant moments due to inertia and anchor motion effects of reversing dynamic loads

[98]

ND-3653.3 Determination of Moments and Section Modulus

(a) For purposes of Eqs. (8), (9), (10), (10a), and (11), the resultant moment for straight through components, curved pipe, or welding elbows may be calculated as follows:

$$M_j = (M_{xj}^2 + M_{yj}^2 + M_{zj}^2)^{1/2}$$

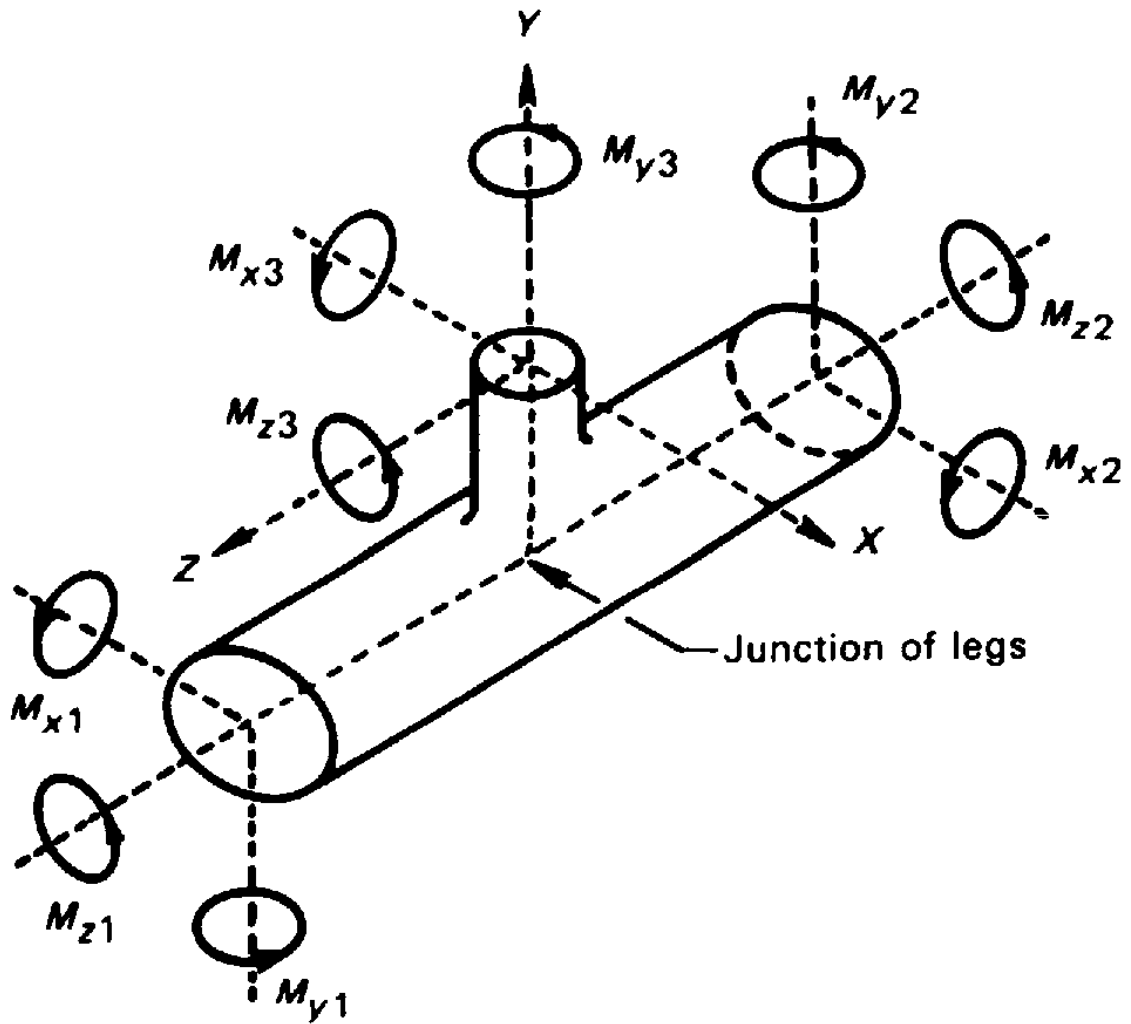
where

j

= A, B, C, or D which are the subscripts of M_A, M_B, M_C, M_D defined in ND-3652, ND-3653.1, and ND-3653.2

(b) When evaluating Eqs. (8) and (9) for branch connections and tees, use the procedure for branch and run moments given in NB-3683.1(d). When evaluating Eqs. (10), (10a), and (11), use (c) and (d) below.

(c) For full outlet branch connections, calculate the resultant moment of each leg separately in accordance with (a) above. Moments are to be taken at the junction point of the legs (Fig. ND-3653.3-1).



**FIG. ND-3653.3-1 REDUCING OR FULL OUTLET
BRANCH CONNECTIONS, OR TEES**

FIG. ND-3653.3-1 REDUCING OR FULL OUTLET BRANCH CONNECTIONS, OR TEES

(d) For reduced outlets, calculate the resultant moment of each leg separately in accordance with (a) above. Moments are to be taken at the junction point of the legs (Fig. ND-3653.3-1), except that for $r'_m/r < 0.5$ the branch moments at the outside surface of the run pipe may be used for the branch leg. For the reduced outlet branch:

$$M_A M_B M_C M_D = (M_{x3}^2 + M_{y3}^2 + M_{z3}^2)^{1/2}$$

and

Z	$= \pi(r'_m)^2 t_s$, in. ³ , except as otherwise defined in Fig. ND-3673.2(b)-1
r	= run pipe mean cross-sectional radius, in.
r'_m	= branch mean cross-sectional radius, in.
t_s	= effective branch wall thickness, in.
	= lesser of T_r or iT_b
T_b	= nominal branch wall thickness, in.
T_r	= nominal wall thickness of run pipe, in.

For the main run outlets, use M_A , M_B , M_C , and M_D , as defined in ND-3653.3(a).

[98]

ND-3654 Consideration of Level C Service Limits

ND-3654.1 Permissible Pressure.

When Level C Service Limits [NCA-2142.4(b)(3) and NB-3113(b)] are

Page 158

specified, the permissible pressure shall not exceed the pressure P_a , calculated in accordance with Eq. (5) of ND-3641.1, by more than 50%.

ND-3654.2 Analysis of Piping Components.

For Service Loadings for which Level C Service Limits [NCA-2142.4(b)(3) and NB-3113(b)] are designated, the requirements of (a) or (b) below shall apply.

(a) For Service Loadings for which Level C Service Limits are designated, which do not include reversing dynamic loads or have reversing dynamic loads combined with nonreversing dynamic loads, the conditions of Eq. (9) of ND-3653.1 shall be met using Service Level C coincident pressure P and moments M_t which result in the maximum calculated stress. The allowable stress to be used for this condition is $2.25S_h$ but not greater than $1.8S_y$.

(b) For Service Loadings for which Level C Service Limits are designated, which include reversing dynamic loads that are not required to be combined with nonreversing dynamic loads, the requirements of ND-3655(b) shall be satisfied, using the allowable stress in ND-3656(b)(2), 70% of the allowable stress in ND-3655(b)(3), and 70% of the allowable loads in ND-3656(b)(4).

ND-3654.3 Deformation Limits.

Any deformation or deflection limits prescribed by the Design Specifications shall be considered with respect to Level C Service Limits.

ND-3655 Consideration of Level D Service Limits

If the Design Specifications specify any Service Loading for which Level D Limits are designated [NCA-2142.2(b)(4)], the requirements of (a), (b), or (c) below shall apply.

(a) For Service Loadings for which Level D Service Limits are designated, which do not include reversing dynamic loads or have reversing dynamic loads combined with nonreversing dynamic loads, the requirements of (1) and (2) below shall apply.

(1) The permissible pressure shall not exceed 2.0 times the pressure P_a calculated in accordance with Eq. (3) of ND-3641.1.

(2)

not greater than $2.0S_y$.

h

(b) For piping fabricated from material designated P-No. 1 through P-No. 9 in Table 2A, Section II, Part D and limited to $D_o/t_n \leq 50$, if Level D Service Limits are designated, which include reversing dynamic loads that are not required to be combined with nonreversing dynamic loads, the requirements of (1) through (5) below shall apply.

(1) The pressure occurring coincident with the earthquake or other reversing type loading shall not exceed the Design Pressure.

(2) The sustained stress due to weight loading shall not exceed the following:

$$B_2 \frac{D_o}{2I} M_W \leq 0.5S_m$$

where

M_W = resultant moment due to weight effects

(3) The stress due to weight and inertial loading due to reversing dynamic loads in combination with the Level D coincident pressure shall not exceed the following:

$$B_1 \frac{P_D D_o}{2t} + B_2 \frac{D_o}{2I} M_E \leq 4.5S_m$$

where

P_D = the pressure occurring coincident with the reversing dynamic load

M_E

= the amplitude of the resultant moment due to the inertial loading from the earthquake, other reversing type dynamic events and weight. Earthquake and other reversing dynamic loads shall be computed from a linear elastic response spectrum analysis as defined in Appendix N-1226, except the spectrum peak broadening value Δ_{fg} in N-1226.3 shall not be less than 15% and, in place of the damping values for both large and small diameter piping systems in Table N-1230-1 for Operating Basis Earthquake and Safe Shutdown Earthquake, a value of 5 shall be used. The ground motion design input for generating the floor response spectrum to be used in the linear elastic analysis shall meet the requirements of Appendix N-1211(a) and N-1211(b). Moments and forces may be computed using a methodology other than prescribed above if the alternate methodology is demonstrated to produce results which envelope the prescribed methodology results. In the combination of loads, all directional moment components in the same direction shall be combined before determining the resultant moment. If the method of analysis is such that only magnitude without algebraic signs are obtained, the most conservative combination shall be assumed.

Page 159

(4) The range of the resultant moment M_{AM} and the amplitude of the longitudinal force F_{AM} resulting from the anchor motions due to earthquake and other reversing type dynamic loading shall not exceed the following:

$$C_2 \frac{M_{AM} D_O}{2I} < S_1$$

$$\frac{F_{AM}}{A_M} < S_2$$

where

S_1	$= 6S_m$
S_2	$= 1.0S_m$
A_M	= cross-sectional area of metal in the piping component wall

(5) Piping displacements shall satisfy Design Specification limitations.

(c) As an alternative to ND-3655(a) and (b), the rules contained in Appendix F may be used in evaluating these service loadings independently of all other Design and Service Loadings.

ND-3658 Analysis of Flanged Joints

The pressure design of flanged joints is covered by ND-3647.1. Flanged joints subjected to combinations of moment and pressure shall meet the requirements of either ND-3658.1, ND-3658.2, or ND-3658.3. In addition, the pipe-to-flange welds shall meet the requirements of ND-3651 through ND-3655 using appropriate stress intensification factors from Fig. ND-3673.2(b)-1. The following nomenclature applies for ND-3658:

P	= Design or Service Condition Pressure as defined in NCA-2140, psi
P_{eq}	= equivalent pressure to account for the moments applied to the flange joint during the Condition, psi
M_{fs}	= bending or torsional moment (considered separately) applied to the joint due to weight, thermal expansion of the piping, sustained anchor movements, relief valve steady-state thrust, and other sustained mechanical loads applied to the flanged joint during the design or service condition, in.-lb. If cold springing is used, the moment may be reduced to the extent permitted by ND-3673.5.
M_{fd}	= bending or torsional moment (considered separately) as defined for M_{fs} but including dynamic loadings applied to the flanged joint during the design or service condition, in.-lb
G	= diameter at location of gasket load reaction as defined in XI-3130, in.
A_b	= total cross-sectional area of bolts at root of thread or section of least diameter under stress, sq in.
C	= bolt circle diameter, in.
S	= allowable bolt stress for the bolt material, psi
S_y	= yield strength, psi, of flange material at Design Temperature (Table Y-1, Section II, Part D, Subpart 2)
D_f	= outside diameter of raised face, in.
P_{fd}	= pressure concurrent with M_{fd} , psi

ND-3658.1 Any Flanged Joint.

Flanged joints may be analyzed and the stresses evaluated by using the methods given in Appendix XI as modified by ND-3658.1(a) or by ND-3658.1(b). Alternatively, they may be analyzed in accordance with Appendix XIII.

(a) If the flanged joint conforms to one of the standards listed in Table ND-3132-1, and if each P' , as calculated by (b) is less than the rated pressure at the Design or Service Temperature utilized, the requirements of ND-3658 are satisfied.

(b) The Design Pressure used for the calculation of H in Appendix XI shall be replaced by a flange design pressure

$$P' = P + P_{eq}$$

The equivalent pressure P_{eq} shall be determined by the greater of:

$$P_{eq} = 16M_{fs}/\pi G^3$$

or

$$P_{eq} = 8M_{fd}/\pi G^3$$

ND-3658.2 Standard Flanged Joints at Moderate Pressures and Temperatures.

Flanged joints conforming to ANSI B16.5, MSS SP-44, API 605, or AWWA C207 Class E (275 psi), and used where neither the Design nor Service Pressure exceeds 100 psi and neither the Design nor Service Temperature exceeds 200°F, meet the requirements of ND-3658, provided the following equations are satisfied:

$$M_{fs} \leq A_b CS/4$$

and

$$M_{fd} \leq A_b CS/2$$

Page 160

ND-3658.3 ANSI B16.5, Flanged Joints With High Strength Bolting.

Flanged joints using flanges, bolting, and gaskets as specified in ANSI B16.5 and using bolting material having an S value at 100°F not less than 20,000 psi may be analyzed in accordance with the following rules.

(a) *Design Limits and Levels A and B Service Limits*

(1) The pressure shall not exceed the rated pressure for Level A Service Limits or 1.1 times the rated pressure for Level B Service Limits.

(2) The limitations given by Eqs. (12) and (13) shall be met:

$$(12) M_{fs} \leq 3125(S_y/36,000) CA_b$$

$$(13) M_{fd} \leq 6250(S_y/36,000) CA_b$$

where the value of $S_y/36,000$ shall not be taken as greater than unity.

(b) *Level C Service Limits*

(1) The pressure shall not exceed 1.5 times the rated pressure.

(2) The limitation given by Eq. (17) shall be met:

$$(17) M_{fd} \leq [11,250A_b - (\pi/16)D_f^2 P_{fd}] C(S_y/36,000)$$

where the value of $S_y/36,000$ shall not be taken as greater than unity.

(c) *Level D Service Limits*

(1) The pressure shall not exceed 2.0 times the rated pressure.

(2) The limitation given by Eq. (17) shall be met, where P_{fd} and M_{fd} are pressures, psi, and moments, in.-lb, occurring concurrently.

(d) *Test Loadings.* Analysis for test loadings is not required.

ND-3660 DESIGN OF WELDS

ND-3661 Welded Joints

ND-3661.1 General Requirements.

Welded joints shall be in accordance with the requirements of ND-4200 except as limited herein.

ND-3661.2 Butt Welded Joints

(a) Girth welds shall be Type 1, 2, or 3 (ND-4245).

(b) Longitudinal welds shall be Type 1 (ND-4245).

ND-3661.3 Socket Welded Joints²⁵

Socket welds shall comply with the requirements of ND-4427.

ND-3661.4 Fillet Welds and Partial Penetration Welds for Branch Connections²⁶

(a) Fillet welds and partial penetration welds may be used within the limitations of ND-3643.1(c).

(b) For fillet welds, the size of the weld shall be specified on the design drawings.

(c) For partial penetration welds, the size of the weld, the depth of the weld groove, and the groove angle shall be specified on the design drawings.

ND-3670 SPECIAL PIPING REQUIREMENTS

ND-3671 Selections and Limitations of Nonwelded Piping Joints

The type of piping joint used shall be suitable for the Design Loadings and shall be selected with consideration of joint tightness, mechanical strength, and the nature of the fluid handled.

ND-3671.1 Flanged Joints.

Flanged joints shall conform to ND-3647 and ND-3658.

ND-3671.2 Expanded or Rolled Joints.

Expanded or rolled joints may be used when experience or test (ND-3649) has demonstrated that the joint is suitable for the Design Loadings and when adequate provisions are made to prevent separation of the joint.

ND-3671.3 Threaded Joints.

Threaded joints may be used within the limitations specified in (a), (b), and (c) below.

(a) All threads on piping products shall be taper pipe threads in accordance with the applicable standard listed in Table ND-3132-1. Threads other than taper pipe threads may be used for piping components where tightness of the joint depends on a seal weld or a seating surface other than the threads and when experience or test (ND-3649) has demonstrated that such threads are suitable.

(b) Threaded joints shall not be used when severe erosion, crevice corrosion, shock, or vibration is expected to occur. Size limits for steam and hot water service above 220°F shall be as follows:

²⁵ Socket welded joints should not be used where the existence of crevices could result in accelerated corrosion.

²⁶ Fillet and partial penetration welds should not be used where severe vibration is expected.

Nominal Size, in.	Pressure, psi
3	400
2	600
1	1,200
$\frac{3}{4}$ and less	1,500

(c) Pipe with a wall thickness less than that of standard weight of ANSI B36.10 steel pipe shall not be threaded, regardless of service. When steel pipe is threaded and used in steam service over 250 psi (1720 kPa) or water service above 100 psi (690 kPa) and 220°F (104°C), the pipe shall be seamless and at least Schedule 80.

ND-3671.4 Flared, Flareless, and Compression Joints.

Flared, flareless, and compression type tubing fittings may be used for tube sizes not exceeding 2 in. O.D. within the limitations of applicable standards and specifications in Table ND-3132-1 and as specified in (a) through (e) below.

(a) Fittings and their joints shall be compatible with the tubing with which they are to be used and shall conform to the range of wall thicknesses and method of assembly recommended by the manufacturer.

(b) Fittings shall be used at pressure-temperature ratings not exceeding the recommendations of the manufacturer. Service Conditions, such as vibration and thermal cycling, shall be considered in the application.

(c) All threads on piping products shall be taper pipe threads in accordance with applicable standards listed in Table ND-3132-1. Exceptions are that threads other than taper pipe threads may be used for piping components where tightness of the joint depends on a seating surface other than the threads and when experience or tests (ND-3649) have demonstrated that such threads are suitable.

(d) In the absence of standards or specifications, the designer shall determine that the type of fitting selected is adequate and safe for the Design Loadings in accordance with the following requirements.

(1) The pressure design shall meet the requirements of ND-3649.

(2) Prototypes of the fittings to be used shall successfully meet performance tests (ND-3649) to determine the safety of the joint under simulated Service Loadings. When vibration, fatigue, cyclic conditions, low temperature, thermal expansion, or hydraulic shock are expected, the applicable conditions shall be incorporated in the test.

(e) Flareless fittings shall be of a design in which the gripping member or sleeve shall grip or bite into the outer surface of the tube with sufficient strength to hold the tube against pressure but without appreciably distorting the inside tube diameter. The gripping member shall also form a pressure seal against the fitting body.

(1) When using bite-type fittings, a spot check shall be made for adequate depth of bite and condition of tubing by disassembling and reassembling selected joints.

(2) Grip-type fittings that are tightened in accordance with manufacturer's instructions need not be disassembled for checking.

ND-3671.5 Caulked Joints.

Caulked or leaded joints shall not be used.

ND-3671.6 Brazed and Soldered Joints

(a) *Brazed Joints.* Brazed joints shall be socket-type, and the minimum socket depth shall be sufficient for the intended service, but in no case less than that specified in Fig. ND-4511-1.

(b) *Soldered Joints.* Soldered joints shall be socket-type and shall be made in accordance with applicable standards listed in Table ND-3132-1.

(c) *Limitations of Brazed and Soldered Joints*

(1)

hazards are involved.

(2) Soldered socket-type joints shall be limited to systems containing nonflammable and nontoxic fluids.

(3) Soldered socket-type joints shall not be used in piping subject to mechanical or thermal shock, or vibration.

(4) Brazed or soldered joints depending solely upon a fillet, rather than primarily upon brazing or soldering material between the pipe and socket, are not acceptable.

(5) Soldered joints shall be pressure and temperature rated in accordance with the applicable standards in Table ND-3132-1, except that they shall not be used at pressures in excess of 175 psi (1207 kPa) or at temperatures in excess of 250°F (121°C).

ND-3671.7 Sleeve-Coupled and Other Patented Joints.

Coupling-type, mechanical gland-type, and other patented joints may be used where experience or tests have demonstrated to the satisfaction of the designer that the joint is safe for the Design Loadings and when adequate provision is made to prevent separation of the joint.

ND-3672 Expansion and Flexibility

ND-3672.1 General Requirements

(a) In addition to the design requirements for pressure, weight, and other loadings, piping systems subject

Page 162

to thermal expansion or contraction or to similar movements imposed by other sources shall be designed in accordance with the requirements for the evaluation and analysis of flexibility and stresses specified in this paragraph.

(b) Piping shall meet the expansion and flexibility requirements of this Subarticle except that, where Class 3 piping is connected to Class 1 piping, the requirements for expansion and flexibility for Class 1 piping shall apply to the Class 3 piping out to the first anchor on the Class 3 piping. However, the effect of expansion stresses in combination with stresses from other causes shall be evaluated in accordance with ND-3650. Other exceptions as stated in the following subparagraphs shall apply.

ND-3672.2 Properties.

Thermal expansion data and moduli of elasticity shall be determined from Tables TE and TM, Section II, Part D, Subpart 2, which cover more commonly used piping materials. For material not included in these Tables, reference shall be to authoritative source data such as publications of the National Institute of Standards and Technology.

ND-3672.3 Thermal Expansion Range.

The thermal expansion range shall be determined from Table TE, Section II, Part D, Subpart 2 as the difference between the unit expansion shown for the highest metal temperature and that for the lowest metal temperature resulting from service and shutdown conditions.

ND-3672.4 Moduli of Elasticity.

The cold and hot moduli of elasticity E_c and E_h shall be as shown in Table TM, Section II, Part D, Subpart 2 for the material based on the temperatures established in ND-3672.3.

ND-3672.5 Poisson's Ratio.

Poisson's ratio, when required for flexibility calculations, shall be taken as 0.3 at all temperatures for all materials.

ND-3672.6 Stresses.

Calculations for the stresses shall be based on the least cross-sectional area of the pipe or fitting, using nominal

dimensions at the location of local strain. Calculations for the expansion stress S_E shall be based on the modulus of elasticity at room temperature E_c .

(a) *Stress Range.* Stresses caused by thermal expansion, when of sufficient initial magnitude, relax in the hot condition as a result of local yielding or creep. A stress reduction takes place and usually appears as a stress of reversed sign when the component returns to the cold condition. This phenomenon is designated as self-springing of the line and is similar in effect to cold springing. The extent of self-springing depends on the material, the magnitude of the initial expansion and fabrication stress, the hot service temperature, and the elapsed time. While the expansion stress in the hot condition tends to diminish with time, the sum of the expansion strains for the hot and cold conditions during any one cycle remains substantially constant. This sum is referred to as the strain range; however, to permit convenient association with allowable stress, stress range is selected as the criterion for the thermal design of piping.

(b) *Local Overstrain.* All the commonly used methods of piping flexibility analysis assume elastic behavior of the entire piping system. This assumption is sufficiently accurate for systems in which plastic straining occurs at many points or over relatively wide regions but fails to reflect the actual strain distribution in unbalanced systems in which only a small portion of the piping undergoes plastic strain or in which, for piping operating in the creep range, the strain distribution is very uneven. In these cases, the weaker or higher stressed portions will be subjected to strain concentrations due to elastic follow-up of the stiffer or lower stressed portions. Unbalance can be produced:

(1) by use of small pipe runs in series with larger or stiffer pipe, with the small lines relatively highly stressed;

(2) by local reduction in size or cross section, or local use of a weaker material;

(3) in a system of uniform size, by use of a line configuration for which the neutral axis or thrust line is situated close to the major portion of the line itself, with only a very small offset portion of the line absorbing most of the expansion strain.

(c) Conditions of this type shall be avoided, particularly where materials of relatively low ductility are used; if unavoidable, they shall be mitigated by the judicious application of cold spring.

(d) It is recommended that the design of piping systems of austenitic steel materials be approached with greater overall care as to general elimination of local stress raisers, examination, material selection, fabrication quality, and erection.

ND-3672.7 Flexibility.

Piping systems shall be designed to have sufficient flexibility to prevent pipe movements from causing failure from overstress of the pipe material or anchors, leakage at joints, or detrimental distortion of connected equipment resulting from excessive thrusts and moments. Flexibility shall be provided by changes of direction in the piping through the use of bends, loops, or offsets; or provisions shall be made to absorb thermal movements by utilizing expansion, swivel, or ball joints or corrugated pipe.

Page 163

ND-3672.8 Expansion, Swivel, or Ball Joints.

Expansion, swivel, or ball joints, if used, shall conform to the requirements and limitations of ND-3649.

ND-3673 Analysis

ND-3673.1 Method of Analysis.

All systems shall be analyzed for adequate flexibility by a structural analysis unless one of the following conditions is met:

(a) The system can be judged technically adequate by an engineering comparison with previously analyzed systems.

(b) The operating temperature of the piping system is at or below 150°F and the piping is laid out with inherent flexibility, as provided in ND-3672.7.

(c) The operating temperature of the piping system is at or below 250°F and the piping is analyzed for flexibility using simplified methods of calculation such as handbooks or charts.

simplified methods of calculation such as handbooks or charts.

[98]

ND-3673.2 Basic Assumptions and Requirements

(a) When calculating the flexibility of a piping system between anchor points, the system between anchor points shall be treated as a whole. The significance of all parts of the line and of all restraints, such as supports or guides, including intermediate restraints introduced for the purpose of reducing moments and forces on equipment or small branch lines, shall be considered.

(b) Comprehensive calculations shall take into account the flexibility factors found to exist in piping products or joints other than straight pipe. Credit may be taken where extra flexibility exists in such products or joints. Flexibility factors and stress intensification factors for commonly used piping products and joints are shown in Fig. ND-3673.2(b)-1. The stress intensification factors and flexibility factors in Fig. ND-3673.2(b)-1 shall be used unless specific experimental or analytical data exist that would warrant lower stress intensification factors or higher flexibility factors.

(c) Flexibility factors are identified herein by k with appropriate subscripts. The general definition of a flexibility factor is:

$$k = \theta_{ab} / \theta_{nom}$$

where

θ_{ab} = rotation of end a , with respect to end b , due to a moment load M and in the direction of the moment M

θ_{nom} = nominal rotation of equivalent straight pipe due to moment load M

The flexibility factor k is defined in detail for specific components in Fig. ND-3673.2(b)-1.

(d) Stress intensification factors are identified herein by i . The definition of a stress intensification factor is based on fatigue bend testing of mild carbon steel fittings and is:

$$iS = 245,000 N^{0.2}$$

where

S = amplitude of the applied bending stress at the point of failure (psi)

N = number of cycles to failure

i = stress intensification factor

= ratio of the bending moment producing fatigue in a given number of cycles in a straight pipe with a girth butt weld to that producing failure in the same number of cycles in the fitting or joint under consideration.

(e) For piping products or joints not listed in Fig. ND-3673.2(b)-1, flexibility or stress intensification factors shall be established by experimental or analytical means.

(f) Experimental determination of flexibility factors shall be in accordance with Appendix II, II-1900. Experimental determination of stress intensification factors shall be in accordance with Appendix II, II-2000.

(g) Analytical determination of flexibility factors shall be consistent with the definition above.

(h) Analytical determination of stress intensification factors may be based on the empirical relationship

$$i = C_2 K_2 / 2, \text{ but not less than } 1.0$$

where C_2 and K_2 are stress indices for Class 1 piping products or joints from NB-3681(a)-1, or are determined as explained below.

Analytical determination of stress intensification factors shall be correlated with experimental fatigue results. Experimental correlation may be with new test data or with test data from similar products or joints reported in literature. Finite element analyses or other stress analysis methods may be used to determine C_2 ; however, test or established stress concentration factor data should then be used to determine K_2 .

(i) For certain piping products or joints the stress intensification factor may vary depending on the direction of the applied moment, such as in an elbow or branch connection. For these cases, the stress intensification factor used in Eqs. (10), (10a), and (11) of ND-3653.2

Page 164

shall be the maximum stress intensification factor for all loading directions as determined in accordance with (f) or (h) above.

(j) Stress intensification factors determined in accordance with (f) above shall be documented in accordance with Appendix II, II-2050. The test report may be included and certified with the Design Report (NCA-3551.1 and NCA-3555) for the individual piping system or a separate report furnished (II-2050).

(k) Stress intensification factors determined in accordance with (h) above shall be documented in a report with sufficient detail to permit independent review. The review shall be performed by an engineer competent in the applicable field of design in accordance with Appendix XXIII. The report shall be included and certified as part of the design report for the piping system (NCA-3551.1 and NCA-3555).

(l) The total expansion range as determined from ND-3672.3 shall be used in all calculations, whether or not the piping is cold sprung. Expansion of the line, linear and angular movements of the equipment, supports, restraints, and anchors shall be considered in the determination of the total expansion range.

(m) Where simplifying assumptions are used in calculations or model tests, the likelihood of underestimates of forces, moments, and stresses, including the effects of stress intensification, shall be evaluated.

(n) Dimensional properties of pipe and fittings used in flexibility calculations shall be based on nominal dimensions.

(o) When determining stress intensification factors by experimental methods, ND-3653.3(d) shall not apply. The nominal stress at the point under consideration (crack site, point of maximum stress, etc.) shall be used.

[98]

ND-3673.3 Cold Springing.

The beneficial effect of judicious cold springing in assisting a system to attain its most favorable position is recognized. Inasmuch as the life of a system under cyclic conditions depends on the stress range rather than the stress level at any one time, no credit for cold spring is allowed with regard to stresses. In calculating end thrusts and moments acting on equipment, the actual reactions at any one time, rather than their range, shall be used. Credit for cold springing is allowed in the calculations of thrusts and moments, provided the method of obtaining the designed cold spring is specified and used.

ND-3673.4 Movements.

Movement caused by thermal expansion and loadings shall be determined for consideration of obstructions and design of proper supports.

[98]

ND-3673.5 Computing Hot and Cold Reactions

(a) In a piping system with no cold spring or an equal percentage of cold springing in all directions, the reactions of R_h and R_c in the hot and cold conditions, respectively, shall be obtained from the reaction R derived from the flexibility calculations based on the modulus of elasticity at room temperature E_c using Eqs. (14) and (15):

$$R_h = \left(1 - \frac{2}{3}C\right) \left(\frac{E_h}{E_c}\right) R \quad (14)$$

$$R_c = CR$$

$$= \left[1 - \frac{(S_h)}{(S_E)} \cdot \frac{(E_c)}{(E_h)}\right] R \quad (15)$$

(14 - 15) whichever is greater, and with the further condition that

$$\frac{(S_h)}{(S_E)} \cdot \frac{(E_c)}{(E_h)} < 1$$

where

C

= cold spring factor varying from zero for no cold spring to 1.00 for 100% cold spring

S_E

= computed expansion stress, psi [ND-3653.2(a)]

E_c

= modulus of elasticity in the cold condition, psi

E_h

= modulus of elasticity in the hot condition, psi

R

= maximum reaction for full expansion range based on E_c which assumes the most severe condition (100% cold spring, whether such is used or not), lb

$R_c R_h$

= maximum reactions estimated to occur in the cold and hot conditions, respectively, lb

(b) If a piping system is designed with different percentages of cold spring in various directions, Eqs. (14) and (15) are not applicable. In this case, the piping system shall be analyzed by a comprehensive method. The calculated hot reactions shall be based on theoretical cold springs in all directions not greater than two-thirds of the cold springs as specified or measured.

[98]

ND-3673.6 Reaction Limits.

The reactions computed shall not exceed limits which the attached equipment can safely sustain.

Page 165

Page 169

Pages 166-168

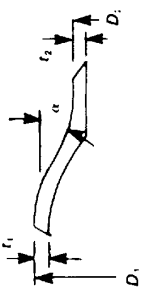
Description	Primary Stress Index		Flexibility Characteristic f	Flexibility Factor R	Stress Intensification Factor I	Sketch
	B_1	B_2				
Welding elbow or pipe bend [Note (1)]	$0.4 \text{ } h = 0.1 \leq 0.5$ and > 0	$\frac{1.30}{h^3}$	$\frac{f_1 R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^3}$	
Closely spaced miter bend [Note (1)] $s < r(1 + \tan \theta)$	Note (2)	Note (2)	$\frac{S_m \cot \theta}{2r^2}$	$\frac{1.52}{h^3}$	$\frac{0.9}{h^3}$	
Widely spaced miter bend [Note (3)] $s \geq r(1 + \tan \theta)$	Note (2)	Note (2)	$\frac{f_1(1 + \cot \theta)}{2r}$	$\frac{1.52}{h^3}$	$\frac{0.9}{h^3}$	
Welding tee per ANSI B16.9	0.5	Branch end: $B_{2b} = 0.4 \left(\frac{r}{L_b} \right)^3$	$\frac{4.4 f_1}{r}$	1	$\frac{0.9}{h^3}$	
		Run end: $B_{2r} = 0.5 \left(\frac{r}{L_r} \right)^3$				
Reinforced fabricated tee [Note (4)]	0.5	Note (2)	$\frac{\left(f_1 + \frac{f_2}{2} \right)}{r \left(\frac{L_b}{L_r} \right)^3}$	1	$\frac{0.9}{h^3} \geq 2.1$	
Unreinforced fabricated tee	0.5	Note (2)	$\frac{f_1}{r}$	1	$\frac{0.9}{h^3} \geq 2.1$	

FIG. ND-3673.2(b)-1 STRESS INDICES, FLEXIBILITY, AND STRESS INTENSIFICATION FACTORS ($D_2/L_2 \leq 100$) [Notes (1), (12), (13)]

Description	Primary Stress Index		Flexibility Factor k	Stress Intensification Factor i	Sketch
	B_1	B_2			
Branch connection [Notes (5), (6)]	0.5	Branch leg: $B_{2b} = 1.5 \left(\frac{R_m}{T_r} \right) \left(\frac{r'_m}{R_m} \right)^{1/3} \left(\frac{T_b}{T_r} \right) \left(\frac{r'_m}{r_p} \right)$	1	Branch leg: $i_b = 1.5 \left(\frac{R_m}{T_r} \right) \left(\frac{r'_m}{R_m} \right)^{1/3} \left(\frac{T_b}{T_r} \right) \left(\frac{r'_m}{r_p} \right)$	Fig. ND-3673.2(b)-2
		Run legs: $B_{2r} = 0.9 \left(\frac{r'_m}{t_n} \right)^{1/4}$		Run legs: $i_r = 0.4 \left(\frac{R_m}{T_r} \right) \left(\frac{r'_m}{R_m} \right)^{2/3} \geq 1.5$	
Fillet welded and partial penetration welded branch connections [Note (6)]	0.5	Branch leg: $B_{2b} = 2.25 \left(\frac{R_m}{T_r} \right) \left(\frac{r'_m}{R_m} \right)^{2/3} \left(\frac{T_b}{T_r} \right) \left(\frac{r'_m}{r_p} \right)$	1	Branch leg: $i_b = 4.5 \left(\frac{R_m}{T_r} \right) \left(\frac{r'_m}{R_m} \right)^{2/3} \left(\frac{T_b}{T_r} \right) \left(\frac{r'_m}{r_p} \right) \geq 3.0$	Fig. ND-3643.2(b)-2
		Run legs: $B_{2r} = 1.3 \left(\frac{r'_m}{t_n} \right)^{1/4}$		Run legs: $i_r = 0.8 \left(\frac{R_m}{T_r} \right) \left(\frac{r'_m}{R_m} \right)^{2/3} \geq 2.1$	
Girth butt weld $t_n \geq 0.237$ in.	0.5	1.0	1	1.0	
Girth butt weld $t_n < 0.237$ in.	0.5	1.0	1	$0.9 (1 + 0.094/t_n) \leq 1.9$	
Circumferential fillet welded or socket welded joints [Note (7)]	$0.75 \left(\frac{t_n}{C_x} \right) \geq 0.5$	$1.5 \left(\frac{t_n}{C_x} \right)$	1	$2.1 (t_n/C_x) \geq 1.3$	Fig. ND-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	Note (2)	Note (2)	1	2.1	Fig. ND-4511-1
30 deg tapered transition (ANSI B16.25) $t_n < 0.237$ in.	0.5	1.0	1	$1.3 + 0.0036 \frac{D_o}{t_n} \leq 1.9$	
30 deg tapered transition (ANSI B16.25) $t_n \geq 0.237$ in.	0.5	1.0	1	$1.3 + 0.0036 D_o/t_n \leq 1.9$	

FIG. ND-3673.2(b)-1 STRESS INDICES, FLEXIBILITY, AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$) [Notes (11), (12), (13)] (CONT'D)

FIG. ND-3673.2(b)-1 STRESS INDICES, FLEXIBILITY, AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$) [Notes (11), (12), (13)] (CONT'D)

Description	Primary Stress Index		Flexibility Factor k	Stress Intensification Factor i	Sketch
	B_1	B_2			
Concentric and eccentric reducers (ANSI B16.9) [Note (8)]	0.5 for $\alpha \leq 30$ deg 1.0 for $30 < \alpha \leq 60$ deg	1.0	1	$0.5 + 0.01 \alpha \left(\frac{D_2}{t_2} \right)^{1/2} \leq 2.0$	
Threaded pipe joint or threaded flange	Note (2)	Note (2)	1	2.3	
Corrugated straight pipe or corrugated or creased bend [Note (9)]	Note (2)	Note (2)	5	2.5	

Notes follow on page 168.

FIG. ND-3673.2(b)-1 STRESS INDICES, FLEXIBILITY, AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$) [Notes (11), (12), (13)] (CONT'D)

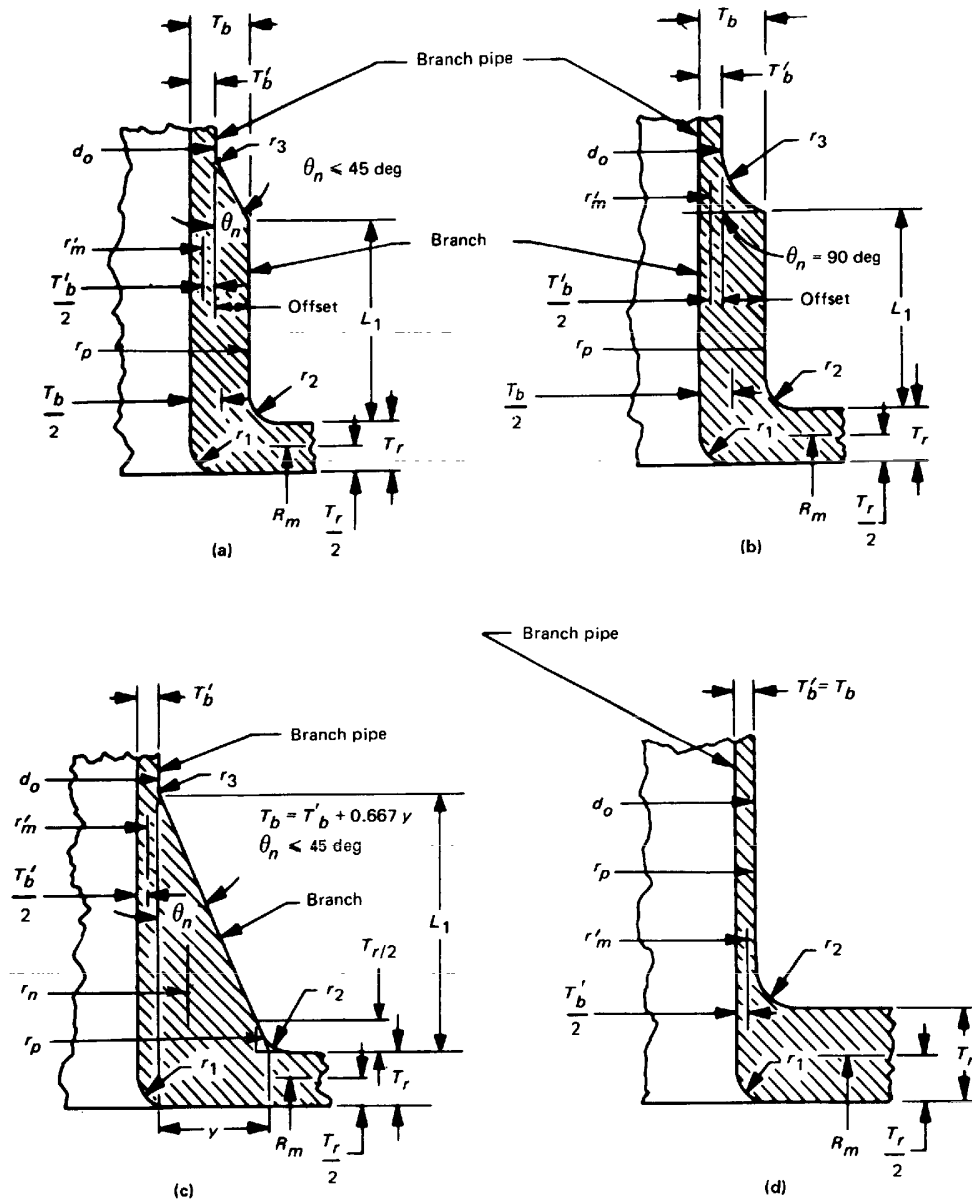
FIG. ND-3673.2(b)-1 STRESS INDICES, FLEXIBILITY, AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$) [Notes (11), (12), (13)] (CONT'D)

NOTES:

- (1) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factor c given below.
 - (a) One end flanged, $c = h^{1/6}$
 - (b) Both ends flanged, $c = h^{1/3}$
- (2) B_1 and B_2 primary stress indices for these products are in course of preparation. In the interim, use $B_1 = 0.5$ and $B_2 = 0.75 i$.
- (3) Also includes single miter joints.
- (4) When $t_o > 1.5 t_n$, $h = 4.05 t_n/r$
- (5) The equation applies only if the following conditions are met.
 - (a) The reinforcement area requirements of ND-3643 are met.
 - (b) The axis of the branch pipe is normal to the surface of run pipe wall.
 - (c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe.
 - (d) The inside corner radius r_1 [Fig. ND-3673.2(b)-2] for nominal branch pipe size greater than 4 in. shall be between 10% and 50% T_r . The radius r_1 is not required for nominal branch pipe size smaller than 4 in.
 - (e) The outer radius r_2 is not less than the larger of $T_o/2$, $(T_b + Y)/2$ [Fig. ND-3673-2 sketch (c)] or $T_r/2$.
 - (f) The outer radius r_3 is not less than the larger of
 - (1) $0.002 \theta D_o$
 - (2) $2 (\sin \theta)^3$ times the offset for the configurations shown in Fig. ND-3673.2(b)-2 sketches (a) and (b).
 - (g) $R_m/T_r \leq 50$ and $r_m/R_m \leq 0.5$.
 - (h) The outer radius r_2 is not required provided an additional multiplier of 2.0 is included in the equations for branch end and run end stress intensification factors. In this case, the calculated value of i for the branch or run shall not be less than 2.1.
- (6) For checking branch leg stress: $Z = \pi (r_m)^2 T_b$.
- (7) In Fig. ND-4427-1(c-1) and (c-2), C_x shall be taken as X_{min} and $C_x \geq 1.25 t_n$. In Fig. ND-4427-1(c-3), $C_x \geq 0.75 t_n$. For unequal leg lengths use the smaller leg length for C_x .
- (8) The equation applies only if the following conditions are met.
 - (a) Cone angle α does not exceed 60 deg.
 - (b) The larger of D_o/t_1 and D_o/t_2 does not exceed 100.
 - (c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2 .
 - (d) For eccentric reducers, α is the maximum cone angle.
- (9) Factors shown apply to bending; flexibility factor for torsion equals 0.9.
- (10) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.
- (11) The following nomenclature applies:

r = mean radius of pipe, in. (matching pipe for tees and elbows)
 t_1 = nominal wall thickness of pipe, in. (matching pipe for tees and elbows, see Note (10))
 R = nominal bend radius of elbow or pipe bend, in.
 θ = one-half angle between adjacent miter axes, deg
 s = miter spacing at center line, in.
 t_o = reinforced thickness, in.
 D_o = nominal outside diameter, in.
- (12) For branch connections nomenclature, refer to Figs. ND-3643.2(b)-2 and ND-3673.2(b)-2.
- (13) The flexibility factors k and stress intensification factors i , and stress indices B_2 apply to bending in any plane for fittings and shall in no case be taken less than 1.0. They apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.
- (13) Primary stress indices are applicable to $D_o/t_n \leq 50$ and stress intensification factors are applicable to $D_o/t_n \leq 100$.

FIG. ND-3673.2(b)-1 STRESS INDICES, FLEXIBILITY, AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$) [Notes (11), (12), (13)] (CONT'D)



d_o = outside diameter of branch pipe, in.
 r'_m = mean radius of branch pipe, in.
 T'_b = nominal thickness of branch pipes, in.
 R_m = mean radius of run pipe, in.
 T_r = nominal thickness of run pipe, in.

GENERAL NOTES:

- (a) T_b , θ , r_1 , r_2 , r_3 , r_p , and y are defined in this figure.
 (b) If L_1 equals or exceeds $0.5 \sqrt{r_1 T_b}$, where r_1 is the inside radius of the branch, then r'_m can be taken as the radius to the center of T_b .

FIG. ND-3673.2(b)-2 BRANCH DIMENSIONS

[98]

FIG. ND-3673.2(b)-2 BRANCH DIMENSIONS

ND-3674 Design of Pipe Supporting Elements

Supporting elements, including hangers, anchors, and sliding supports, shall be designed in accordance with the requirements of Subsection NF.

ND-3677 Pressure Relief Piping

ND-3677.1 General Requirements.

Pressure relief piping within the scope of this Subarticle shall be supported to sustain reaction forces and shall conform to the requirements of the following subparagraphs.

ND-3677.2 Piping to Pressure Relieving Safety Devices

(a) Piping that connects a pressure relief device to a piping system shall comply with all the requirements of the Class of piping of the system which it is designed to relieve.

(b) There shall be no intervening stop valves between systems being protected and their protective device or devices, except as provided for in ND-7142.

ND-3677.3 Discharge Piping From Pressure Relieving Safety Devices

(a) Discharge piping from pressure relief devices shall comply with the requirements of the Class of piping applicable to the conditions under which it operates.

(b) There shall be no intervening stop valves between the protective device or devices and the point of discharge, except as provided for in ND-7142.

(c) When discharging directly to the atmosphere, discharge shall not impinge on other piping or equipment and shall be directed away from platforms and other areas used by personnel.

(d) It is recommended that individual discharge lines be used, but if two or more reliefs are combined:

(1) the discharge piping shall be designed with sufficient flow area so as not to affect operation of the relief devices, and

(2) in no case shall the area of such common lines be less than the combined area of all lines discharging into it.

(e) Discharge lines from pressure relieving safety devices within the scope of this Subarticle shall be designed to facilitate drainage.

(f) When the umbrella or drip pan type of connection is used, the discharge piping shall be so designed as to prevent binding due to expansion movements. Drainage shall be provided to remove water collected above the safety valve seat.

ND-3678 Temporary Piping Systems

Prior to service of piping systems and associated equipment, certain temporary piping may be installed to accommodate cleaning by blowing out with steam or air, or by acid or caustic fluid circulation, or other flushing methods. Such temporary piping shall be designed to safeguard against rupture or other failure which could become a hazard to health or safety.

ND-3690 DIMENSIONAL REQUIREMENTS FOR PIPING PRODUCTS

ND-3691 Standard Piping Products

Dimensions of standard piping products shall comply with the standards and specifications listed in Table ND-3132-1.

ND-3692 Nonstandard Piping Products

The dimensions of nonstandard piping products shall be such as to provide strength and performance equivalent to standard products, except as permitted in ND-3641.

ND-3700 ELECTRICAL AND MECHANICAL PENETRATION ASSEMBLIES

ND-3720 DESIGN RULES

(a) The design of the pressure retaining portion of electrical and mechanical penetration assemblies shall be the same as for vessels (ND-3300).

(b) For closing seams in electrical and mechanical penetration assemblies meeting the requirements of ND-4730(c), the closure head shall meet the requirements of ND-3325 using a factor $C = 0.20$. The fillet weld shall be designed using an allowable stress of 0.5S.

ND-3800 DESIGN OF ATMOSPHERIC STORAGE TANKS

ND-3810 GENERAL REQUIREMENTS

ND-3811 Acceptability

The requirements for acceptability of atmospheric storage tanks are given in the following subparagraphs.

ND-3811.1 Scope.

The design rules for atmospheric storage tanks cover vertical cylindrical flat bottom above

Page 171

ground²⁷ welded tanks at atmospheric pressure. The tanks may contain liquids such as refueling water, condensate, boroated reactor coolant, or liquid radioactive waste. Such tanks may be within building structures, depending upon the liquid to be contained, or they may be above grade exposed to atmospheric conditions.

ND-3811.2 Design Requirements.

The design rules for atmospheric storage tanks shall conform to the design requirements of ND-3100 and ND-3300, except as they may be modified by the requirements of this Subarticle. The joint efficiency E shall be based on the requirements of ND-3352. The specific design requirements shall be stipulated in the Design Specifications.

ND-3812 Design Report

The manufacturer of a storage tank conforming to the design requirements of this Subarticle is required to provide a Design Report as part of his responsibility of achieving structural integrity of the tank. The Design Report shall be certified when required by NCA-3550.

ND-3820 DESIGN CONSIDERATIONS

ND-3821 Design and Service Conditions

(a) Conditions shall be identified as Design or Service, and if Service they shall have Level A, B, C, or D Service Limits designated.

(b) The provisions of ND-3110 shall apply.

(c) The stress limits given in ND-3821.5 shall be met.

ND-3821.1 Design Pressure.

The Design Pressure²⁸ shall be atmospheric.

The Design Pressure shall be atmospheric.

ND-3821.2 Design Temperature.

The Design Temperature shall be not greater than 200°F.

ND-3821.3 Loadings.

The requirements of ND-3111 shall be met.

ND-3821.4 Welded Joint Restrictions.

The restrictions given in (a) through (c) below on type and size of joints or welds shall apply.

27 These rules do not limit storage tanks from being installed below grade or below ground, provided the tanks are not subject to external pressure resulting from earth or fill.

28 The limitation of the Design Pressure to atmospheric is not intended to preclude the use of these tanks at vapor pressure slightly above or below atmospheric within the range normally required to operate vent valves. If these pressure or vacuums exceed $\frac{1}{2}$ oz /sq in., especially in combination with large diameter tanks, the forces involved may require special consideration in the design.

TABLE ND-3324.8(b)-1
VALUES OF FACTOR M
Use Nearest Value of L/r ; Interpolation Unnecessary

L/r	1.0	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50
M	1.00	1.03	1.06	1.08	1.10	1.13	1.15	1.17	1.18	1.20	1.22
L/r	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
M	1.25	1.28	1.31	1.34	1.36	1.39	1.41	1.44	1.46	1.48	1.50
L/r	9.5	10.00	10.5	11.0	11.5	12.0	13.0	14.0	15.0	16.0	16.67
M	1.52	1.54	1.56	1.58	1.60	1.62	1.65	1.69	1.72	1.75	1.77

NOTE:

(1) Maximum ratio allowed by ND-3324.5(d) when L equals the outside diameter of the skirt of the head.

TABLE ND-3821.5-1 DESIGN AND SERVICE LIMITS

(a) Tack welds shall not be considered as having any strength value in the finished structure.

(b) The minimum size of fillet welds shall be in accordance with ND-4246.6.

(c) All nozzle welds shall be in accordance with ND-4246.5.

ND-3821.5 Limits of Calculated Stresses for Design and Service Loadings.

Stress²⁹ limits for Design and Service Loadings are specified in Table ND-3821.5-1. The symbols used in Table ND-3821.5-1 are defined as follows:

σ_m

= general membrane stress, psi. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.

σ_L

= local membrane stress, psi. This stress is the same as σ_m except that it includes the effect of discontinuities.

σ_b

= bending stress, psi. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations,

S

and is produced only by pressure and other mechanical loads.
= allowable stress value given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1, psi. The allowable stress shall correspond to the highest metal temperature at the section under consideration during the loading under consideration.

29 Stress means the maximum normal stress.

Page 172

Typical examples of locations and loadings for which σ_m , σ_L , and σ_b are applicable are shown in Table XIII-1130-1, with σ considered as equivalent to P in Table XIII-1130-1.

ND-3830 BOTTOM DESIGN

ND-3831 Plate Sizes

- (a) All bottom plates shall have a minimum nominal thickness of $\frac{1}{4}$ in. (6 mm) exclusive of any corrosion allowance required by the Design Specifications.
- (b) Bottom plates shall be ordered of sufficient size so that, when trimmed, at least a 1 in. (25 mm) width will project beyond the outside edge of the weld attaching the bottom to the shell plate.
- (c) The type of foundation used for supporting the tank shall be taken into account in the design of the bottom plates and welds. For recommended practice for construction of foundations, see API-650, Appendix B.

ND-3832 Methods of Construction

Bottoms shall be built to either one of the alternative methods of construction given in ND-4246.1.

ND-3833 Shell-to-Bottom Attachment

The requirements for shell-to-bottom attachments are given in ND-4246.2.

ND-3840 SHELL DESIGN

ND-3841 Loads

- (a) Thicknesses shall be computed on the basis of the specific gravity of the stored material, but in no case shall the specific gravity be less than 1.00. The tension in each ring shall be computed 12 in. (305 mm) above the center line of the lower horizontal joint of the course in question. In computing these stresses, the tank diameter shall be taken as the nominal diameter of the bottom course.
- (b) Isolated radial loads on tank shells, such as caused by heavy loads on platforms and elevated walk ways between tanks, shall be distributed by rolled structural sections, plate ribs, or built-up members, preferably in a horizontal position.

ND-3842 Diameters and Thicknesses of Shell Plates

- (a) For method of determining minimum thicknesses³⁰ of shell plates, see ND-3324.3. See ND-2121 for pressure retaining material.
- (b) In no case shall the nominal thickness³¹ of shell plates be less than the following:

Ferrous Material		Aluminum material	
Nominal Tank Diameter, ft ³²	Nominal Thickness, in.	Nominal Tank Diameter, ft ³²	Nominal Thickness, in.
Smaller than 60	$\frac{3}{16}$ ₁	Smaller than 20	$\frac{3}{16}$ ₁

(c) The maximum nominal thickness of tank shell plates shall be $1\frac{1}{2}$ in. (38 mm).

ND-3843 Arrangement of Members

(a) The tank shell shall be designed to have all courses vertical. Unless otherwise specified, abutting shell plates at horizontal joints shall have a common vertical center line of thickness. Vertical joints in adjacent shell courses shall not be in alignment but shall be offset from each other a minimum distance of 6 in.

(b) Except as specified for self-supporting roofs and for tanks having the flanged roof-to-shell detail described in (c) below, tank shells shall be supplied with top angles of not less than the following sizes: tanks 35 ft (10.6 m) and smaller in diameter, $2\frac{1}{2}$ in. $\times$ $2\frac{1}{2}$ in. $\times$ $\frac{1}{4}$ in. (64 mm $\times$ 65 mm $\times$ 6 mm); tanks of more than 35 ft to 60 ft (10.6 m to 18.3 m), inclusive, in diameter, $2\frac{1}{2}$ in. $\times$ $2\frac{1}{2}$ in. $\times$ $\frac{5}{16}$ in. (64 mm $\times$ 64 mm $\times$ 8 mm); tanks larger than 60 ft (18.3 m) in diameter, 3 in. $\times$ 3 in. $\times$ $\frac{3}{8}$ in. (76 mm $\times$ 76 mm $\times$ 10 mm). The outstanding leg of the top angle may extend inside or outside the tank shell.

(c)(1) For tanks not exceeding 35 ft (10.6 m) in diameter and having supported cone roofs, the top edge of the shell may be flanged in lieu of installing a top angle. The radius of bend and the width of the flanged edge shall conform to the details of Fig. ND-4246.3-1 sketch (c).

30 Any specified corrosion allowance for the shell plates shall be added to the calculated thickness.

31 The nominal thickness of shell plates refers to the tank shell as constructed. The thickness specified are based on erection requirements.

32 Nominal tank diameter shall be the center line diameter of the shell plates, unless otherwise stipulated in the Design Specifications.

(2) This construction may be used for any tank having a self-supporting roof if the total cross-sectional area of the junction fulfills the stated area requirements for the top angle construction. No additional member, such as an angle or bar, shall be added to the flanged roof-to-shell detail.

(d) For tanks not exceeding 35 ft (10.6 m) in diameter and having a supported flat roof, the roof plates may be flanged and butt welded to the shell. The flanged tank roof plates shall be butt welded. The inside radius of the knuckle shall not be less than $1.75t$ nor more than $8t$.

ND-3850 ROOF DESIGN

ND-3851 Types of Roofs

The types of roofs are defined in the following subparagraphs.

ND-3851.1 Supported Cone Roof.

A supported cone roof is a roof formed to approximately the surface of a right cone, with its principal support provided by either rafters on girders and columns or rafters on trusses with or without columns.

ND-3851.2 Supported Flat Roof.

A supported flat roof is a roof which is essentially flat, with its principal support provided by either rafters supported by the shell without columns or by rafters in conjunction with girders and trusses with or without columns.

ND-3851.3 Self-Supporting Cone Roof.

A self-supporting cone roof is a roof formed to approximately the surface of a right cone, supported only at its periphery.

ND-3851.4 Self-Supporting Dome Roof.

A self-supporting dome roof is a roof formed to approximately a spherical surface, supported only at its periphery.

ND-3851.5 Self-Supporting Umbrella Roof.

A self-supporting umbrella roof is a modified dome roof so formed that any horizontal section is a regular polygon with as many sides as there are roof plates, supported only at its periphery.

ND-3852 General Roof Design Requirements

ND-3852.1 Loading Requirements.

All roofs and supporting structures shall be designed to support dead load, plus a uniform live load of not less than 25 lb/sq ft (1.2 kPa) of projected area unless otherwise specified, except that tanks installed in an enclosed area, not exposed to the elements, shall be designed to support the dead load plus a uniform live load of not less than 10 lb/sq ft (0.5 kPa).

ND-3852.2 Minimum Plate Thickness.

Roof plates shall have a minimum nominal thickness of $\frac{3}{16}$ in. (4.8 mm). A greater thickness may be required for self-supporting roofs. Any specified corrosion allowance for the plates of self-supporting roofs shall be added to calculated thickness. Any specified corrosion allowance for plates of supported roofs shall be added to the minimum nominal thickness.

ND-3852.3 Minimum Thickness of Supporting Members.

All internal and external structural members shall have a minimum nominal thickness, in any component, of 0.17 in. (4.3 mm).

ND-3852.4 Attachment of Roof Plates.

Roof plates shall be attached to the top angle of the tank in accordance with ND-4246.3. Roof plates of supported roofs shall not be attached to internal supporting members.

ND-3852.5 Welding of Roof Plates

(a) If the continuous fillet weld between the roof plates and the top angle does not exceed $\frac{3}{16}$ in. (4.8 mm) and the slope of the roof at the top angle attachment does not exceed 2 in./ft, the joint may be considered to serve as an emergency venting device which, in case of excessive internal pressure, will fail before failure occurs in the tank shell joints or the shell-to-bottom joint. Failure of the roof-to-shell joint may be accompanied by buckling of the top angle.

(b) Where the weld size exceeds $\frac{3}{16}$ in. (4.8 mm) or where the slope of the roof at the top angle attachment is greater than 2 in./ft, emergency venting devices conforming to the specifications noted in API Standard 2000³³ shall be provided. The Certificate Holder shall provide a suitable tank connection for the device.

(c) Roof plates shall be welded in accordance with ND-4246.4.

ND-3852.6 Allowable Stresses for Ferrous Steel Structures.³⁴

All parts of the structure shall be so proportioned that the sum of the static stresses shall not exceed the values given in (a) through (d) below.

(a) *Tension*

(1) in rolled steel, on net section, 20.0 ksi (138 MPa);

³³ API Standard 2000, 1968 Edition, Venting Atmospheric and Low Pressure Storage Tanks, American Petroleum Institute, 1801 K St., N.W., Washington, D.C. 20036.

³⁴ The decrease in yield stress at Design Temperature shall be taken into account.

(2) in full penetration groove welds on the thinner plate area, 18.0 ksi (124 MPa).

(b) Compression

(1) in rolled steel, where lateral deflection is prevented, 20.0 ksi (138 MPa);

(2) in full penetration groove welds on the thinner plate area, 20.0 ksi (138 MPa);

(3) in columns, on cross-sectional area, ksi:

For L/r not over 120:

$$\left[1 - \frac{(L/r)^2}{34,700} \right] \left[\frac{33 Y}{FS} \right]$$

For L/r over 120 to 131.7, inclusive:

$$\frac{\left[1 - \frac{(L/r)^2}{34,700} \right] \left[\frac{33 Y}{FS} \right]}{1.6 - (L/200r)}$$

For L/r over 131.7:

$$\frac{(149,000 Y)}{(L/r)^2 [1.6 - (L/200r)]}$$

where

L = unbraced length of column, in.

r = least radius of gyration of column, in.

FS = factor of safety

=

$$5/3 + \left[\frac{(L/r)}{350} \right] - \left[\frac{(L/r)^3}{18,300,000} \right]$$

Y = 1.0 for structural sections or tubular sections having t/R values equal to or exceeding 0.015

= $(200/3)(t/R)[2 - (200/3)(t/R)]$ for tubular sections having t/R values less than 0.015

t = thickness of tubular section, in.; $1/4$ in. minimum for main compression members, $3/16$ in. minimum for bracing and other secondary members

R = outside radius of tubular section, in.

For main compression members, the ratio L/r shall not exceed 180. For bracing and other secondary members, the ratio L/r shall not exceed 200.

(c) Bending

(1) in tension and compression on extreme fibers of rolled shapes and built-up members with an axis of symmetry in the plane of loading, where the laterally unsupported length of compression flange is no greater than 13 times its width, the compression flange width-thickness ratio does not exceed 17, and the web depth-thickness ratio does not exceed 70, 22.0 ksi (152 MPa);

(2) in tension and compression on extreme fibers of unsymmetrical members, where the member is supported

laterally at intervals no greater than 13 times its compression flange width, 20.0 ksi;

(3) in tension on extreme fibers of other rolled shapes, built-up members, and plate girders, 20.0 ksi;

(4) in compression on extreme fibers of other rolled shapes, plate girders, and built-up members having an axis of symmetry in the plane of loading, the larger value computed by the following, ksi:

$$20.0 - \frac{0.571}{1000} (l/r)^2$$

or

$$\frac{12,000}{ld / A_f} \leq 20.0$$

where

l = unbraced length of compression flange, in.

r = radius of gyration of section about an axis in the plane of loading, in.

d = depth of section, in.

A_f = area of compression flange, sq in.

Compression on extreme fibers of other unsymmetrical sections, ksi:

$$\frac{12,000}{ld / A_f} \leq 20$$

(d) *Shearing*

(1) in fillet, plug, slot, and partial penetration groove welds across throat area, 13.6 ksi (94 MPa);

(2) on the gross area of the webs of beams and girders, when t is the thickness of the web, in., and h , the clear distance between web flanges, in., is not more than $60t$, or when the web is adequately stiffened, 13.0 ksi (90 MPa);

(3) on the gross area of the webs of beams and girders, if the web is not stiffened so that h is more than $60t$, the greatest average shear V/A shall not exceed, ksi:

$$\frac{19.5}{1 + h^2 / 7200t^2}$$

where

V

V

= the total shear, kips

A

= the gross area of the web, sq in.

ND-3852.7 Allowable Stresses for Aluminum Structures.

All parts of the structure shall be so proportioned that the sum of the static stresses shall

Page 175

not exceed the allowable stresses given in Tables ND-3852.7-1 through ND-3852.7-6.

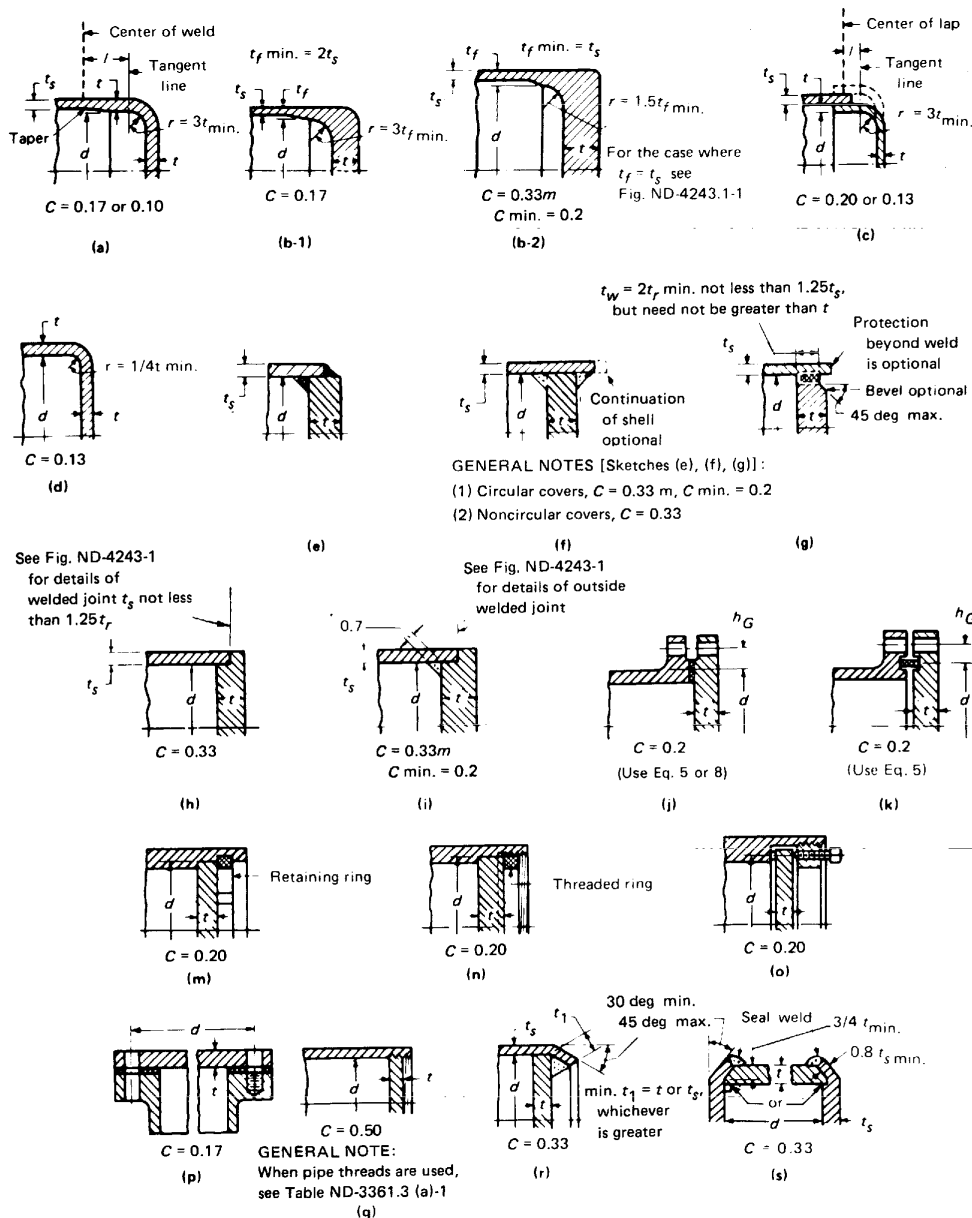


FIG. ND-3325-1 SOME ACCEPTABLE TYPES OF UNSTAYED FLAT HEADS AND COVERS
The Above Illustrations Are Diagrammatic Only. Other Designs That Meet The Requirements of ND-3325 Are Acceptable.

TABLE ND-3852.7-1 ALLOWABLE TENSILE STRESSES FOR ROOF SUPPORTS

ND-3853 Supported Cone Roofs - General Requirements

ND-3853.1 Slope of Roof.

The slope of roof shall be $\frac{3}{4}$ in./ft (6.25%) or greater. If the rafters are set directly on chord girders, producing slightly varying rafter slopes, the slope of the flattest rafter shall conform to the specified roof slope.

ND-3853.2 Main Supporting Members.

Main supporting members, including those supporting the rafters, may be rolled or fabricated sections or trusses. Although these members may be in contact with the roof plates, the compression flange of a member or the top chord of a truss shall be considered to receive no lateral support from the roof plates and shall be laterally braced, if necessary, by other acceptable methods. The allowable stresses in these members shall be governed by ND-3852.6.

ND-3853.3 Design of Rafters.

Structural members, serving as rafters, may be rolled or fabricated sections but in all cases shall conform with the rules of ND-3852 through ND-3853. Rafters in direct contact with the roof plates applying the loading to the rafters may be considered to receive adequate lateral support from the friction between the roof plates and the compression flanges of the rafters, with the following exceptions:

- (a) trusses and open web joints used as rafters;
- (b) rafters having a nominal depth greater than 15 in. (381 mm);
- (c) rafters having a slope greater than 2 in./ft. (16.7%)

ND-3853.4 Spacing of Rafters.

Rafters shall be spaced so that, in the outer ring, their centers shall not be more than 6.28 ft (1.9 m) apart, measured along the circumference of the tank. Spacing on inner rings shall not be greater than $5\frac{1}{2}$ ft (1.7 m).

ND-3853.5 Roof Columns.

Roof columns shall be made from structural shapes or pipe.

ND-3853.6 Attachment of Rafter Clips and Column Base Clip Guides.

Rafter clips for the outer row of rafters shall be welded to the tank shell. Column base clip guides shall be welded to the tank bottom to prevent lateral movement of column bases. All other structural attachments shall be either bolted or welded.

ND-3853.7 Welding of Roof Plates.

Roof plates shall be welded in accordance with ND-4246.4. The size of the roof-to-top angle weld shall be $\frac{3}{16}$ in. (4.8 mm) or smaller.

ND-3854 Supported Flat Roofs

ND-3854.1 General Requirements.

The use of supported flat roofs shall be limited to tanks having diameters not greater than 35 ft (10.6 mm). The design of supported flat roofs shall be in accordance with ND-3853 except as noted below.

ND-3854.2 Main Supporting Members

- (a)

= combined cross-sectional area of roof plate, shell plate, and top shell angle, sq in.

TABLE ND-3852.7-2
ALLOWABLE AXIAL COMPRESSION STRESSES FOR ROOF SUPPORTS
Axial Compression [See Notes (1) and (2)]

Alloy and Temper	Maximum Temp., °F	Cross Sections Farther Than 1.0 in. From Any Weld					Cross Sections Within 1.0 in. of a Weld				
		Allowable Stress for Slenderness Less Than S_1 , ksi	Slenderness Limit S_1	Allowable Stress for Slenderness Between S_1 and S_2 , ksi	Slenderness Limit S_2	Allowable Stress for Slenderness Greater Than S_2 , ksi	Allowable Stress for Slenderness Less Than S_3 , ksi	Slenderness Limit S_3	Allowable Stress for Slenderness Between S_3 and S_4 , ksi	Slenderness Limit S_4	Allowable Stress for Slenderness Greater Than S_4 , ksi
6061-T6	To 100	19	$\frac{L}{r} = 10$	$20.4 - 0.135 \frac{L}{r}$	$\frac{L}{r} = 67$	$\frac{L}{r} = 68$ [Note (4)]	...	11 [Note (3)]	...	...	51,000 $(\frac{L}{r})^2$
	150	19	$\frac{L}{r} = 8.9$	$20.2 - 0.135 \frac{L}{r}$	$\frac{L}{r} = 67$	$\frac{L}{r} = 67$ [Note (4)]	...	11 [Note (3)]	...	...	50,000 $(\frac{L}{r})^2$
	200	18	$\frac{L}{r} = 14$	$19.8 - 0.133 \frac{L}{r}$	$\frac{L}{r} = 67$	$\frac{L}{r} = 67$ [Note (4)]	...	11 [Note (3)]	...	...	49,000 $(\frac{L}{r})^2$
6063-T6	To 100	13.5	$\frac{L}{r} = 11$	$14.4 - 0.080 \frac{L}{r}$	$\frac{L}{r} = 80$	$\frac{L}{r} = 88$ [Note (4)]	...	6.5	...	...	51,000 $(\frac{L}{r})^2$
	150	13	$\frac{L}{r} = 11$	$13.8 - 0.076 \frac{L}{r}$	$\frac{L}{r} = 81$	$\frac{L}{r} = 88$ [Note (4)]	...	6.5	...	...	50,000 $(\frac{L}{r})^2$
	200	12.5	$\frac{L}{r} = 11$	$13.3 - 0.073 \frac{L}{r}$	$\frac{L}{r} = 82$	$\frac{L}{r} = 90$ [Note (4)]	...	6	...	...	49,000 $(\frac{L}{r})^2$

NOTES:

- [illegible]

TABLE ND-3852.7-3
ALLOWABLE BENDING STRESSES FOR ROOF SUPPORTS
Compression in Extreme Fibers of Shapes, Girders, and Built-Up Members, Subjected to Bending
[See Notes (1), (2), and (3)]

Alloy and Temper	Maximum Temp., °F	Cross Sections Farther Than 1.0 in. From Any Weld				Cross Sections Within 1.0 in. of a Weld			
		Allowable Stress for Slenderness Less Than S_1 , ksi	Slenderness Limit S_1	Allowable Stress for Slenderness Between S_1 and S_2 , ksi	Slenderness Limit S_2	Allowable Stress for Slenderness Greater Than S_2 , ksi	Slenderness Limit S_1	Allowable Stress for Slenderness Between S_1 and S_2 , ksi	Slenderness Limit S_2
6061-T6	To 100	19	$\frac{L_b}{r_y} = 12$	$20.4-0.113 \frac{L_b}{r_y}$	$\frac{L_b}{r_y} = 81$	$\frac{74,000}{(L_b/r_y)^2}$	...	11 [Note (4)]	$\frac{L_b}{r_y} = 82$ [Note (5)]
	150	19	$\frac{L_b}{r_y} = 11$	$20.2-0.112 \frac{L_b}{r_y}$	$\frac{L_b}{r_y} = 80$	$\frac{72,000}{(L_b/r_y)^2}$	...	11 [Note (4)]	$\frac{L_b}{r_y} = 81$ [Note (5)]
	200	18	$\frac{L_b}{r_y} = 16$	$19.8-0.111 \frac{L_b}{r_y}$	$\frac{L_b}{r_y} = 80$	$\frac{71,000}{(L_b/r_y)^2}$	...	11 [Note (4)]	$\frac{L_b}{r_y} = 80$ [Note (5)]
6063-T6	To 100	13.5	$\frac{L_b}{r_y} = 14$	$14.4-0.066 \frac{L_b}{r_y}$	$\frac{L_b}{r_y} = 96$	$\frac{74,000}{(L_b/r_y)^2}$	...	6.5	$\frac{L_b}{r_y} = 107$
	150	13	$\frac{L_b}{r_y} = 13$	$13.8-0.064 \frac{L_b}{r_y}$	$\frac{L_b}{r_y} = 97$	$\frac{72,000}{(L_b/r_y)^2}$	...	6.5	$\frac{L_b}{r_y} = 105$
	200	12.5	$\frac{L_b}{r_y} = 13$	$13.3-0.061 \frac{L_b}{r_y}$	$\frac{L_b}{r_y} = 98$	$\frac{71,000}{(L_b/r_y)^2}$	...	6	$\frac{L_b}{r_y} = 109$

NOTES:

- (1) L_b = length of beam between points at which the compression flange is supported against movement or length of cantilever beam from free end to point at which the compression flange is supported against lateral movement, in.
- (2) r_y = radius of gyration of beam about axis parallel to web, in. For beams that are unsymmetrical about the horizontal axis, r_y should be calculated as though both flanges were the same as the compression flange.
- (3) Rafter with compression flanges in direct contact with the roof plates which they support may be considered to have adequate and continuous lateral support; therefore, allowable stresses for zero length may be used.
- (4) These allowable stresses apply to all material welded with 5556 or 5356 filler alloy for temperatures not exceeding 150°F, and to material $\frac{3}{8}$ in. or less in thickness welded with 4043 or 5554 filler alloy. For thicker material welded with 4043 or 5554 filler alloy, these allowable stresses shall be reduced by multiplying them by 0.8. Allowable stresses not marked with a number in parentheses apply to material welded with either 5556 or 5356 filler alloy for temperatures not exceeding 150°F, or either 4043 or 5554 alloy.
- (5) These slenderness limits apply to all material welded with 5556 or 5356 filler alloy for temperatures not exceeding 150°F, and to material $\frac{3}{8}$ in. or less in thickness welded with 4043 or 5554 filler alloy. For thicker material welded with 4043 or 5554 filler alloy, these slenderness limits must be adjusted to correspond to the reduced values of maximum allowable stresses indicated in Note (4) above.

TABLE ND-3852.7-4
ALLOWABLE SHEAR STRESSES FOR ROOF SUPPORTS
 Shear in Webs of Beams and Girders [See Notes (1) and (2)]

Alloy and Temper	Maximum Temp., °F	Allowable Stress for Slenderness Less Than S_1 , ksi	Slenderness Limit S_1	Allowable Stress for Slenderness Between S_1 and S_2 , ksi	Slenderness Limit S_2	Allowable Stress for Slenderness Greater Than S_2 , ksi	Allowable Stress for Slenderness Less Than S_1 , ksi	Slenderness Limit S_1	Allowable Stress for Slenderness Greater Than S_1 , ksi
		Cross Sections Farther Than 1.0 in. From Any Weld					Cross Sections Within 1.0 in. of a Weld		
6061-T6	To 100	12	$\frac{h}{t} = 18$	$13.7 - 0.092 \frac{h}{t}$	$\frac{h}{t} = 66$	$\frac{33,000}{(h/t)^2}$	7 [Note (3)]	$\frac{h}{t} = 69$ [Note (4)]	$\frac{33,000}{(h/t)^2}$
	150	12	$\frac{h}{t} = 16$	$13.5 - 0.093 \frac{h}{t}$	$\frac{h}{t} = 66$	$\frac{32,000}{(h/t)^2}$	7 [Note (3)]	$\frac{h}{t} = 68$ [Note (4)]	$\frac{32,000}{(h/t)^2}$
	200	11.5	$\frac{h}{t} = 20$	$13.3 - 0.092 \frac{h}{t}$	$\frac{h}{t} = 66$	$\frac{31,000}{(h/t)^2}$	7 [Note (3)]	$\frac{h}{t} = 67$ [Note (4)]	$\frac{31,000}{(h/t)^2}$
6063-T6	To 100	8.5	$\frac{h}{t} = 19$	$9.5 - 0.054 \frac{h}{t}$	$\frac{h}{t} = 79$	$\frac{33,000}{(h/t)^2}$	4	$\frac{h}{t} = 91$	$\frac{33,000}{(h/t)^2}$
	150	8.5	$\frac{h}{t} = 13$	$9.2 - 0.052 \frac{h}{t}$	$\frac{h}{t} = 79$	$\frac{32,000}{(h/t)^2}$	3.6	$\frac{h}{t} = 94$	$\frac{32,000}{(h/t)^2}$
6063-T6	200	8	$\frac{h}{t} = 16$	$8.8 - 0.049 \frac{h}{t}$	$\frac{h}{t} = 80$	$\frac{31,000}{(h/t)^2}$	3.5	$\frac{h}{t} = 94$	$\frac{31,000}{(h/t)^2}$

NOTES:

(1) h = clear height of web, in.(2) t = thickness of web, in.(3) These allowable stresses apply to all material welded with 5556 or 5356 filler alloy for temperatures not exceeding 150°F, and to material $\frac{3}{8}$ in. or less in thickness welded with 4043 or 5554 filler alloy. For thicker material welded with 4043 or 5554 filler alloy, these allowable stresses shall be reduced by multiplying them by 0.8. Allowable stresses not marked with a number in parentheses apply to material welded with either 5556 or 5356 filler alloy for temperatures not exceeding 150°F, or either 4043 or 5554 alloy.(4) These slenderness limits apply to all material welded with 5556 or 5356 filler alloy for temperatures not exceeding 150°F, and to material $\frac{3}{8}$ in. or less in thickness welded with 4043 or 5554 filler alloy. For thicker material welded with 4043 or 5554 filler alloy, these slenderness limits must be adjusted to correspond to the reduced values of maximum allowable stresses indicated in Note (3) above.

TABLE ND-3852.7-4 ALLOWABLE SHEAR STRESSES FOR ROOF SUPPORTS

TABLE ND-3852.7-5
ALLOWABLE SHEAR AND TENSION STRESSES FOR
BOLTS FOR ROOF SUPPORTS
Bolts Shall Not be Welded

Description of Bolt	Allowable Stress, ksi		
	Maximum Temperature, °F		
	To 100	150	200
2024-T4 bolts	Shear		
	16	15	14.5
	Tension		
	26	26	25
2024-T4 bolts 6061-T6 bolts	18	17	17

TABLE ND-3852.7-5 ALLOWABLE SHEAR AND TENSIONS STRESSES FOR BOLTS FOR ROOF SUPPORTS

D	= nominal diameter of tank shell, ft
θ	= angle of cone elements with the horizontal, deg
f	= tensile working stress for the material of the roof plates, shell plates, or top shell angle, whichever is the least value, at the service temperature, psi
P	= dead load of roof, plus the live load, lb/sq ft
R	= radius of curvature of roof, ft
t_r	= nominal thickness of roof plates, in.

TABLE ND-3852.7-6
ALLOWABLE BEARING STRESSES FOR
BOLTS FOR ROOF SUPPORTS
Bolts Shall Not be Welded

Alloy and Temper	Maximum Temperature, °F	Allowable Stress, ksi	
		Cross Sections Farther Than 1.0 in. From Any Weld	Cross Sections Within 1.0 in. of a Weld
		Bolts [Note (1)]	
6061-T6	To 100	34	18 [Note (2)]
	150	33	18 [Note (2)]
	200	32	18 [Note (2)]
6063-T6	To 100	24	10
	150	23	9.5
	200	22	9

NOTES:

- (1) These values apply for a ratio of edge distance to bolt diameter of 2 or more. For smaller ratios, multiply these allowable stresses by the ratio (edge distance)/(twice the bolt diameter).
- (2) These allowable stresses apply to all material welded with 5556 or 5356 filler alloy for temperatures not exceeding 150°F, and to material $\frac{3}{8}$ in. or less in thickness welded with 4043 or 5554 filler alloy. For thicker material welded with 4043 or 5554 filler alloy, these allowable stresses shall be reduced by multiplying them by 0.8.

TABLE ND-3852.7-6 ALLOWABLE BEARING STRESSES FOR BOLTS FOR ROOF SUPPORTS

ND-3855.2 Design Requirements for Ferrous Material.

Self-supporting cone roofs shall conform to the requirements³⁵ of (a) through (c) below.

(a) Slope

Maximum $\theta=37$ deg (tangent=9:12)

Minimum $\sin \theta=0.165$ [slope 2 in./ft (16.7%)]

(b) Plate Thickness

(1) Minimum $t_r = \frac{D}{400 \sin \theta}$ but not less than $\frac{3}{16}$ in.

Maximum $t_r = \frac{1}{2}$ in.

(2) Self-supporting roofs having the roof plates stiffened by sections welded to the plates need not conform to the minimum thickness requirements but shall be not less than $\frac{3}{16}$ in.

(c) Top Angle to Roof-to-Shell Joint. The cross-sectional area of the top angle, in square inches, plus the cross-sectional areas of the shell and roof plates within a distance of 16 times their thicknesses, measured from their most remote point of attachment to the top angle, shall equal or exceed:

$$\frac{D^2}{3000 \sin \theta}$$

ND-3855.3 Design Requirements for Aluminum Material.

Self-supporting cone roofs shall conform to the requirements of (a) through (c) below.

(a) Slope

Minimum $\sin \theta=0.165$ [slope 2 in./ft (16.7%)]

Maximum $\theta=37$ deg (tangent=9:12)

(b) Plate Thickness

$$t_r = \frac{D}{1414 \sin \theta} \sqrt{P}$$

but not less than $\frac{3}{16}$ in. nominal.

(c) *Top Angle to Roof-to-Shell Joint.* The cross-sectional area of the top angle, in square inches, plus the cross-sectional areas of the shell and roof plates within a distance of 16 times their thicknesses, measured from their most remote point of attachment to the top angle, shall equal or exceed:

$$\text{Minimum } A_t = \frac{PD^2}{8f \sin \theta}$$

³⁵ The Formulas applying to self-supporting roof provide for a uniform live load of 25 lb/ft².

ND-3856 Self-Supporting Dome and Umbrella Roofs

ND-3856.1 Nomenclature.

See ND-3855.1 for nomenclature.

ND-3856.2 Design Requirements for Ferrous Material.

Self-supporting dome and umbrella roofs shall conform to the requirements³² of (a) through (c) below.

(a) Radius of Curvature

$R = D$ unless otherwise specified

Minimum $R = 0.80D$

Maximum $R = 1.2D$

(b) Plate Thickness

(1) Minimum $t = R/200$ but not less than $\frac{3}{16}$ in.

Maximum $t = \frac{1}{2}$ in.

(2) Self-supporting roofs having the roof plates stiffened by sections welded to the plates need not conform to the minimum thickness requirements but shall be not less than $\frac{3}{16}$ in.

(c) *Top Angle to Roof-to-Shell Joint.* The cross-sectional area of the top angle, in square inches, plus the cross-sectional areas of the shell and roof plates within a distance of 16 times their thicknesses, measured from their most remote point of attachment to the top angle, shall equal or exceed:

$$\frac{DR}{1500}$$

ND-3856.3 Design Requirements for Aluminum Material.

Self-supporting dome and umbrella roofs shall conform to the requirements of (a) through (c) below.

(a) Radius of Curvature

Minimum $R = 0.80D$

Maximum $R = 1.2D$

(b) Plate Thickness

$$t_r = \frac{R}{707} \sqrt{P}$$

but not less than $\frac{3}{16}$ in. nominal.

(c) *Top Angle to Roof-to-Shell Joint.* The cross-sectional area of the top shell angle, in square inches, plus the cross-sectional areas of shell and roof plates within a distance of 16 times their thicknesses, measured from their most remote point of attachment to the top shell angle, shall equal or exceed:

$$t_r = \frac{R}{707} \sqrt{P}$$

ND-3856.4 Top Angle Attachment for Self-Supporting Roofs

(a) The top angle sections for self-supporting roofs shall meet the requirements of ND-4246.6(d). Joint efficiency factors need not be applied.

(b) For self-supporting roofs, the edges of the roof plates may be flanged horizontally to rest flat against the top angle to improve welding conditions.

ND-3860 TANK CONNECTIONS AND APPURTENANCES

ND-3861 Roof Manholes

Roof manholes shall conform to Fig. ND-3861-1 and Table ND-3861-1, except that alternative designs which provide equivalent strength are permissible if agreed to by the Owner or his designee.

ND-3862 Roof Nozzles

(a) Flanged roof nozzles shall conform to Fig. ND-3862(a)-1 and Table ND-3862(a)-1. Threaded nozzles shall conform to Fig. ND-3862(a)-2 and Table ND-3862(a)-2. Alternative designs for flanged roof nozzles and threaded nozzles can be used, provided they are of equivalent strength and are agreed to by the Owner or his designee.

(b) Roof nozzles are not intended to take loads from pipe reactions. Earthquake loadings need not be considered.

ND-3863 Bottom Outlet Elbows

Bottom outlet elbows shall conform to Fig. ND-3863-1 and Table ND-3863-1.

ND-3864 Threaded Connections

Threaded piping connections shall be female and shall be tapered. The threads shall conform to the requirements for taper pipe threads included in ANSI B1.20.1.

ND-3865 Platforms, Walkways, and Stairways

Platforms, walkways, and stairways shall be in accordance with Tables ND-3865-1 through ND-3865-3.

Page 181

**TABLE ND-3861-1
ROOF MANHOLES**
See Fig. ND-3861-1 All Dimensions Are in Inches.

Size of Manhole	Diameter of Neck I.D.	Diameter of Cover Plate D_C	Diameter of Bolt Circle D_B	Number of Bolts	Diameter of Gasket		Diameter of Hole in Roof Plate or Reinforcing Plate D_P	O.D. of Reinforcing Plate D
					I.D.	O.D.		
20	20	26	23½	16	21½	26	20⅝	42
24	24	30	27½	20	25½	30	24⅝	46

TABLE ND-3861-1 ROOF MANHOLES

ND-3866 Nozzle Piping Transitions

The stress limits of Table ND-3821.5-1 shall apply to all portions of nozzles which lie within the limits of reinforcement given in ND-3334, except as provided in ND-3867. Stresses in the extension of any nozzle beyond the limits of reinforcement shall be subject to the stress limits of ND-3600.

ND-3867 Consideration of Standard Reinforcement

(a) Where a nozzle-to-shell junction is reinforced in accordance with the rules of ND-3334, the stresses in this region due to internal pressure may be considered to satisfy the limits of Table ND-3821.5-1. Under these conditions, no analysis is required to demonstrate compliance for pressure induced stresses in the nozzle region.

(b) Where external piping loads are to be designed for, membrane plus bending stresses due to these loads shall be calculated in the nozzle, and membrane stresses shall be calculated in the local nozzle-to-shell region. These stresses, in conjunction with pressure induced stresses, shall meet the limits of Table ND-3821.5-1 for $(\sigma_m \text{ or } \sigma_L) + \sigma_b$. In this case, the pressure induced stresses in the $(\sigma_m \text{ or } \sigma_L) + \sigma_b$ category may be assumed to be no greater than the limit specified for σ_m in Table ND-3821.5-1, for a given loading.

ND-3900 DESIGN OF 0-15 psi (0-103 kPa) STORAGE TANKS

ND-3910 GENERAL REQUIREMENTS

ND-3911 Acceptability

36 These rules do not limit storage tanks from being installed below grade or below ground, provided the tanks are not subject to external pressure resulting from earth or fill.

ND-3911.1 Scope.

The design rules for 0-15 psi (0-103 kPa) storage tanks shall cover above ground³⁶ welded storage tanks. These tanks may contain liquids or gases such as refueling water, condensate, borated reactor coolant, or radioactive waste. Such tanks are normally located within building structures.

ND-3911.2 Design Requirements

(a) The design requirements for 0-15 psi (0-103 kPa) storage tanks shall conform to the design rules of ND-3100 and ND-3300 except where they are modified by the requirements of this Subarticle. The joint efficiency E shall be based on the requirements of ND-3352. The specific design requirements shall be stipulated by the Design Specifications.

(b) The total liquid capacity of a tank shall be defined as the total volumetric liquid capacity below the high liquid design level. The nominal liquid capacity of a tank shall be defined as the total volumetric liquid capacity between the plane of the high liquid design level and the elevation of the tank grade immediately adjacent to the wall of the tank or such other low liquid design level as the Certificate Holder shall stipulate.

ND-3912 Design Report

The Certificate Holder of a storage tank conforming to the design requirements of this Subarticle is required to provide a Design Report as part of his responsibility of achieving structural integrity of the tank. The Design Report shall be certified when required by NCA-3550.

ND-3920 DESIGN CONSIDERATIONS

ND-3921 Design and Service Loadings

(a) Loadings shall be identified as Design or Service, and, if Service, they shall have Level A, B, C, or D Service Limits designated (NCA-2142).

(b) The provisions of ND-3110 shall apply.

(c) The stress limits of ND-3921.8 shall be met.

Page 182

Page 183

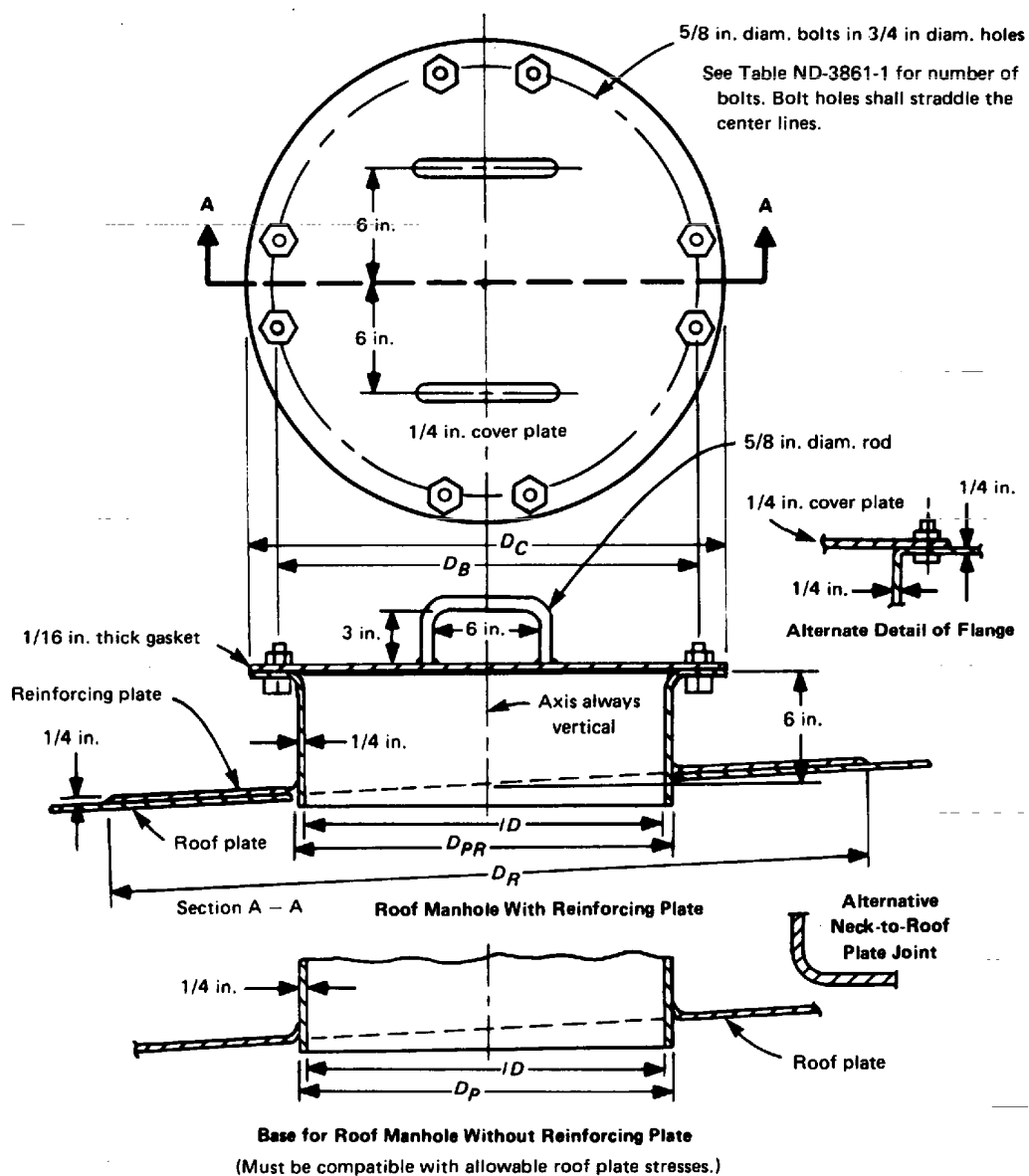


FIG. ND-3861-1 ROOF MANHOLES
See Table ND-3861-1

FIG. ND-3861-1 ROOF MANHOLES

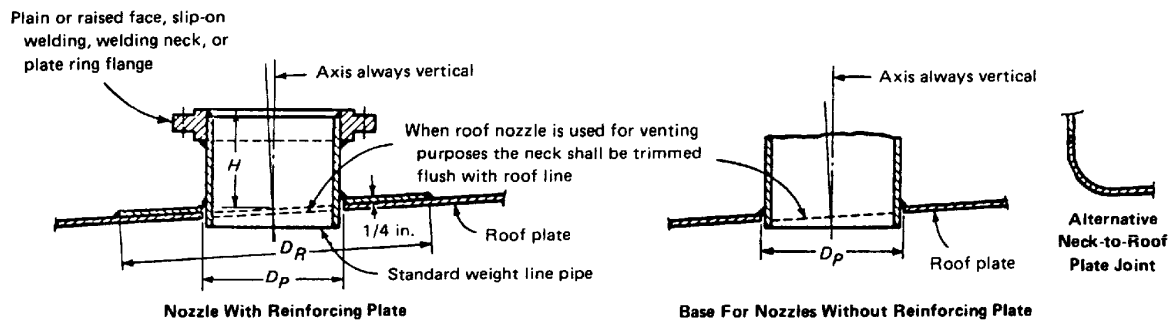
TABLE ND-3862(a)-1
FLANGED ROOF NOZZLES
 See Fig. ND-3862(a)-1. All Dimensions Are in Inches.

Nominal Size of Nozzle	O.D. of Pipe Neck	Diameter of Hole in Roof Plate or Reinforcing Plate D_P	Height of Nozzle H	O.D. of Reinforcing Plate D_R
1½	1.900	2	6	5 [Note (1)]
2	2⅜	2½	6	7 [Note (1)]
3	3½	3⅝	6	9 [Note (1)]
4	4½	4⅝	6	11 [Note (1)]
6	6⅝	6¾	6	15 [Note (1)]
8	8⅝	8⅞	6	18
10	10¾	11	8	22
12	12¾	13	8	24

NOTE:

(1) Reinforcing plates are not required on 6 in. or smaller nozzles, but may be used if desired.

TABLE ND-3862(a)-1 FLANGED ROOF NOZZLES



GENERAL NOTES:

- (a) Slip-on welding and welding neck flanges shall conform to the requirements for 150 lb forged carbon steel raised face flanges as given in ANSI B16.5.
- (b) Plate ring flanges shall conform to all dimensional requirements for slip-on welding flanges, except that the extended hub on the back of the flange may be omitted.

FIG. ND-3862(a)-1 FLANGED ROOF NOZZLES
See Table ND-3862(a)-1

TABLE ND-3862(a)-1 FLANGED ROOF NOZZLES

TABLE ND-3862(a)-2
SCREWED OR SOCKET WELD ROOF NOZZLES
See Fig. ND-3862(a)-2. All Dimensions Are in Inches.

Nominal Size of Nozzle	Nominal Size of Coupling	Diameter of Hole in Roof Plate or Reinforcing Plate D_P	O.D. of Reinforcing Plate D_R
$\frac{3}{4}$	$\frac{3}{4}$	$1\frac{7}{16}$	4 [Note (1)]
1	1	$1\frac{23}{32}$	$4\frac{1}{2}$ [Note (1)]
$1\frac{1}{2}$	$1\frac{1}{2}$	$2\frac{11}{32}$	5 [Note (1)]
2	2	3	7 [Note (1)]
3	3	$4\frac{1}{8}$	9 [Note (1)]
4	4	$5\frac{11}{32}$	11 [Note (1)]
6	6	$7\frac{17}{32}$	15 [Note (1)]
8	8	$9\frac{7}{8}$	18
10	10	12	22
12	12	$14\frac{1}{4}$	24

NOTE:

- (1) Reinforcing plates are not required on 6 in. or smaller nozzles, but may be used if desired.

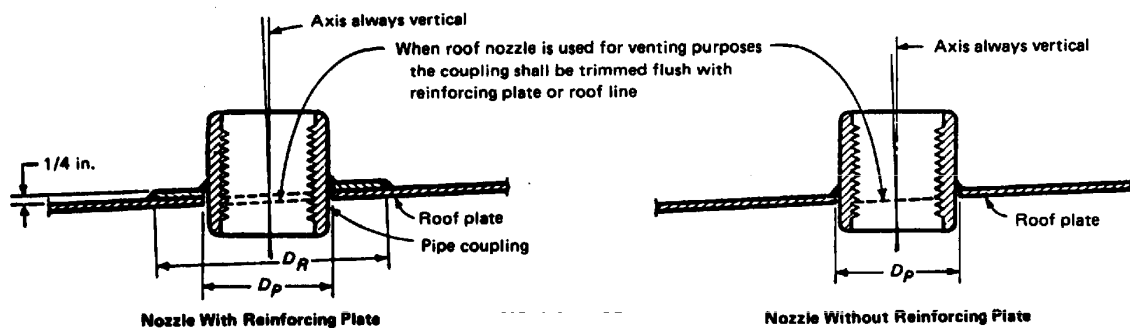


FIG. ND-3862(a)-2 SCREWED OR SOCKET WELD ROOF NOZZLES
See Table ND-3862(a)-2, ND-3864

FIG. ND-3862(a)-2 SCREWED OR SOCKET WELD ROOF NOZZLES

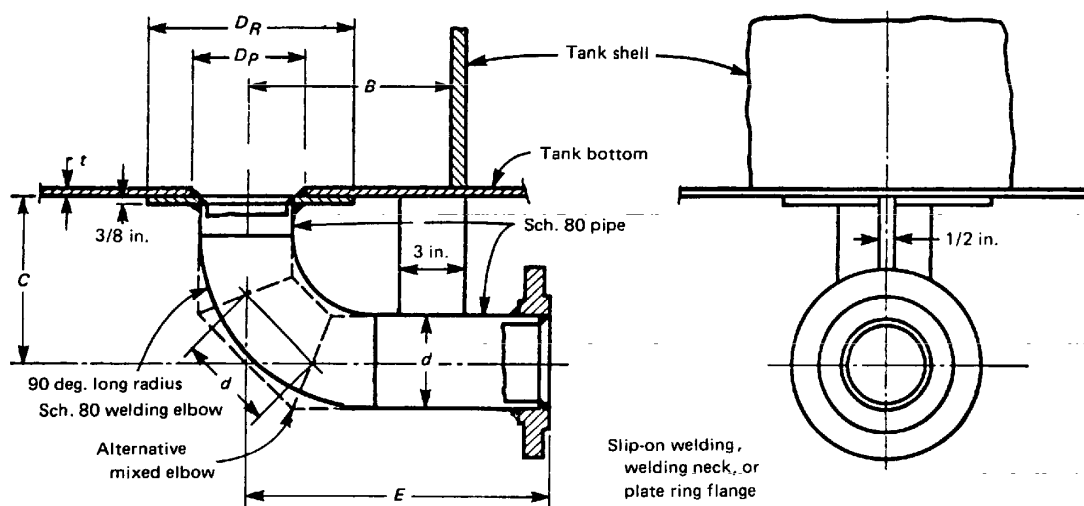
TABLE ND-3863-1
WELDED BOTTOM OUTLET ELBOW
See Fig. ND-3863-1. All Dimensions Are in Inches.

Nominal Pipe Size ¹	Distance from Center of Elbow to Shell B	Distance from Center of Outlet to Bottom C	Diameter of Hole in Tank Bottom D_P	O.D. of Reinforcing Plate D_R	Distance from Center of Elbow to Face of Flange E
2	$7\frac{1}{2}$	6	$3\frac{1}{8}$	$6\frac{1}{4}$	12
3	$8\frac{1}{2}$	7	$4\frac{1}{4}$	$7\frac{3}{4}$	13
4	$9\frac{1}{2}$	$7\frac{13}{16}$	$5\frac{1}{4}$	$9\frac{3}{4}$	14
6	11	$9\frac{3}{8}$	$7\frac{3}{8}$	$12\frac{3}{4}$	16
8	13	$12\frac{3}{8}$	$9\frac{3}{8}$	$16\frac{1}{2}$	18

NOTE:

(1) Extra-strong pipe, refer to ANSI B36.10M.

TABLE ND-3863-1 WELDED BOTTOM OUTLET ELBOW



GENERAL NOTES:

- (a) Slip-on welding and welding neck flanges shall conform to the requirements for 150 lb forged carbon steel raised face flanges as given in ANSI B16.5.
- (b) Plate ring flanges shall conform to all dimensional requirements for slip-on welding flanges, except that the extended hub on the back of the flange may be omitted.

FIG. ND-3863-1 WELDED BOTTOM OUTLET ELBOW
See Table ND-3863-1

FIG. ND-3863-1 WELDED BOTTOM OUTLET ELBOW

TABLE ND-3865-1

PLATFORMS AND WALKWAYS

1. All parts to be made of metal.
 2. Width of floor level (min.): 24 in.
 3. Flooring to be made of grating or nonslip material.
 4. Height of top railing above floor¹: 42 in.
 5. Height of toeboard (min.): 3 in.
 6. Space between top of floor and bottom of toeboard (max.): $\frac{1}{4}$ in.
 7. Height of midrail: approximately one-half the distance from top of walkway to top of railing.
 8. Distance between railing posts (max.): 96 in.
 9. The completed structure shall be capable of supporting a moving concentrated load of 1000 lb, and the handrailing structure shall be capable of withstanding a load of 200 lb applied in any direction at any point on the top rail.
 10. Handrails to be on both sides of platform, discontinuing where necessary for access.
 11. At handrail openings, any space between tank and platform wider than 6 in. should be floored.
 12. Tank runways, which extend from one part of a tank to any part of an adjacent tank, or to ground or other structure, shall be so supported as to permit free relative movement of the structures joined by the runway. This may be accomplished by firm attachment of runway to one tank, but with a slip joint at point of contact between runway and other tank. This is to permit either tank to settle or be disrupted by an explosion without endangering the other.
-

NOTE:

- (1) Handrail height as required by ANSI specifications. This height is mandatory in some states.

TABLE ND-3865-1 PLATFORMS AND WALKWAYS

37 Whenever a tank is to be operated with liquid levels which at no time reach the top of the roof, but is to be filled to the very top of the roof during the hydrostatic test, it shall be designed for both of these maximum liquid level conditions, using in each case the density of the liquid employed. If a tank is not designed to be filled to the very top of the roof, overfill protection is required.

38 A suitable margin shall be allowed between the pressure at which the relief valves are set, so as to allow for the increases in pressure caused by variations in the temperature or gravity of the liquid contents of the tank and other factors affecting the pressure in the gas or vapor space.

39 The partial vacuum shall be greater than that at which the vacuum relief valves are set to open.

ND-3921.1 Design Pressure

(a) The walls of the gas or vapor space and other components of the tank above the maximum liquid level³⁷ at the top of the tank shall be designed for a pressure not less than that at which the pressure relief valves are to be set³⁸ and for the maximum partial vacuum which can be developed in such space³⁹ when the inflow of air, gas, or vapor through the vacuum relief valves is at its maximum specified rate. The maximum positive gage pressure for which this space is designed shall be understood to be the nominal pressure rating for the tank and shall not exceed 15 psi (103 kPa).

TABLE ND-3865-2 STAIRWAYS

1. All parts to be made of metal.
2. Width of stairs (min.): 24 in.
3. Angle¹ of stairway with a horizontal line (max.): 50 deg
4. Width of stair treads (min.): 8 in. [The run (defined as the horizontal distance between the noses of successive tread pieces) and the rise of stair treads shall be such that the sum of twice the rise, plus the run, shall be not less than 24 in. nor more than 26 in. Rises shall be uniform throughout the height of the stairway.]
5. Treads to be made of grating or nonslip material.
6. Top railing shall join platform handrail without offset, and the height measured vertically from tread level at nose of tread shall be 30 to 34 in.
7. Distance between railing posts (max.) measured along slope of railing: 96 in.
8. The completed structure shall be capable of supporting a moving concentrated load of 1000 lb, and the handrailing structure shall be capable of withstanding a load of 200 lb applied in any direction at any point on the top rail.
9. Handrails shall be on both sides of straight stairs; also, handrails shall be on both sides of circular stairs when the clearance between tank shell and stair stringer exceeds 8 in.
10. Circumferential stairways should be completely supported on the shell of the tank, and ends of the stringers should be clear of the ground.

NOTE:

- (1) It is recommended that the same angle be employed for all stairways in a tank group or plant area.

TABLE ND-3865-2 STAIRWAYS

(b) All portions of the tank at levels below maximum liquid level shall be designed for the most severe combination of gas pressure, partial vacuum, and static liquid head.

ND-3921.2 Design Temperature.

The Design Temperature shall not be greater than 200°F (93°C).

ND-3921.3 Tank Shape.

Tank walls shall be so shaped as to avoid any pockets on the inside where gases may become trapped when the liquid level is being raised or pockets on the outside where rainwater may collect.

ND-3921.4 Loadings.

See ND-3111 for loadings to be considered.

ND-3921.5 Corrosion Allowance.

When corrosion is expected on any part of the tank wall or on any external or internal supporting or bracing members upon which the safety of the completed tank depends, additional metal thickness in excess of that required by the design computations shall be provided or some satisfactory method of protecting these surfaces from

Page 187

corrosion shall be employed. Such added thickness need not be the same for all zones of exposure inside and outside of the tank.

TABLE ND-3865-3
STAIRWAY RISE, RUN, AND ANGLE RELATIONSHIPS

Height of Rise, in. <i>R</i>	$2R + r = 24$ in.			$2R + r = 26$ in.		
	Width of Run, in. <i>r</i>	Angle		Width of Run, in. <i>r</i>	Angle	
		deg	min.		deg	min.
$5\frac{1}{4}$	$13\frac{1}{2}$	21	15	...	...	...
$5\frac{1}{2}$	13	22	56	15	20	9
$5\frac{3}{4}$	$12\frac{1}{2}$	24	43	$14\frac{1}{4}$	21	38
6	12	26	34	14	23	12
$6\frac{1}{4}$	$11\frac{1}{2}$	28	30	$13\frac{1}{2}$	24	53
$6\frac{1}{2}$	11	30	35	13	26	34
$6\frac{3}{4}$	$10\frac{1}{2}$	32	45	$12\frac{1}{2}$	28	23
7	10	35	0	12	30	15
$7\frac{1}{4}$	$9\frac{1}{2}$	38	20	$11\frac{1}{2}$	32	13
$7\frac{1}{2}$	9	39	50	11	34	18
$7\frac{3}{4}$	$8\frac{1}{2}$	42	22	$10\frac{1}{2}$	36	26
8	8	45	0	10	38	40
$8\frac{1}{4}$	$7\frac{1}{2}$	47	43	$9\frac{1}{2}$	41	0
$8\frac{1}{2}$	...	...	...	9	43	23
$8\frac{3}{4}$	...	...	...	$8\frac{1}{2}$	45	49
9	...	...	...	8	48	22

TABLE ND-3865-3 STAIRWAY RISE, RUN, AND ANGLE RELATIONSHIPS

ND-3921.6 Linings.

When corrosion resistant linings are attached to any element of the tank wall, including nozzles, their thickness shall not be included in the computation for the required wall thickness.

ND-3921.7 Welded Joint Restrictions.

The restrictions on type and size of joints or welds given in (a) through (c) below shall apply.

(a) Tack welds shall not be considered as having any strength value in the finished structure.

(b) The weld joint requirements shall be as given in ND-4247.

(c) All nozzle welds shall be in accordance with ND-4244.

40.Stress means the maximum normal stress.

ND-3921.8 Limits of Calculated Stresses for Design and Service Loadings.

Stress⁴⁰ limits for Design and Service Loadings are specified in Table ND-3921.8-1. The symbols used in Table ND-3921.8-1 are defined as follows:

σ_m	= general membrane stress, psi. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.
σ_L	= local membrane stress, psi. This stress is the same as σ_m , except that it includes the effect of discontinuities.
σ_b	= bending stress, psi. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes
	discontinuities and concentrations, and is produced only by pressure and other mechanical loads.
S	= allowable stress value given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1, psi. The allowable stress shall correspond to the highest metal temperature at the section under consideration during the loading under consideration.

**TABLE ND-3921.8-1
DESIGN AND SERVICE LIMITS
FOR STEEL TANKS**

Service Limit	Stress Limits ^{1,2}
Design and Level A	$\sigma_m \leq 1.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5S$
Level B	$\sigma_m \leq 1.10S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65S$
Level C	$\sigma_m \leq 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$
Level D	$\sigma_m \leq 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$

NOTES:

- (1) See ND-3921.8 for definitions of symbols.
- (2) These limits do not take into account either local or general buckling which might occur in thin wall vessels.

TABLE ND-3921.8-1 DESIGN AND SERVICE LIMITS FOR STEEL TANKS

Typical examples of locations and loadings for which σ_m , σ_L , and σ_b are applicable are shown in Table XIII-1130-1 with σ in Table ND-3921.8-1 considered as equivalent to P in Table XIII-1130-1.

ND-3922 Maximum Allowable Stress Values for Tanks

ND-3922.1 Nomenclature.

The various symbols used for stresses are defined as follows:

t	= thickness, in., of sidewalls, roof, or bottom, including corrosion allowance
c	= allowance for corrosion, in.
R	= radius of the wall, in.
R	= radius of curvature of the tank wall in a meridian plane, in.

R_2	= length, in., of the normal to the tank wall measured from the wall of the tank to its axis of revolution
T_1	= meridional unit force in the wall of the tank, lb/in. of latitudinal arc
T_2	= latitudinal unit force in the wall of the tank, lb/in. of meridional arc
S_{ts}	= maximum allowable stress for simple tension, psi (Tables 1A, 1B, and 3, Section II, Part D, Subpart 1)
S_{cs}	= maximum allowable longitudinal compressive stress, psi, for a cylindrical wall acted upon by an axial load with neither a tensile nor a compressive force acting concurrently in a circumferential direction, and determined in accordance with ND-3922.3(a) for the thickness-radius ratio involved
S_{ta}	= allowable tensile stress, psi, which is lower than S_{ts} because of the presence of a coexistent compressive stress perpendicular to it
S_{ca}	= allowable compressive stress, psi, which is lower than S_{cs} because of the presence of a coexistent tensile or compressive stress perpendicular to it
S_{tc}	= computed tensile stress, psi, at the point under consideration
S_{cc}	= computed compressive stress, psi, at the point under consideration
S_t	= general symbol for indicating a tensile stress, psi, which may be either an allowable or computed value, depending on the context in which the symbol is used
S_c	= general symbol for indicating a compressive stress, psi, which may be either an allowable or computed value, depending on the context in which the symbol is used
N	= ratio of the tensile stress S_t to the maximum allowable stress for simple tension S_{ts}
M	= ratio of the compressive stress S_c to the maximum allowable compressive stress S_{cs} (Fig. ND-3922.1-2)

ND-3922.2 Maximum Tensile Stresses.

The maximum tensile stresses in the outside walls of a tank, as determined for any loadings or any concurrent combination of such loadings, shall not exceed the applicable stress values determined in accordance with (a) or (b) below.

(a) If both the meridional and latitudinal unit forces T_1 and T_2 are tensile, or if one of these forces is tensile and the other is zero, the computed tensile stress S_{tc} shall not exceed the applicable value given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1.

(b) If the meridional unit force T_1 is tensile and the coexistent latitudinal unit force T_2 is compressive, or if T_2 is tensile and T_1 is compressive, the computed tensile stress S_{tc} shall not exceed a value of S_{ta} obtained by multiplying the applicable stress value given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1 by the appropriate value of N obtained from Fig. ND-3922.1-1 for the value of compressive stress ($S_c = S_{cc}$) and co-related ratio $(t - c)/R$ involved. However, in

For $(t - c)/R$ values less than 0.00667:

$$S_{cs} = 1,800,000(t - c)/R$$

For $(t - c)/R$ values between 0.00667 and 0.0175:

$$S_{cs} = 10,150 + 277,400(t - c)/R$$

For $(t - c)/R$ values greater than 0.0175:

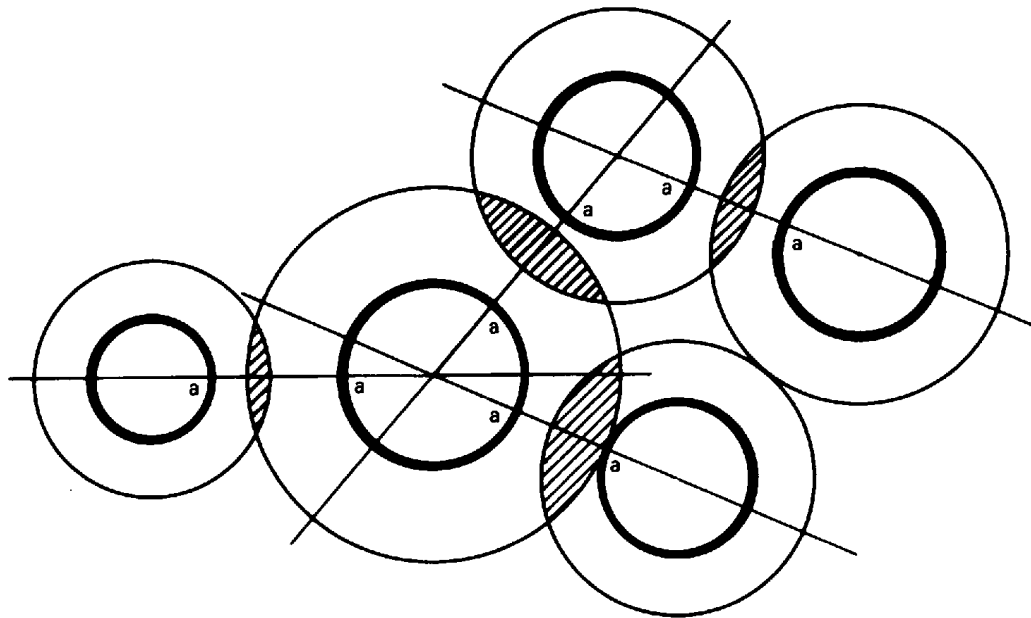
$$S_{cs} = 15,000$$

However, values of S_{cs} calculated as above, but with R taken as equal to R_1 when the compressive unit force under consideration is latitudinal or with R taken as equal to R_2 when the compressive unit force is meridional, form the basis for the rules given in (b), (c), and (d) below which apply to walls of double curvature.

(b) If both the meridional and latitudinal unit forces T_1 and T_2 are compressive and of equal magnitude, the computed compressive stress S_{ce} shall not exceed a value S_{ca} established for the applicable thickness-radius as follows.

Page 190

Page 191



GENERAL NOTES:

- (1) Hatched area represents overlapping of the reinforcement limits.
- (2) Each cross-section indicated by a straight line a-a must be investigated for adequacy of reinforcement.
- (3) Heavy circles represent openings, and light circles represent limits of reinforcement.

FIG. ND-3335.2-1 ARRANGEMENT OF MULTIPLE OPENINGS

FIG. ND-3922.1-2 REDUCTION OF DESIGN STRESSES REQUIRED TO ALLOW FOR BIAXIAL STRESSES OF OPPOSITE SIGN

For $(t - c)/R$ values less than 0.00667:

$$S_{ca} = 1,000,000(t - c)/R$$

For $(t - c)/R$ values between 0.00667 and 0.0175:

$$S_{ca} = 5,650 + 154,200(t - c)/R$$

For $(t - c)/R$ values greater than 0.0175:

$$S_{ca} = 8,340$$

(c) If both the meridional and latitudinal unit forces T_1 and T_2 are compressive but of unequal magnitude, both the larger and the smaller computed compressive stresses shall be limited to values which satisfy the following requirements:⁴³

$$\frac{(\text{larger stress}) + 0.8 (\text{smaller stress})}{S_{cs} \text{ determined using } R \text{ for the larger unit force}} \leq 1.0$$

$$\frac{1.8 (\text{smaller stress})}{S_{cs} \text{ determined using } R \text{ for the smaller unit force}} \leq 1.0$$

(d) If the meridional unit force T_1 is compressive and the coexistent unit force T_2 is tensile or if T_2 is compressive and T_1 is tensile, the computed compressive stress S_{cc} shall not exceed a value of S_{ca} determined from Fig. ND-3922.1-1 by entering the computed value of N and the value of $(t - c)/R$ associated with the compressive unit stress and by reading the value of S_c which corresponds to that point. Such value of S_c will be the limiting value of S_{ca} for the given conditions. Section F.1 of Appendix F of API 620, Feb. 1970 Ed. gives examples illustrating the determination of allowable compressive stress values S_{ca} .

(e) The allowable compressive stresses previously specified in this subparagraph are predicated on butt welded construction. If one or more of the main joints across which the compressive force acts are of the lap welded type, the allowable compressive stress shall be determined as above except that the maximum compressive stress shall be subject to the limitations of ND-3933.1 and the applicable joint efficiency.

⁴³ In these expressions if the unit force is latitudinal, R shall be considered to be R_1 and, if meridional, R shall be considered as equal to R_2 .

ND-3922.4 Maximum Shear Stresses.

The maximum shear stresses in welds used for attaching man ways, nozzles, reinforcements, or other attachments to

the walls of a tank, and in sections of manway or nozzle necks serving as reinforcement attachment, shall not exceed 80% of the applicable maximum allowable tensile stress value S_{ts} .

ND-3923 Maximum Allowable Stress Values for Structural Members

ND-3923.1 General Stress Limits.

Subject to the provisions of ND-3923.2(c) the maximum stresses in internal or external diaphragms, webs, trusses, columns, and other framing, as determined for any loadings shall not exceed the applicable allowable stresses given in Table ND-3923.1-1.

ND-3923.2 Slenderness Ratio Limits.

The slender ness ratio (i.e., the ratio of the unbraced length l to the least radius of gyration r) for structural members in compression and for tension members other than rods shall not exceed the following values, except as provided in (a) below.

	Maximum l/r
For main compression members	120
For bracing and other secondary members in compression	200
For main tension members	240
For bracing and other secondary members in tension	300

(a) The slenderness ratio of main compression members inside of a tank may exceed 120, but not 200, provided the member is not ordinarily subject to shock or vibration loads and the unit stress under full Design Loadings does not exceed the following fraction of the stress value given in Table ND-3923.1-1 for the member's actual l/r ratio:

$$f = 1.6 - \frac{1}{200r}$$

(b) The gross and net sections of structural members shall be as determined in (1) through (5) below.

(1) The gross section of a member at any point shall be determined by summing the products of the thickness and the gross width of each element as measured normal to the axis of the member. The net section shall be determined by substituting for the gross width the net width which, in the case of a member having a chain of holes extending across it in any diagonal or zigzag line, shall be computed by deducting from the gross width the sum of the diameters of all

$$\frac{s^2}{4g}$$

s = longitudinal spacing (pitch), in., of any two successive holes
 g = transverse spacing (gage), in., of the same two holes

Pages 193-194

TABLE ND-3923.1-1
 MAXIMUM ALLOWABLE STRESS VALUES FOR STRUCTURAL MEMBERS

	Column 1 For Members Not Subject to Pressure-Imposed Loads, ksi	Column 2 For Internal Members Resisting Pressure, ksi
(a) Tension		
Roller steel, on net section.....	18.0	[Note (1)]
Butt welds, on cross-sectional area in, or at edge of, weld ²	18.0	[Note (1)]
Bolts and other threaded parts, on net area at root of thread.....	18.0	[Note (1)]
(b) Compression		
For axially loaded structural columns, structural bracing, and structural secondary members, on gross section.....	18 $1 + \frac{f^2}{18,000r^2}$ but not to exceed 15	Same values as for Column 1
For axially loaded tubular columns, tubular bracing, and tubular secondary members, on gross section (minimum permissible thickness, $\frac{1}{4}$ in.)	$18.0Y$ $1 + \frac{f^2}{18,000r^2}$ but not to exceed 15 Y	Same values as for Column 1
where f = unbraced length of column, in. r = corresponding least radius of gyration of column, in. R = outside radius of tubular column, in. t = thickness of tubular column, in. Y = unity (1.0) for values of t/R equal to or exceeding 0.015 = $\frac{2}{3}$ (100 t/R)(2 - $\frac{2}{3}$ (100 t/R)), for values of t/R less than 0.015		
Butt welds, on least cross-sectional area in, or at edge of, weld (crushing)	18.0	15.0
Plate girder stiffeners, on gross section	18.0	15.0
(c) Bending		
Tension on extreme fibers of rolled sections, plate girders, and built-up members.....	18.0	[Note (1)]
Compression on extreme fibers of rolled sections, plate girders, and built-up members:		
With Id/bt not in excess of 600.....	18.0	Same as tension value ²

TABLE ND-3923.1-1 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES FOR STRUCTURAL MEMBERS

	Column 1 For Members Not Subject to Pressure-Imposed Loads, ksi	Column 2 For Internal Members Resisting Pressure, ksi
With ld/bt in excess of 600.....	10,800.0	$(600) \times \text{tension value}^1$
	ld/bt	ld/bt
where l = unsupported length of the member, in., except that, for a cantilever beam not fully stayed at its outer end against translation or rotation, l shall be taken as twice the length of the compression flange d = depth of the member, in. b = width of its compression flange, in. t = thickness of its compression flange, in.		
Stress on extreme fibers of pins.....	27.0	20.0
Members subjected to both axial and bending loads shall be so proportioned that the maximum combined axial and bending stress will not exceed the permissible value for axial loading alone. Fiber stresses in butt welds resulting from bending shall not exceed the values prescribed for tension and compression, respectively. (Such values for welds in tension must be multiplied by the applicable joint efficiency.)		
(d) Shearing		
Pins and turned bolts in reamed or drilled holes	13.5	12.0
Unfinished bolts.....	10.0	8.0
Webs of beams and plate girders where h/t is not more than 60, or where web is adequately stiffened, on gross section of web.....	12.0	Two-thirds of tension value ¹
Webs of beams and plate girders where web is not adequately stiffened and h/t is more than 60, on gross section of web	18.0	Tension value ¹
	$1 + \frac{h^2}{7200t^2}$	$1 + \frac{h^2}{7200t^2}$
where h = clear distance between web flanges, in. t = thickness of the web, in.		
Fillet welds where load is perpendicular to length of weld, on section through throat ²	12.6	70% of tension value ¹
Fillet welds where load is parallel to length of weld, on section through throat ²	9.0	50% of tension value ¹
Plug welds or slot welds, on effective faying-surface area of weld ²	11.7	65% of tension value ¹
Butt welds, on least cross-sectional area in, or at edge of, weld ²	14.4	80% of tension value ¹

TABLE ND-3923.1-1 (CONT'D) MAXIMUM ALLOWABLE STRESS VALUES FOR STRUCTURAL MEMBERS

TABLE ND-3923.1-1 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES FOR STRUCTURAL MEMBERS

	Column 1 For Members Not Subject to Pressure-Imposed Loads, ksi	Column 2 For Internal Members Resisting Pressure, ksi
(e) Bearing		
Pins and turned bolts in reamed or drilled holes:		
Load applied to bolt at only one side of member connected	24.0	1.33 (tension value ¹)
Load approximately uniformly distributed across thickness of member connected	30.0	1.67 (tension value ¹)
Unfinished bolts:		
Load applied to bolt at only one side of member connected	16.0	0.9 (tension value ¹)
Load approximately uniformly distributed across thickness of member connected	20.0	1.1 (tension value ¹)

NOTES:

(1) Tables 1A, 1B, and 3, Section II, Part D, Subpart 1.

(2) All values for butt welds in tension or shear shall be multiplied by the applicable joint efficiency. These values are obtained by combining the following: a factor of 80% for shear strength of weld metal; an efficiency factor of approximately 85% for fillet welds or 80% for plug welds and slot welds; and a factor of 100% for perpendicular loading or approximately 75% for parallel loading.

[98]

TABLE ND-3923.1-1 (CONT'D) MAXIMUM ALLOWABLE STRESS VALUES FOR STRUCTURAL MEMBERS

(2) In the case of angles, the gage for holes in opposite legs shall be the sum of the gages from the back of the angle less the thickness.

(3) In determining the net section across plug or slot welds, the weld metal shall not be considered as adding to the net area.

(4) For splice members, the thickness considered shall be only that part of the thickness of the member which has been developed by the welds or other attachments beyond the section considered.

(5) In pin connected tension members other than forged eyebars, the net section across the pinhole transverse to the axis of the member shall not be less than 135%, and the net section beyond the pinhole parallel to the axis of the member shall not be less than 90% of the net section of the body of the member. The net width of a pin connected member across the pinhole transverse to the axis of the member shall not exceed eight times the thickness of the member at the pin, unless lateral buckling is prevented.

(c) External structural or tubular columns and framing subject to stresses produced by a combination of wind and other applicable loads specified in ND-3921.4 may be proportioned for unit stresses 25% greater than those specified in Table ND-3923.1-1, provided the section thus required is not less than that required for all other applicable loads combined on the basis of the unit stresses specified in Table ND-3923.1-1. A corresponding increase may be applied to the allowable unit stresses in the connecting bolts or welds.

ND-3930 DESIGN PROCEDURE

ND-3931 Design of Tank Walls

(a) Free body analyses shall be made at successive levels from the top to the bottom of the tank for the purpose of determining the magnitude and character of the meridional and latitudinal unit forces which will exist in the walls of the tank at critical levels under all the various combinations of gas pressure or partial vacuum and liquid head to be encountered in service which may have a controlling effect on the design. To this end it will sometimes be necessary to make several analyses at a given level of the tank to establish the governing conditions of gas pressure and liquid head for

that level. The thicknesses required in the main walls of the tank shall then be computed by the applicable procedures given in ND-3932.3.

(b) For tanks having points of marked discontinuity in the direction of the meridional tangent, such as occurs at the juncture between a conical or dished roof or bottom and a cylindrical sidewall or at the juncture between a conical reducer and a cylindrical sidewall, the portions of the tank near such points shall be designed in accordance with the provisions of ND-3933.

ND-3932 Design of Sidewalls, Roofs, and Bottoms

ND-3932.1 Nomenclature.

The symbols are defined as follows:

P	$= P_L + P_G$ = total pressure, psi, acting at a given level of the tank under a particular condition of loading
P_L	= pressure resulting from the liquid head at the level under consideration in the tank, psi
P_G	= gas pressure, psi, above the surface of the liquid. The maximum value, a pressure not exceeding 15 psig, is the nominal pressure rating of the tank. P_G is positive except in computations for investigating the ability of a tank to withstand a partial vacuum, where the value is negative.
T_1	= meridional unit force in the wall of the tank at the level under consideration, lb/in. of latitudinal arc. T_1 is positive when in tension.
T_2	= latitudinal unit force in the wall of the tank at the level under consideration, lb/in. of meridional arc. T_2 is positive when in tension. In cylindrical sidewalls the latitudinal unit forces are circumferential unit forces.
R_1	= radius of curvature of the tank wall in a meridian plane, at the level under consideration, in. R_1 is to be considered negative when it is on the opposite side of the tank wall from R_2 except as provided in ND-3932.2(f).
R_2	= length, in., of the normal to the tank wall at the level under consideration, measured from the wall of the tank to its axis of revolution. R_2 is always positive except as provided in ND-3932.2(f).
W	= total weight, lb, of that portion of the tank and its contents either above the level under consideration, as in Fig. ND-3932.1-1 sketch (b), or below such level, as in Fig. ND-3932.1-1 sketch (a) which is treated as a free body in the computations for such level. W shall be given same sign as P when acting in the same direction as the pressure on the horizontal face of the free body, and the opposite sign when acting in the opposite direction.
F	= summation, lb, of the vertical components of the forces in all internal or external ties, braces, diaphragms, trusses, columns, skirts, or other structural devices or supports acting on the free body. F shall be given the same sign as P when

	acting in the same direction as the pressure on the horizontal face of the free body and the opposite sign when acting in the opposite direction.
A_T	= cross-sectional area of the interior of the tank at the level under consideration, sq in.
E	= efficiency, expressed as a decimal, of the weakest joint across which the stress under consideration acts
S_{ts}	= maximum allowable stress for simple tension, psi (Tables 1A, 1B, and 3, Section II , Part D, Subpart 1)
S_{ta}	= allowable tension stress, psi, as required in ND-3922.2(b)
S_{ca}	= allowable compression stress, psi, as required in ND-3922.3
S_{tc}	= computed tension stress, psi, at the point under consideration
S_{cc}	= computed compression stress, psi, at the point under consideration

44 (a) Equation (2) has been derived from a summation of the components, normal to the surface, of the T_1 and T_2 forces acting on a unit area of the tank wall subjected only to a pressure P . To be technically correct, the normal to the surface components of other loads, such as metal, snow, or insulation, should be added to or subtracted from the term P . For the usual internal Design Pressure, these added loads are small compared to the pressure P and can be omitted without significant error. When the pressure P is relatively small including the case of the partial vacuum loading, the other load components can have a substantial effect on the calculated T_2 force and the resultant thickness.

(b) Example F.3.01 in Appendix F of API 620 Feb. 1970 Edition calculates the required roof thicknesses under a small vacuum by considering the metal, insulation, and snow loads in Eqs. (1) through (6). The designer should note that if these loads had been omitted the calculated thicknesses would have been much less than the correct values.

(c) In Eqs. (1), (5), (7), and (10), the term W is intended to include loads, such as metal weight, of significant value. At points away from the vertical center line of the roof, the value of T_2 is required for the thickness calculations of Eqs. (18), (20), and (22) and the value of P in Eqs. (2), (6), and (9) must be modified by the normal components of the added loads for the correct determination of T_2 .

ND-3932.2 Computation of Unit Forces

(a) At each level of the tank selected for free body analysis as specified in ND-3931 (Fig. ND-3932.1-1) and for each condition of gas and liquid loading which must be investigated at such level, the magnitude of the meridional and latitudinal unit forces in the wall of the tank shall be computed from Eqs.⁴⁴ (1) and (2) below, except as provided in ND-3932.6 or ND-3933.

Page 196

Page 197

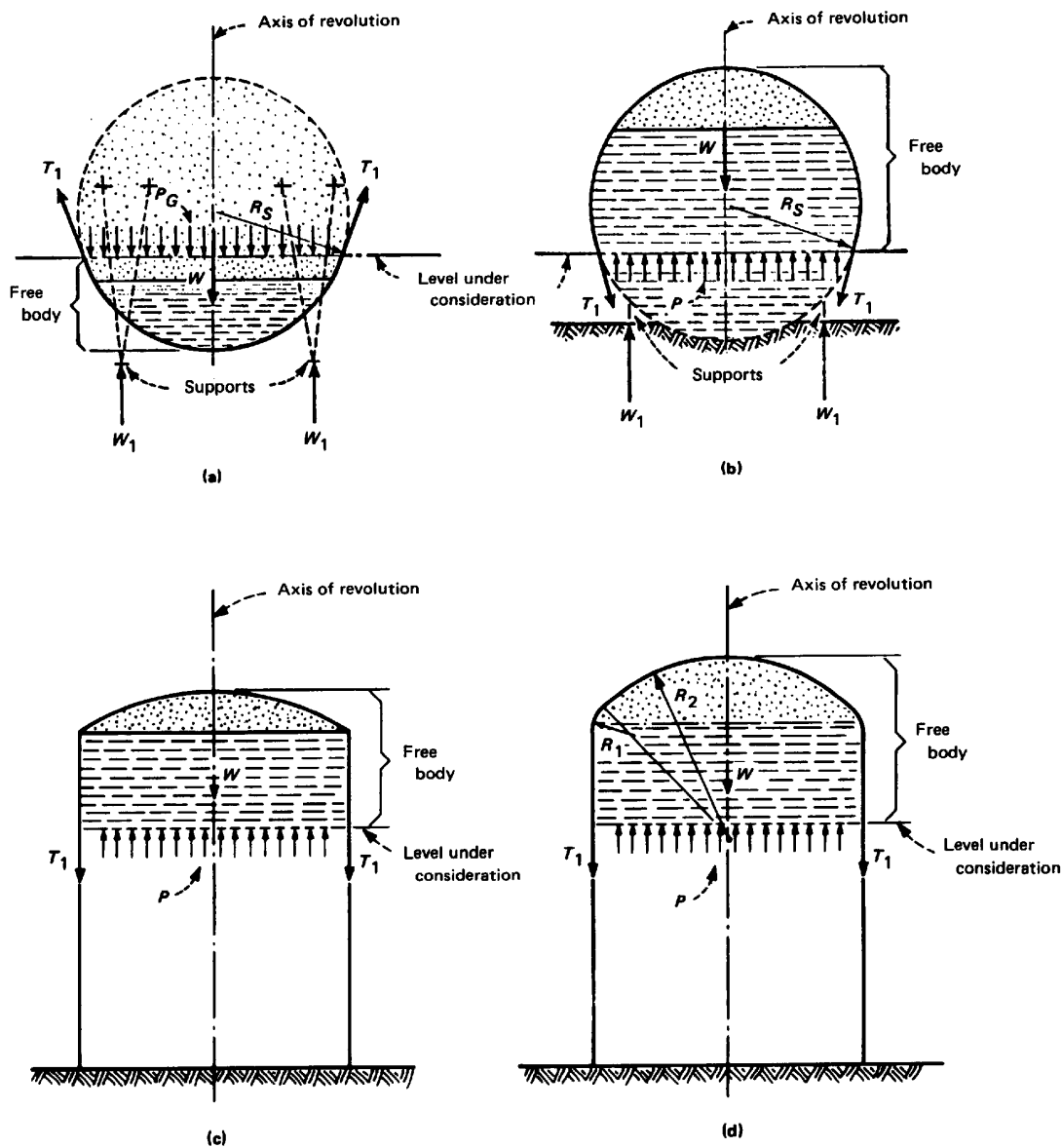


FIG. ND-3932.1-1 SOME TYPICAL FREE BODY DIAGRAMS FOR CERTAIN SHAPES OF TANKS

FIG. ND-3932.1-1 SOME TYPICAL FREE BODY DIAGRAMS FOR CERTAIN SHAPES OF TANKS

$$T_1 = \frac{R_2}{2} \left(P + \frac{W + F}{A_T} \right) \quad (1)$$

$$T_2 = R_2 \left(P - \frac{T_1}{R_1} \right) \quad (2)$$

$$= R_2 \left[P \left(1 - \frac{R_2}{2R_1} \right) - \frac{R_2}{2R_1} \left(\frac{W + F}{A_T} \right) \right]$$

(1 - 2)

(b) Positive values of T_1 and T_2 indicate tensile forces, and negative values indicate compressive forces.

(c) It will usually be necessary to make such analyses at the level of each horizontal joint in the sidewalls, roof, and bottom of the tank and at any intermediate levels at which the center of curvature changes significantly. Moreover, the maximum total pressure, liquid head plus gas pressure which can exist at a given level will not necessarily be the governing condition for that level; sufficient analyses shall be made at each level to establish that combination of liquid head and gas pressure or partial vacuum which, in conjunction with the allowable tensile and compressive stresses, will control the design at such level. Even though a tank may normally be operated at a fixed height of liquid contents, it shall be made safe for any conditions which might develop in filling or emptying the tank.

(d) The values for a point at a horizontal distance x from the vertical axis of a roof or bottom in which the length of the horizontal semiaxis a is two times the length of the vertical semiaxis b may be determined by multiplying the length a by the factor from Table ND-3932.2(d)-1. Values for ellipsoidal shapes of other proportions shall be calculated from the following equations:

$$R_1 = \frac{b^2}{a^4} \left[\frac{a^4}{b^2} + \left(1 - \frac{a^2}{b^2} \right) x^2 \right]^{3/2} = \frac{b^2 (R_2)^3}{a^4} \quad (3)$$

(3)

$$R_2 = \left[\frac{a^4}{b^2} + \left(1 - \frac{a^2}{b^2} \right) x^2 \right]^{1/2} \quad (4)$$

(4)

(e) Equations (1) and (2) are general formulas applicable to any tank having a single vertical axis of revolution and to any free body which is isolated by a horizontal plane which intersects the walls of the tank in only one circle [ND-3932.2(f)]. For shapes most commonly used, these equations reduce to the simplified equations given in (1) through (3) below for the respective shapes indicated.

TABLE ND-3932.2(d)-1
FACTORS FOR DETERMINING VALUES OF
 R_1 AND R_2 FOR 2:1 ELLIPSIODAL
ROOFS AND BOTTOMS

x/α	$u = R_1/\alpha$	$v = R_2/\alpha$
0.00	2.000	2.000
0.05	1.994	1.998
0.10	1.978	1.993
0.15	1.950	1.983
0.20	1.911	1.970
0.25	1.861	1.953
0.30	1.801	1.931
0.35	1.731	1.906
0.40	1.651	1.876
0.45	1.562	1.842
0.50	1.465	1.803
0.55	1.360	1.759
0.60	1.247	1.709
0.65	1.129	1.653
0.70	1.006	1.591
0.75	0.879	1.521
0.80	0.750	1.442
0.85	0.620	1.354
0.90	0.492	1.253
0.95	0.367	1.137
1.00	0.250	1.000

x = horizontal distance from point in roof or bottom to axis of revolution

α = horizontal semiaxis of elliptical cross section

$R_1 = u\alpha$

$R_2 = v\alpha$

TABLE ND-3932.2(d)-1 FACTORS OF DETERMINING VALUES OF R_1 AND R_2 FOR 2:1 ELLIPSIODAL ROOFS AND BOTTOMS

(1) For a Spherical Tank or Spherical Segment of a Tank. $R_1 = R_2 = R_s$, the spherical radius of the tank or segment, and Eqs. (1) and (2) become:

$$T_1 = \frac{R_s}{2} \left(P + \frac{W + F}{A_T} \right) \quad (5)$$

$$T_2 = R_s P - T_1 \quad (6)$$

(5 - 6)

If the sphere is for gas pressure only and if $(W + F)/A_T$ is negligible as compared with P_G Eqs. (5) and (6) reduce to:

$$(7) T_1 = T_2 = \frac{1}{2} P_G R_s$$

(2) For a Conical Roof or Bottom

$$R_1 = \text{infinity}$$

and

$$R_2 = \frac{R_3}{\cos \alpha}$$

where

R_3

= horizontal radius of the base of the cone at the level under consideration, in.

α

= one-half the included apex angle of the conical roof or bottom

For this condition, Eqs. (1) and (2) reduce to:

$$T_1 = \left(\frac{R_3}{2 \cos \alpha} \right) \left(P + \frac{W + F}{A_T} \right) \quad (8)$$

$$T_2 = \frac{PR_3}{\cos \alpha} \quad (9)$$

(8 - 9)

(3) For Cylindrical Sidewalls of a Vertical Tank. $R_1 = \text{infinity}$ and $R_2 = R_c$ the radius of the cylinder, and Eqs. (1) and (2) become:

$$T_1 = \frac{R_c}{2} \left(P + \frac{W + F}{A_T} \right) \quad (10)$$

$$T_2 = PR_c \quad (11)$$

(10 - 11)

If the cylinder is for gas pressure only and if $W + F/A_T$ is negligible as compared with P_G , Eqs. (10) and (11) reduce to:

$$(12) T_1 = \frac{1}{2} P_G R_c$$

$$(13) T_2 = P_G R_c$$

(f) In the case of a torispherical head shown in Fig. ND-3932.1-1(d), applicable equations for the meridional and latitudinal unit forces in the walls of the segment are as follows:

$$(14) T_1 = (\text{in preparation})$$

$$(15) T_2 = (\text{in preparation})$$

[98]

ND-3932.3 Required Thickness.

The thickness of the tank wall at any given level shall be not less than the largest value of t as determined for the level by the methods prescribed in (a) through (d) below. In addition, provision shall be made by means of additional metal, where needed, for the loadings other than internal pressure or possible partial vacuum enumerated in ND-3921.4, and if the tank walls have points of marked discontinuity in the direction of the meridional tangent, such as occur at the juncture between a conical or dished roof or bottom and a cylindrical sidewall, the portions of the tank near such points shall be designed in accordance with the provisions of ND-3933.

(a) If the unit forces T_1 and T_2 are both positive for the governing combination of gas pressure or partial vacuum and liquid head at a given level of the tank, the larger of the two shall be used for computing the thickness required at such level, as follows:

$$t = \frac{T_1}{S_{ts}E} + c \quad \text{or} \quad t = \frac{T_2}{S_{ts}E} + c \quad (16)$$

(16)

(b) If the unit force T_1 is positive and T_2 is negative for the governing combination of gas pressure or partial vacuum and liquid head at a given level of the tank or if T_2 is positive and T_1 is negative, the thickness of tank wall required for this condition shall be determined by assuming different thicknesses until one is found for which the simultaneous values of the calculated tension stress S_{tc} and the calculated compression stress S_{cc} satisfy the requirements of ND-3922.2 (b) and ND-3922.3(d), respectively. The determination of this thickness will be facilitated by using a graphical solution such as illustrated in Appendix F, Section F.2 of API Standard 620, Feb. 1970 Edition. If the unit force acting in compression does not exceed 5% of the coexistent tensile unit force acting perpendicular to it, the designer may determine the thickness required for this condition by using the method specified in (a) above.

NOTE: The value of the joint efficiency factor E will not enter into this determination unless the magnitude of the allowable tensile stress S_{ta} is governed by the product ES_{ts} as provided in ND-3922.2(b).

(c) If the unit forces T_1 and T_2 are both negative and are of equal magnitude for the governing condition of loading at a given level of the tank, the thickness of tank wall required shall be calculated as follows:

$$t = \frac{T_1}{S_{ca}} + c = \frac{T_2}{S_{ca}} + c \quad (17)$$

(17) where S_{ca} has the appropriate value for the thickness-radius ratio involved, as required in ND-3922.3(b) and (e).

Page 199

(d) If the unit forces T_1 and T_2 are both negative but of unequal magnitude for the governing condition of loading at a given level, the thickness of tank wall required for this condition shall be the largest of those thickness values, calculated by the following procedure, which show a proper correlation with the respective thickness-radius ratios involved in their computation (Steps 2 and 4).

Step 1: Calculate the values of

$$t = \frac{\sqrt{(T' + 0.8T'')R'}}{1342} + c \quad (18)$$

(18)

and

$$t = \frac{\sqrt{T''R''}}{1000} + c \quad (19)$$

(19) using values of T' equal to the larger of the two coexistent unit forces and T'' equal to the smaller of the two unit forces, and taking R' and R'' as equal to R_1 and R_2 , respectively, if the larger unit force is latitudinal; but, conversely, taking R' and R'' as equal to R_2 and R_1 , respectively, if the larger unit force is meridional.

Step 2: Deduct the corrosion allowance from each of the two thicknesses calculated in Step 1 and check the thickness-radius ratio $(t - c)/R$ for each based on the value of R used in Eq. (18) or (19). If both such thickness-radius ratios are less than 0.00667, the larger of the two thicknesses calculated in Step 1 will be the required thickness for the condition under consideration. Otherwise, proceed with Step 3.

Step 3: If one or both thickness-radius ratios determined in Step 2 exceed 0.00667, calculate the values of:

$$t = \frac{T' + 0.8T''}{15,000} + c \quad (20)$$

(20)

and

$$t = \frac{T''}{8340} + c \quad (21)$$

(21)

Step 4: Deduct the corrosion allowance from each of the two thicknesses calculated in Step 3 and check the thickness-radius ratio $(t - c)/R$ for each using a value of R equal to R' as defined in Step 1 in connection with the thickness determined from Eq. (20) and a value of R equal to R'' in connection with the thickness determined from Eq. (21). If both such thickness-radius ratios are greater than 0.0175, the larger of the two thicknesses calculated in Step 3 will be the required thickness for the condition under consideration. Otherwise, proceed with Step 5.

Step 5: If one or more of the thickness-radius ratios determined in Step 2 or Step 4 fall between 0.00667 and 0.0175 and the thickness involved was calculated by Eq. (18) or (20), find a thickness which satisfies the following equation:

$$\frac{10,150 (t - c) + 277,400 (t - c)^2}{R'} = T' + 0.8T'' \quad (22)$$

(22) or, if the thickness involved was calculated by Eq. (19) or (21), find a thickness which satisfies the following equation:

$$\frac{5,650 (t - c) + 154,200 (t - c)^2}{R''}$$

$$= T'' \quad (23)$$

(23)

Step 6: Make a selection of thickness from the values calculated. Calculate the values of S_{cc} for both T_1 and T_2 and check that values of S_{cc} satisfy the requirements of ND-3922.3(c).

NOTE: The procedure described in ND-3932.3(d) is predicated on the assumption that the problem is one in which biaxial compression with unit forces of unequal magnitude is the governing condition. In many cases, however, a tentative thickness will have been established previously by other design considerations and only needs to be checked for the external pressure or partial vacuum condition. In such cases, the problem is greatly simplified because the designer has only to compute the values of S_{cc} for both T_1 and T_2 and then check to see that these values satisfy the requirements of ND-3922.3(c), as specified in Step 6 [see Section F.3 of Appendix F of API Standard 620, Feb. 1970 Edition, for examples illustrating the application of ND-3932.3(a)].

[98]

ND-3932.4 Least Permissible Thickness.

In no event shall the net thickness after fabrication of any plate subject to pressure imposed membrane stresses be less than $\frac{3}{16}$ in., exclusive of corrosion allowance. For tanks having cylindrical sidewalls with diameters from 60 ft up to but not including 120 ft, such thickness for

Page 200

sidewall plates shall not be less than $\frac{1}{4}$ in. exclusive of corrosion allowance.

ND-3932.5 External Pressure Limitations.

The thickness computed by the equations and procedures specified in ND-3932, using a negative value of P_G equal to the partial vacuum for which the tank is to be designed, will ensure stability against collapse for tank surfaces of double curvature in which the meridional radius R_1 is equal to or less than R_2 or does not exceed R_2 by more than a very small amount. Data on the stability of sidewall surfaces of prolate spheroids are lacking, and it is not intended that the formulas and procedures be used for evaluating the stability of such surfaces or of cylindrical surfaces against external pressure. However, cylindrical sidewalls of vertical tanks designed in accordance with these rules for storage of liquids⁴⁵ with the thickness of upper courses no t less than specified in ND-3932.4 for the size of tank involved and with increasing thicknesses from top to bottom as required for the combined gas and liquid loadings may safely be subjected to a partial vacuum in the gas or vapor space not exceeding 1 oz/sq in. (0.4 kPa)⁴⁶ with the operating liquid level in the tank at any stage from full to empty.

ND-3932.6 Special Considerations Applicable to Bottoms Resting Directly on Foundations

(a) *Uplift Considerations.* In the case of tanks with cylindrical sidewalls and flat bottoms, the uplift⁴⁷ from the pressure acting on the underside of the roof must not exceed the weight of the sidewalls plus the weight of that portion of the roof which is carried by the sidewalls when no uplift exists, unless such excess is counteracted by increasing the magnitude

of the downward acting forces. This shall be a matter of agreement between the Certificate Holder and Owner. Similar precautions must be taken with flat bottom tanks of other shapes. All weights used in such calculations shall be based on net thicknesses of the materials, exclusive of corrosion allowance.

45 These rules do not contain provisions in respect to the design of cylindrical sidewalls subject to partial internal vacuum in tanks constructed for storage of gases or vapors alone.

46 The vacuum relief valve or valves shall be set to open at a smaller partial vacuum so that the 1 oz partial vacuum will not be exceeded when the inflow of air or gas through the valves is at its maximum specified rate.

47 If external anchors bolts are used for resisting such uplift, it is recommended that their nominal diameter be not less than 1 in. plus a corrosion of a least $\frac{1}{4}$ in. on the diameter.

48 These forces are computed by the applicable equations in ND-3932.

(b) *Foundation Considerations.* The type of foundation used for supporting the tank shall be taken into account in the design of bottom plates and welds. For recommended practice for construction of foundations, see API Standard 620, Feb. 1970 Edition, Appendix C.

ND-3933 Design of Roof and Bottom Knuckle Regions, and Compression Ring

ND-3933.1 Nomenclature.

The symbols used are defined as follows:

w_h	= width, in., of the roof or bottom plate considered to participate in resisting the circumferential force acting on the compression ring region
w_c	= corresponding width, in., of the participating sidewall plate
t_h	= thickness, in., of the roof or bottom plate at and near the juncture of the roof or bottom and sidewalls, including corrosion allowance
t_c	= corresponding thickness, in., of the cylindrical sidewalls at and near such juncture
R_2	= length, in., of the normal to the roof or bottom at the juncture between the roof or bottom and the sidewalls, measured from the roof or bottom to the tank's vertical axis of revolution
R_c	= horizontal radius, in., of the cylindrical sidewall at its juncture with the roof or bottom
T_1	= meridional unit force in the roof or bottom of the tank at its juncture with the sidewall, lb/in. of circumferential arc
T_2	= corresponding latitudinal unit force in the roof or bottom, lb/in. of meridian arc
T_{2s}	= circumferential unit force ⁴⁸ in the cylindrical sidewall of the tank at its juncture with the roof or bottom, lb/in., measured along an element of the cylinder
α	= angle between the direction of T_1 and a vertical line. In a conical surface it is also one-half of the total vertex angle of the cone.
Q	= total circumferential force, lb acting on a vertical cross section through the compression ring region
A	

A_c	= net area, sq in., of the vertical cross section of metal required in the compression ring region, exclusive of all corrosion allowances
S_{ts}	= maximum allowable stress value for simple tension, psi (Tables 1A, 1B, and 3, Section II, Part D, Subpart 1)
E	= efficiency, expressed as a decimal, of meridional joints in the compression ring region in the event that Q should have a positive value, indicating tension

ND-3933.2 General Requirements.

When the roof or bottom of a tank is a cone or partial sphere and is attached to cylindrical sidewalls, the membrane stresses in the roof or bottom act inward on the periphery of the sidewalls. This results in circumferential compressive forces at the juncture, which shall be resisted either by a knuckle curvature in the roof or bottom or by a limited zone at the juncture of the intersecting roof or bottom plates and sidewall plates, supplemented in some cases by an angle, a rectangular bar, or a ring girder.

ND-3933.3 Requirements for Knuckle Regions

(a) If a curved knuckle is provided, a ring girder or other form of compression ring shall not be used and there shall be no sudden changes in the direction of a meridional line at any point. In addition, the radius of curvature of the knuckle in a meridional plane shall not be less than 6%, and preferably not less than 12%, of the diameter of the sidewalls.⁴⁹ Subject to the provisions of (b) below, the thickness of the knuckle at all points shall satisfy the requirements of ND-3932.

(b) Application of the equations in ND-3932.2 to levels immediately above and below a point where two surfaces of differing meridional curvature have a common meridional tangent, as at the juncture between the knuckle region and the spherically dished portion of a torispherical roof, will result in the calculation of two latitudinal unit forces, differing in magnitude and perhaps in sign, at the same point. The latitudinal unit force at such a point will be between the two calculated values, depending on the geometry of the tank wall in that area.

ND-3933.4 Requirements for Compression Rings

(a) If a curved knuckle is not provided, the circumferential compressive forces shall be resisted by other means in the compression ring region of the tank walls. The zone of the tank walls at the juncture between the roof or bottom and the sidewalls includes that width of plate on each side of the juncture which is considered to participate in resisting these forces [Fig. ND-3933.4(a)-1]. The thickness of the wall plate on either side of the juncture shall not be less than the thickness needed to satisfy the requirements of ND-3932, and the widths of plate making up the compression ring region shall be computed from the following equations:

⁴⁹ Use of a knuckle radius as small as 6% of the sidewall diameter will frequently require an excessively heavy thickness for the knuckle region. The thickness requirements for such region will be found more reasonable if larger knuckle radius is used.

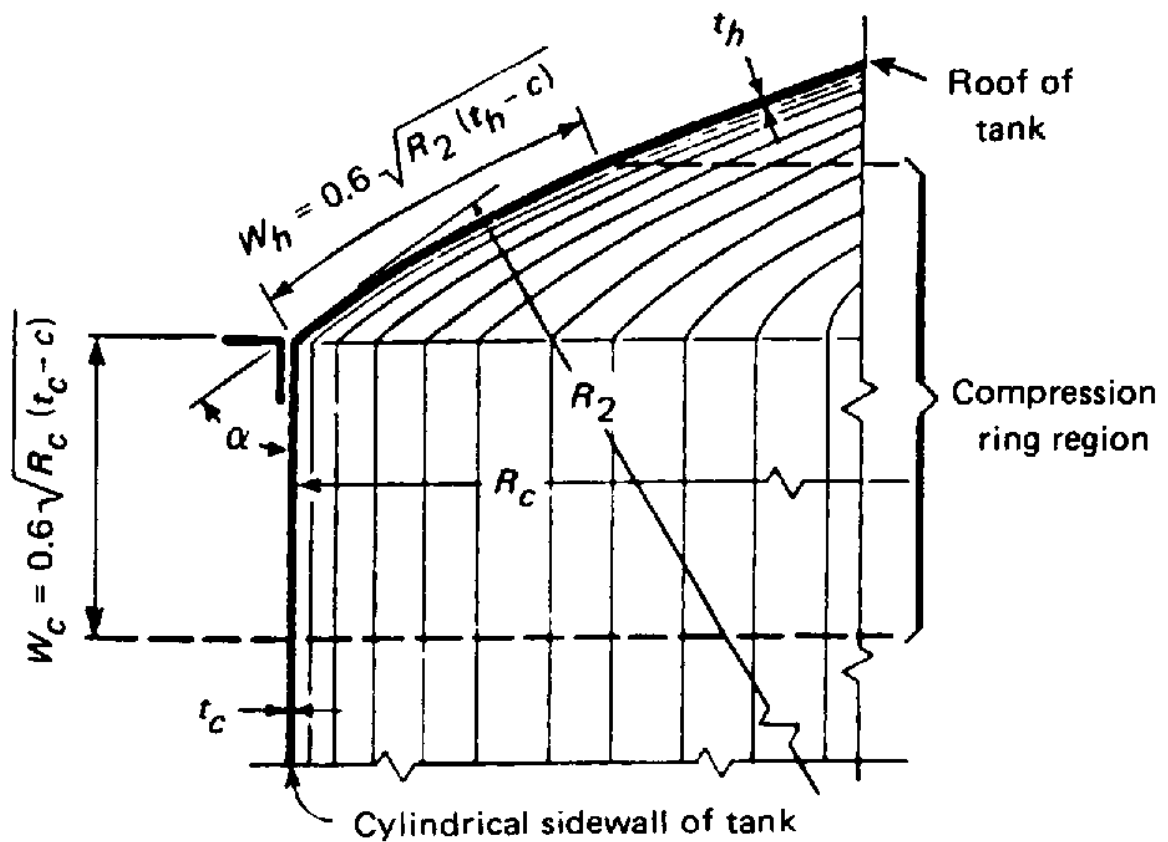


FIG. ND-3933.4(a)-1 COMPRESSION RING REGION

FIG. ND-3933.4(a)-1 COMPRESSION RING REGION

$$w_h = 0.6 \sqrt{R_2(t_h - c)} \quad (24)$$

$$w_c = 0.6 \sqrt{R_c(t_c - c)} \quad (25)$$

(24 - 25)

(b) The magnitude of the total circumferential force acting on any vertical cross section through the compression ring region shall be computed as follows:

$$(26) Q = T_2 w_h + T_2 w_c - T_1 R_c \sin \alpha$$

and the net cross-sectional area provided in the compression ring region shall not be less than that found to be required by the following equation:

$$A_c = \frac{Q}{15,000} \quad \text{or} \quad \frac{Q}{S_{ts} E} \quad (27)$$

(27)

depending on whether the value of Q as determined by Eq. (26) is negative⁵⁰ or positive.

50 Because of the discontinuities and other conditions found in a compression ring region, biaxial stress design criteria are not considered applicable for a compressive force determined as in Eq.

(26). Experience has shown that a compressive stress of the order of 15,000 psi, as indicated in Eq. (27), is permissible in this case, provided the requirements of ND-3933.5 are satisfied.

ND-3933.5 Details of Compression Ring Regions

(a) If the force Q is negative, indicating compression, the horizontal projection of the effective compression ring region shall have a width in a radial direction not less than 0.015 times the horizontal radius of the tank wall at the level of the juncture between the roof or bottom and the sidewalls. If such projected width

Page 202

does not meet this requirement, appropriate corrective measures shall be taken as specified in this subparagraph.

(b) Whenever the circumferential force Q determined in accordance with ND-3933.4 is of such magnitude that the area required by Eq. (27) is not provided in a compression ring region with plates of the minimum thicknesses established by

the requirements of ND-3932, or when Q is compressive and the horizontal projection of the width w_h is less than specified in ND-3933.5(a), the compressional ring region shall be reinforced either by thickening the roof or bottom and sidewall plates as required to provide a compressional ring region having the necessary cross-sectional area and width as determined on the basis of the thicker plates,⁵¹ or by adding an angle, a rectangular bar, or a ring girder at the juncture of the roof or bottom and sidewall plates, or by a combination of these alternatives.

(c) Such an angle, bar, or ring girder, if used, may be located either inside or outside of the tank⁵² and shall have a cross section of such dimensions that:

(1) its area makes up the deficiency between the area A_c required by Eq. (27) and the cross-sectional area provided by the compression ring region in the walls of the tank;

(2) the horizontal width of the angle, bar, or ring girder is not less than 0.015 times the horizontal radius R_c of the tank wall at the level of the juncture of the roof or bottom and the sidewalls, except that, when the cross-sectional area to be added in an angle or bar is not more than one-half the total area required by Eq. (27), the width requirement for this member may be disregarded, provided the horizontal projection of the width w_h of participating roof or bottom plates alone is equal to or greater than $0.015R_c$ or, with an angle or bar located on the outside of a tank, the sum of the projection of the width w_h and the horizontal width of the added angle or bar is equal to or greater than $0.015R_c$;

(3) when bracing must be provided as specified in ND-3933.5(h), the moment of inertia of the cross section about a horizontal axis shall be not less than that required by Eq. (28).

51 Note that, unless the effect of the unit forces T_2 and T_3 on the resulting increments in width of participating plate may safely be neglected, the use of thicker plates involves recomputing not only w_h and w but also Q and A for the increased plate thicknesses; hence, the design of the compression ring region in this case resolves into a trial and error procedure.

52 See Fig. ND-3933.5(d)-1 for some acceptable details of construction of compression rings.

(d) When the vertical leg of an angle ring or a vertical flange of a ring girder is located on the sidewall of the tank, it may be built into the sidewall if its thickness is not less than that of the adjoining wall plates. However, if this construction is not used, the leg, edge, or flange of the compression ring next to the tank shall make good contact with the wall of the tank around the entire circumference and, except as provided in (e) below, shall be attached along both the top and bottom edges by continuous fillet welds. These welds shall be of sufficient size to transmit to the compression ring angle, bar, or girder that portion of the total circumferential force Q , assuming, in the case of welds separated by the width of a leg or flange of a structural member as shown in Fig. ND-3933.5(d)-1 sketches (a), (g), and (j), that only the weld nearest the roof or bottom is effective. The part thicknesses and weld sizes in Table ND-4247.6(d)-1 relate to dimensions in the as-welded condition before deduction of corrosion allowances, but all other part thicknesses and weld sizes referred to in this subparagraph relate to dimensions after deduction of corrosion allowance.

(e) If a continuous weld is not needed for strength or as a seal against corrosive elements, attachment welds along the lower edge of a compression ring on the outside of a tank may be intermittent provided:

(1) the summation of their lengths is not less than one-half the circumference of the tank;

(2) the unattached width of tank wall between the ends of welds does not exceed eight times the tank wall thickness exclusive of corrosion allowance;

(3) the welds are of such size as needed for strength but in no case smaller than specified in Table ND-4247.6(d)-1.

(f) The projecting part of a compression ring shall be placed as close as possible to the juncture between the roof or bottom plates and the sidewall plates.

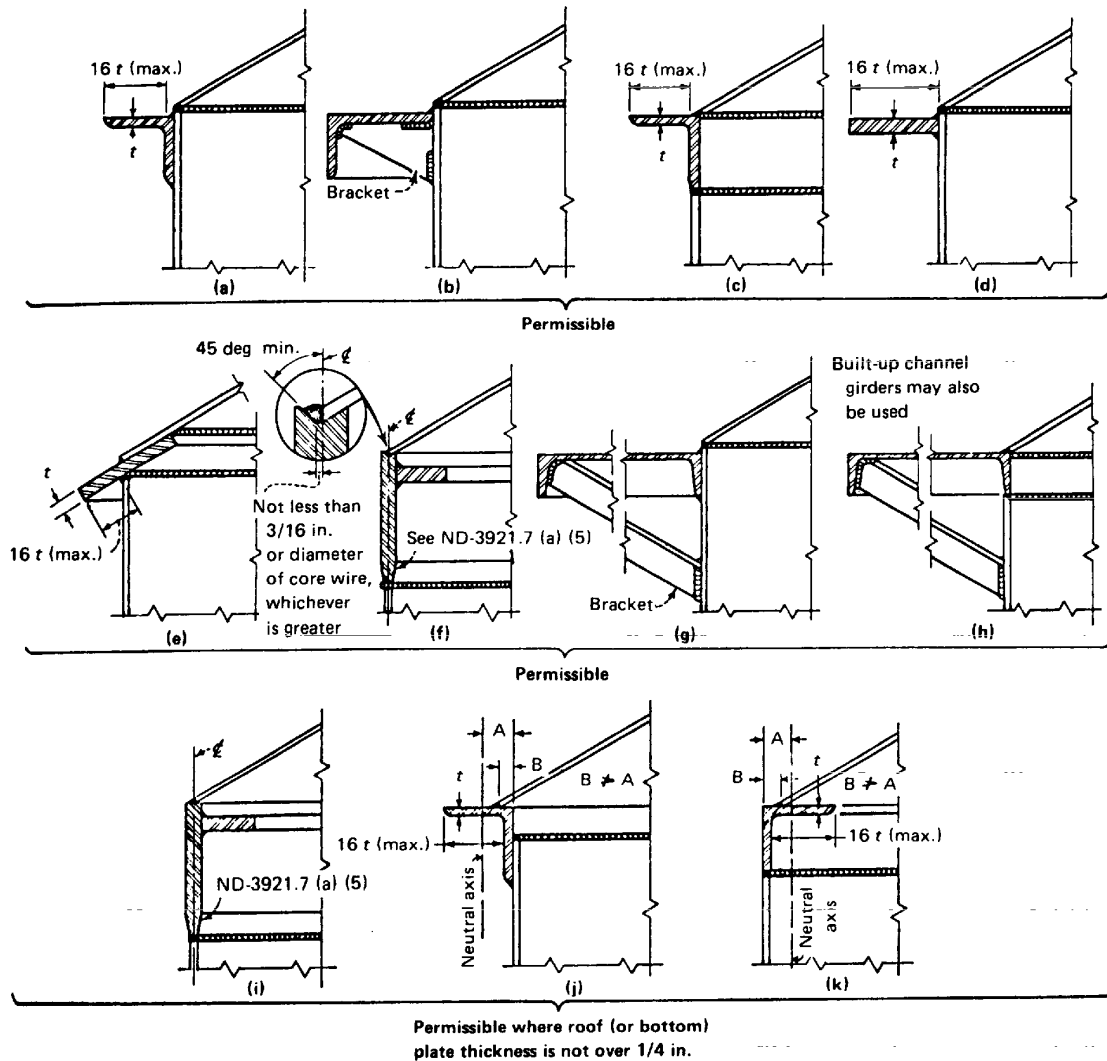
(g) If a compression ring on either the inside or outside of a tank is of such shape that liquid may be trapped, it shall be provided with adequate drain holes uniformly distributed along its length. Similarly, if the shape of a compression ring on the inside of a tank is such that gas would be trapped on the underside thereof when the tank is being filled with liquid, adequate vent holes shall be provided along its length. Where feasible, such drain or vent holes shall be not less than $\frac{3}{4}$ in. diameter.

(h) The projecting part of a compression ring without an outer vertical flange need not be braced, provided the width of such projecting part in a radial vertical plane does not exceed 16 times its thickness. With this exception, the horizontal

part of the compression ring shall be braced at intervals around the circumference of the tank with brackets or other suitable members securely attached to both the ring and the tank wall to prevent such part of the ring from buckling laterally.

Page 203

Page 204



GENERAL NOTES:

- (a) See ND-3350 for limitations concerning locations where various types of welded joints may be used.
- (b) For sketches (j) and (k), dimension B shall not exceed A.

FIG. ND-3933.5(d)-1 PERMISSIBLE DETAILS OF COMPRESSION RING CONSTRUCTION

FIG. ND-3933.5(d)-1 PERMISSIBLE DETAILS OF COMPRESSION RING CONSTRUCTION

When such bracing is required, the moment of inertia of the cross section of the angle, bar, or ring girder about a horizontal axis shall be not less than that calculated to be required by the following equation:⁵³

$$I_1 = \frac{1.44 Q_p R_c^2}{29,000,000 k} = 5 \frac{Q_p R_c^2}{k} \times 10^{-8} \quad (28)$$

(28)

where

I_1

= required moment of inertia, in.⁴, for the cross section of a steel compression ring with respect to a horizontal axis through the centroid of the section, not taking credit for any portion of the tank wall except that, in the case of an angle ring whose vertical leg is attached to or forms a part of the tank wall, the moment of inertia of only the horizontal leg shall be considered, and it shall be figured with respect to a horizontal axis through the centroid of such leg⁵³

Q_p

= that portion of the total circumferential force Q , lb, [Eq. (26)] which is carried by the compression ring angle, bar, or girder, as computed from the ratio of the cross-sectional area of the compression ring to the total area of the compression zone

R_c

= horizontal radius, in., of the cylindrical sidewall of the tank at its juncture with the roof or bottom

k

= a constant whose value depends on the magnitude of the angle θ , subtended at the central axis of the tank by the space between adjacent brackets or other supports, which value shall be determined from the tabulation in Table ND-3933.5(h)-1, in which n is the number of brackets or other supports evenly spaced around the circumference of the tank

⁵³ Note that the value required for I_1 as calculated from Eq. (28) is not applicated for materials other than steel.

**TABLE ND-3933.5(h)-1
SOME VALUES FOR k BASED ON n, θ**

n	30	24	20	18	15	12
θ , deg	12	15	18	20	24	30
k	186.6	119.1	82.4	66.6	45.0	29.1
N	10	9	8	6	5	4
θ , deg	36	40	45	60	72	90
k	20.0	16.0	12.5	6.7	4.4	2.6

GENERAL NOTE: In no case shall θ be larger than 90 deg.

TABLE ND-3933.5(h)-1 SOME VALUES FOR k BASED ON n, θ

ND-3934 Nozzle Piping Transitions

The stress limits of Table ND-3921.8-1 shall apply to all portions of nozzles which lie within the limits of reinforcement given in ND-3334, except as provided in ND-3935. Stresses in the extension of any nozzle beyond the limits of reinforcement shall be subject to the stress limits of ND-3600.

ND-3935 Consideration of Standard Reinforcement

(a) Where a nozzle-to-shell junction is reinforced in accordance with the rules of ND-3334, the stresses in this region due to internal pressure may be considered to satisfy the limits of Table ND-3921.8-1. Under these conditions, no analysis is required to demonstrate compliance for pressure induced stresses in the nozzle region.

(b) Where external piping loads are to be designed for, membrane plus bending stresses due to these loads shall be calculated in the nozzle, and membrane stresses shall be calculated in the local nozzle-to-shell region. These stresses, in conjunction with pressure induced stresses, shall meet the limits of Table ND-3921.8-1 for $(\sigma_m \text{ or } \sigma_L) + \sigma_b$. In this case, the pressure induced stresses in the $(\sigma_m \text{ or } \sigma_L) + \sigma_b$ category may be assumed to be no greater than the limit specified for σ_m in Table ND-3921.8-1, for a given condition.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 ND-4000

ARTICLE ND-4000 FABRICATION AND INSTALLATION

Page 205

ND-4100 GENERAL REQUIREMENTS

ND-4110 INTRODUCTION

(a) Components, parts, and appurtenances shall be fabricated and installed in accordance with the rules of this Article and shall be manufactured from materials which meet the requirements of ND-2000.

(b) Atmospheric and 0-15 psi (0-103 kPa) storage tanks shall be fabricated in accordance with the rules of this Article.

ND-4120 CERTIFICATION OF MATERIAL AND FABRICATION BY COMPONENT CERTIFICATE HOLDER

ND-4121 Means of Certification

The Certificate Holder for an item shall certify, by application of the appropriate Code Symbol and completion of the appropriate Data Report in accordance with NCA-8000, that the material used complies with the requirements of ND-2000 and that the fabrication or installation complies with the requirements of this Article.

ND-4121.1 Certification of Treatments, Tests, and Examinations.

If a Certificate Holder or Subcontractor performs treatments, tests, repairs, or examinations required by other Articles of this Subsection, the Certificate Holder shall certify that this requirement has been fulfilled (NCA-3862). Reports of all required treatments and of the results of all required tests, repairs, and examinations performed shall be available to the Inspector.

ND-4121.2 Repetition of Tensile or Impact Tests.

If during the fabrication or installation of the item the material is subjected to heat treatment that has not been covered by treatment of the test coupons (ND-2200) and that may reduce either tensile or impact properties below the required values, the tensile and impact tests shall be repeated by the Certificate Holder on test specimens taken from test coupons which have been taken and treated in accordance with the requirements of ND-2000.

ND-4121.3 Repetition of Surface Examination After Machining.

During the fabrication or installation of an item if materials for pressure containing parts are machined, the Certificate Holder shall reexamine the surface of the material in accordance with ND-2500 when:

(a) the surface was required to be examined by the magnetic particle or liquid penetrant method in accordance with ND-2500; and

(b) the amount of material removed from the surface exceeds the lesser of $\frac{1}{8}$ in. (3.2 mm) or 10% of the minimum required thickness of the part.

ND-4122 Material Identification

(a) Material for pressure retaining parts shall carry identification markings which will remain distinguishable until the component is assembled or installed. If the original identification markings are cut off or the material is divided, the same marks shall either be transferred to the parts cut or a coded marking shall be used to assure identification of each piece of material during subsequent fabrication or installation. In either case, an as-built sketch or a tabulation of materials shall be made identifying each piece of material with the Certified Material Test Report, where applicable, and the coded marking. For studs, bolts, nuts, and heat exchanger tubes it is permissible to identify the Certified Material Test Reports for material in each component in lieu of identifying each piece of material with the Certified Material Test Report and the coded marking. Material supplied with a Certificate of Compliance, and welding and brazing material, shall be identified and controlled so that they can be traced to each component or installation of a piping system, or else a control

Page 212

procedure shall be employed which ensures that the specified materials are used.

(b) Material from which the identification marking is lost shall be treated as nonconforming material until appropriate tests or other verifications are made and documented to assure material identification. Testing is required unless positive identification can be made by other documented evidence. The material may then be remarked upon establishing positive

identification.

ND-4122.1 Marking Material.

Material shall be marked in accordance with ND-2150.

ND-4123 Examinations

Visual examination activities that are not referenced for examination by other specific Code paragraphs, and are performed solely to verify compliance with requirements of ND-4000, may be performed by the persons who perform or supervise the work. These visual examinations are not required to be performed by personnel and procedures qualified to ND-5100 and ND-5500, respectively, unless so specified.

ND-4125 Testing of Welding and Brazing Material

All welding and brazing material shall meet the requirements of ND-2400.

ND-4130 REPAIR OF MATERIAL

Material originally accepted on delivery in which defects exceeding the limits of ND-2500 are known or discovered during the process of fabrication or installation is unacceptable. The material may be used provided the condition is corrected in accordance with the requirements of ND-2500 for the applicable product form, except that:

- (a) the limitation on the depth of the weld repair does not apply; and
- (b) the time of examination of the weld repairs to weld edge preparations shall be in accordance with ND-5120;
- (c) radiographic examination is not required for weld repairs to seal membrane material when the material thickness is $\frac{1}{4}$ in. (6 mm) or less;
- (d) radiographic examination is not required for welded repairs in material used in components, provided that the welded joints in these materials are not required to be radiographed, the extent of the welded repair does not exceed 10 sq in. (6452 mm²) of the surface area, and the magnetic particle or liquid penetrant examination of the repair is made as required by ND-2539.4.

ND-4200 FORMING, FITTING, AND ALIGNING

ND-4210 CUTTING, FORMING, AND BENDING

ND-4211 Cutting

Materials may be cut to shape and size by mechanical means such as machining, shearing, chipping, or grinding, or by thermal cutting.

ND-4211.1 Preheating Before Thermal Cutting.

When thermal cutting is performed to prepare weld joints or edges, to remove attachments or defective material, or for any other purpose, consideration shall be given to preheating the material, using preheat schedules such as suggested in Appendix D.

ND-4212 Forming and Bending Processes

Any process may be used to hot or cold form or bend pressure retaining material, including weld metal, provided the required dimensions are attained (see ND-4214 and ND-4220), and provided the impact properties of the materials, when required, are not reduced below the minimum specified values or they are effectively restored by heat treatment following the forming operation. *Hot forming* is defined as forming with the material temperature higher than 100°F (56°C) below the lower transformation temperature of the material. When required, the process shall be qualified for impact properties as outlined in ND-4213. When required, the process shall be qualified to meet thickness requirements as outlined in ND-4223.1.

ND-4213 Qualification of Forming Processes for Impact Property Requirements

When impact testing is required by the Design Specifications a procedure qualification test shall be conducted using specimens taken from material of the same specification, grade or class, heat treatment, and with similar impact properties as required for the material in the component. These specimens shall be subjected to the equivalent forming or bending process and heat treatment as the material in the component. Applicable tests shall be conducted to determine that the required impact properties of ND-2300 are met after straining.

Page 213

ND-4213.1 Exemptions.

Procedure qualification tests are not required for materials listed in (a) through (f) below:

- (a) hot formed material, such as forging, in which the hot forming is completed by the Material Organization prior to removal of the impact test specimens;
- (b) hot formed material represented by test coupons which has been subjected to heat treatment representing the hot forming procedure and the heat treatments to be applied to the parts;
- (c) material which does not require impacts in accordance with ND-2300;
- (d) material which has a final strain less than 0.5%;
- (e) material where the final strain is less than that of a previously qualified procedure for that material;
- (f) material from which the impact testing required by ND-2300 is performed on each heat and lot, as applicable, after forming.

[98]

ND-4213.2 Procedure Qualification Test.

The procedure qualification test shall be performed in the manner stipulated in (a) through (f) below.

- (a) The tests shall be performed on three different heats of material both before straining and after straining and heat treatment to establish the effects of the forming and subsequent heat treatment operations.
- (b) Specimens shall be taken in accordance with the requirements of ND-2000 and shall be taken from the tension side of the strained material.
- (c) The percent strain shall be established by the following equations.

For cylinders:

$$\% \text{ strain} = \frac{50t}{R_f} \left(1 - \frac{R_f}{R_o} \right)$$

For spherical or dished surfaces:

$$\% \text{ strain} = \frac{75t}{R_f} \left(1 - \frac{R_f}{R_o} \right)$$

For pipe:

$$\% \text{ strain} = \frac{100r}{R}$$

where

t	= nominal thickness, in.
R_f	= final radius to center line of shell, in.
R_n	= original radius (equal to infinity for a flat part), in.
R	= nominal bending radius to the center line of the pipe, in.
r	= nominal radius of the pipe, in.

(d) The procedure qualification shall simulate the maximum percent surface strain, employing a bending process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient Charpy V-notch test specimens shall be taken from each of the three heats of material to establish a transition curve showing both the upper and lower shelves. On each of the three heats, tests consisting of three impact specimens shall be conducted at a minimum of five different temperatures distributed throughout the transition region. The upper and lower shelves may be established by the use of one test specimen for each shelf. Depending on the product form, it may be necessary to plot the transition curves using both the lateral expansion and energy level data (ND-2300). In addition, drop weight tests shall be made when required by ND-2300.

(f) Using the results of the impact test data from each of three heats, taken both before and after straining, determine either of (1) or (2) below:

(1) the maximum change in NDT temperature along with:

(a) the maximum change of lateral expansion and energy at the temperature under consideration, or

(b) the maximum change in temperature at the lateral expansion and energy levels under consideration; or

(2) where lateral expansion is the acceptance criteria (ND-2300), either the maximum change in temperature or the maximum change in lateral expansion.

[98]

ND-4213.3

ND-4213.3 Acceptance Criteria for Formed Material.

To be acceptable, the formed material used in the component shall have impact properties before forming sufficient to compensate for the maximum loss of impact properties due to the qualified forming procedure used.

ND-4213.4 Requalification.

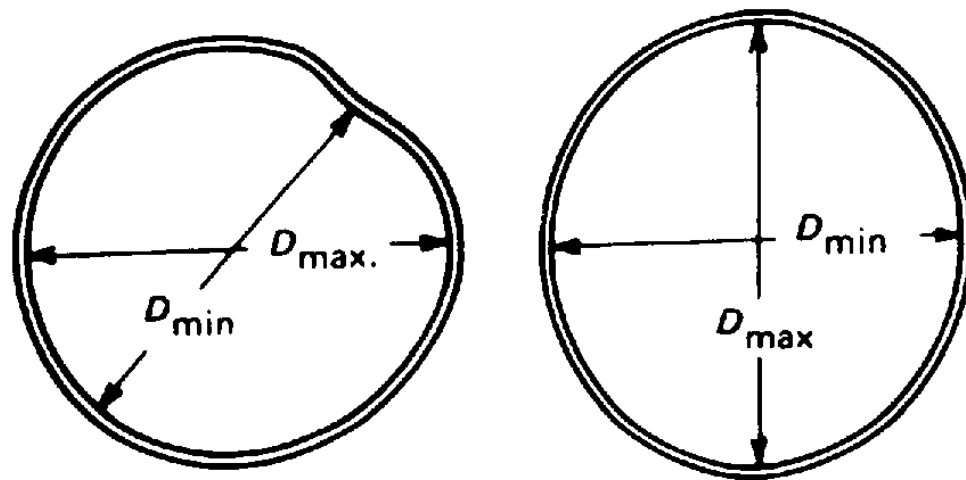
A new procedure qualification test is required when any of the following changes in (a), (b), or (c) below are made:

(a) the actual postweld heat treatment time at temperature is greater than previously qualified considering ND-2211; if the material is not postweld heat treated, the procedure must be qualified without postweld heat treatment;

(b) the maximum calculated strain of the material exceeds the previously qualified strain by more than 0.5%;

(c) where preheat over 250°F (121°C) is used in the forming or bending operation but not followed by a subsequent postweld heat treatment.

Page 214



**FIG. ND-4221.1-1 MAXIMUM DIFFERENCE
IN CROSS-SECTIONAL DIAMETERS**

FIG. ND-4221.1-1 MAXIMUM DIFFERENCE IN CROSS-SECTIONAL DIAMETERS

ND-4214 Minimum Thickness of Fabricated Material

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of ND-2124 and ND-3000, the material may be repaired in accordance with ND-4130.

ND-4220 FORMING TOLERANCES

ND-4221 Tolerance for Vessel Shells

Cylindrical, conical, or spherical shells of a completed vessel except formed heads covered by ND-4222 shall meet the requirements of the following subparagraphs at all cross sections.

ND-4221.1 Maximum Difference in Cross-Sectional Diameters.

The difference in inches between the maximum and minimum diameters at any cross section shall not exceed the smaller of $(D + 50)/200$ and $D/100$, where D is the nominal inside diameter in inches at the cross section under consideration. The diameters may be measured on the inside or outside of the vessel. If measured on the outside, the diameters shall be corrected for the plate thickness at the cross section under consideration (Fig. ND-4221.1-1). When the cross section passes through an opening, the permissible difference in inside diameters given herein may be increased by 2% of the inside diameter of the opening. For vessels with longitudinal lap joints, the permissible difference in inside diameters may be increased by the nominal plate thickness.

ND-4221.2 Maximum Deviation From True Theoretical Form for External Pressure.

Vessels designed for external pressure shall meet the following tolerances.

(a) The maximum plus or minus deviation from the true circular form of cylinders or the theoretical form of other shapes, measured radially on the outside or inside of the component, shall not exceed the maximum permissible deviation obtained from Fig. ND-4221.2(a)-1. Measurements shall be made from a segmental circular template having the design inside or outside radius depending on where the measurements are taken and a chord length equal to twice the arc length obtained from Fig. ND-4221.2(a)-2. For Fig. ND-4221.2(a)-1, the maximum permissible deviation e need not be less than $0.3t$. For Fig. ND-4221.2(a)-2, the arc length need not be greater than $0.3D_o$. Measurements shall not be taken on welds or other raised parts.

(b) The value of t in inches at any cross section is the nominal plate thickness less corrosion allowance for sections of constant thickness and the nominal thickness of the thinnest plate less corrosion allowance for sections having plates of more than one thickness. For vessels with longitudinal lap joints, t is the nominal plate thickness and the permissible deviation is $(t + e)$.

(c) The value of L in Figs. ND-4221.2(a)-1 and ND-4221.2(a)-2 is determined by (1) through (3) below.

(1) For cylinders, L is as given in ND-3133.2.

(2) For cones, L is the axial length of the conical section if no stiffener rings are used or, if stiffener rings are used, the axial length from the head bend line at the large end of the cone to the first stiffener ring, with D_o taken as the outside diameter in inches of the cylinder at the large end of the cone.

(3) For spheres, L is one-half of the outside diameter D_o in.

(d) The dimensions of a completed vessel may be brought within the requirements by any process which will not impair the strength of the material.

(e) Sharp bends and flat spots shall not be permitted unless provision is made for them in the design.

ND-4221.3 Deviations From Tolerances.

Deviations from the tolerance requirements stipulated in ND-4221.1 and ND-4221.2 are permitted, provided the drawings are modified and reconciled with the design calculations.

ND-4221.4 Tolerance Deviations for Vessel Parts Fabricated From Pipe.

Vessel parts subjected to either internal or external pressure and fabricated from pipe, meeting all other requirements of this Subsection, may have variations of diameter and deviations from circularity permitted by the specification for such pipe.

ND-4221.5 Localized Thin Areas.

Localized thin areas are permitted if the adjacent areas surrounding each has sufficient thickness to provide the necessary reinforcement according to the rules for reinforcement in ND-3330.

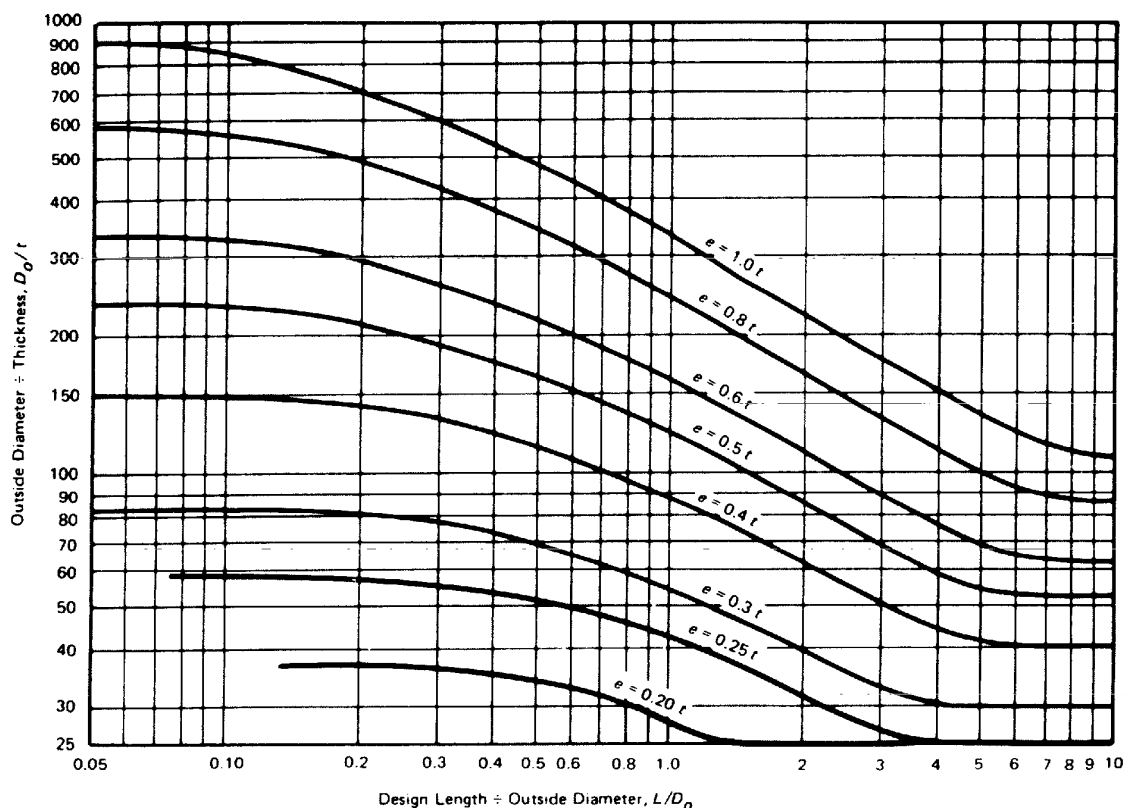


FIG. ND-4221.2(a)-1 MAXIMUM PERMISSIBLE DEVIATION e FROM A TRUE CIRCULAR FORM

FIG. ND-4221.2(a)-1 MAXIMUM PERMISSIBLE DEVIATION e FROM A TRUE CIRCULAR FORM

ND-4222 Tolerances for Formed Vessel Heads

The tolerances for formed vessel heads shall be as set forth in the following subparagraphs.

ND-4222.1 Maximum Difference in Cross-Sectional Diameters.

The skirt or cylindrical end of a formed head shall be circular to the extent that the difference in inches between the maximum and minimum diameters does not exceed the lesser of $(D + 50)/200$ and $(D + 12)/100$, where D is the nominal inside diameter in inches and shall match the cylindrical edge of the adjoining part within the alignment tolerance specified in ND-4232.

ND-4222.2 Deviation From Specified Shape

(a) The inner surface of a torispherical or ellipsoidal head shall not deviate outside the specified shape by more than $1\frac{1}{4}\%$ of D , nor inside the specified shape by more than $\frac{5}{8}\%$ of D , where D is the nominal inside diameter of the vessel. Such deviations shall be measured perpendicular to the specified shape and shall not be abrupt. The knuckle radius shall not be less than specified. For 2:1 ellipsoidal heads, the knuckle radius may be considered to be 17% of the diameter of

the vessel.

(b) Hemispherical heads and any spherical portion of a formed head shall meet the local tolerances for spheres as given in ND-4221.2, using L as the outside spherical radius in inches and D_o as two times L .

(c) Deviation measurements shall be taken on the surface of the base material and not on welds.

ND-4223 Tolerances for Formed or Bent Piping

The tolerances for formed or bent piping shall be as set forth in the following subparagraphs.

Page 216

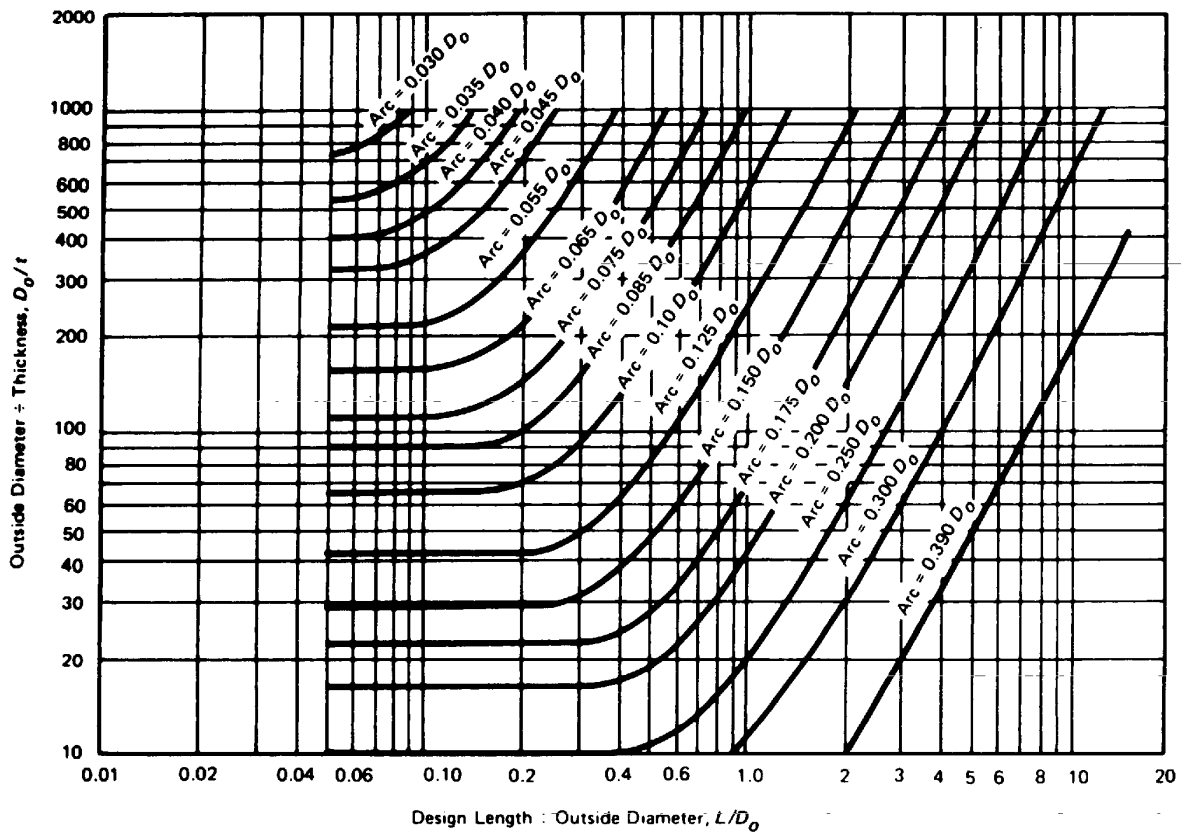


FIG. ND-4221.2(a)-2 MAXIMUM ARC LENGTH FOR DETERMINING PLUS OR MINUS DEVIATION

FIG. ND-4221.2(a)-2 MAXIMUM ARC LENGTH FOR DETERMINING PLUS OR MINUS DEVIATION

[98]

ND-4223.1 Minimum Wall Thickness

(a) In order to assure that the wall thickness requirements of the design calculations are met, the actual thickness shall be measured, or the process shall be qualified by demonstrating that it will maintain the required wall thickness.

(b) As an alternative to (a) above, the requirements of Table ND-3642.1(c)-1 shall be followed.

[98]

ND-4223.2 Ovality Tolerance.

Unless otherwise justified by the design calculations, the ovality of piping after bending shall not exceed 8% as determined by:

$$100 \times (D_{\max} - D_{\min})/D_o$$

where

D_o	= the nominal pipe outside diameter, in.
$D_{\min}$	= the minimum outside diameter after bending or forming, in.
$D_{\max}$	= the maximum outside diameter after bending or forming, in.

ND-4224 Tolerances for Storage Tanks

The horizontal circular cross section of storage tanks shall be sufficiently true to round so that the difference between the maximum and minimum diameters measured inside or outside at any section in a cylindrical wall shall not exceed 1% of the average diameter or 12 in. (305 mm), whichever is less, measured 6 ft (1.8 m) or one plate width from the top or bottom juncture, respectively, if these junctures are of a type which offers serious restraint when the tank is filled or under the specified maximum vapor pressure. At

Page 217

any section in a sidewall having double curvature, this difference in diameter shall not exceed $\frac{1}{2}\%$ of the average diameter or 6 in., whichever is less.

ND-4224.1 Maximum Difference in Cross-Sectional Diameters for Tanks of Double Curvature.

For tanks of double curvature, the meridian curvature of the plate surface shall not deviate from the design shape by more than $\frac{1}{2}\%$ of the radius, measured radially, and shall not show abrupt changes. Plate surfaces shall merge smoothly into the adjoining surfaces in all directions. Local inward deviations, such as flat spots, shall be limited by ND-4224.2.

ND-4224.2 Local Inward Deviations.

Local inward deviations, such as flat spots, if present on wall or bottom surfaces having double curvature, shall not be greater than the plate thickness and shall not have a diameter d greater than $\sqrt{8Rt}$, where R is the radius of the tank and t is the thickness of the plate involved. R shall be taken as R_1 , with d being the chord in a meridional direction, and as R_2 , with d being the chord in a latitudinal direction.

ND-4224.3 Tolerance Measurements.

The tolerance measurements are given for a tank while empty and shall be taken with a steel tape, making corrections for temperature, sag, and wind.

ND-4230 FITTING AND ALIGNING

ND-4231 Fitting and Aligning Methods

Parts that are to be joined by welding may be fitted, aligned, and retained in position during the welding operation by the use of bars, jacks, clamps, tack welds, or temporary attachments.

ND-4231.1 Tack Welds.

Tack welds used to secure alignment either shall be removed completely when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified welders using qualified welding procedures. When tack welds are to become part of the finished weld, they shall be visually examined and defective tack

procedures. When tack welds are to become part of the finished weld, they shall be visually examined and defective tack welds removed.

**TABLE ND-4232(a)-1
MAXIMUM ALLOWABLE OFFSET IN
FINAL WELDED JOINTS**

Section Thickness, in.	Direction of Joints	
	Longitudinal	Circumferential
Up to $\frac{1}{2}$, incl.	$\frac{1}{4}t$	$\frac{1}{4}t$
Over $\frac{1}{2}$ to $\frac{3}{4}$, incl	$\frac{1}{8}$ in.	$\frac{1}{4}t$
Over $\frac{3}{4}$ to $1\frac{1}{2}$, inc.	$\frac{1}{8}$ in.	$\frac{3}{16}$ in.
Over $1\frac{1}{2}$ to 2, inc.	$\frac{1}{8}$ in.	$\frac{1}{8}t$
Over 2	Lesser of $\frac{1}{16}t$ or $\frac{3}{8}$ in.	Lesser of $\frac{1}{8}t$ or $\frac{3}{4}$ in.

TABLE ND-4232(a)-1 MAXIMUM ALLOWABLE OFFSET IN FINAL WELDED JOINTS

ND-4232 Alignment Requirements When Components Are Welded From Two Sides

(a) Alignment of sections which are welded from two sides shall be such that the maximum offset of the finished weld will not be greater than the applicable amount listed in Table ND-4232(a)-1, where t is the nominal thickness of the thinner section at the joint.

(b) Joints in spherical vessels and joints within heads and joints between cylindrical shells and hemispherical heads shall meet the requirements in Table ND-4232(a)-1 for longitudinal joints.

ND-4232.1 Fairing of Offsets.

Any offset within the allowable tolerance provided above shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld.

ND-4233 Alignment Requirements When Inside Surfaces Are Inaccessible

(a) When the inside surfaces of items are inaccessible for welding or fairing in accordance with ND-4232, alignment of sections shall meet the requirements of (1) and (2) below.

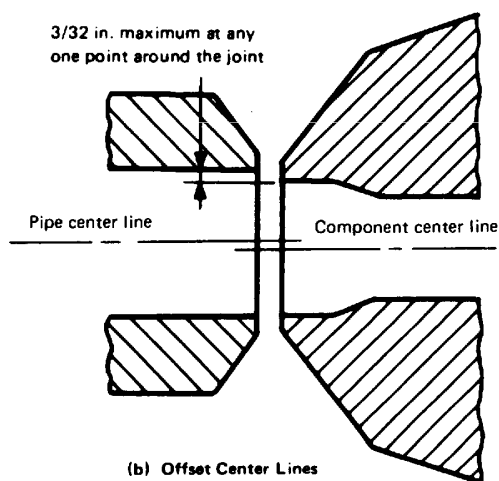
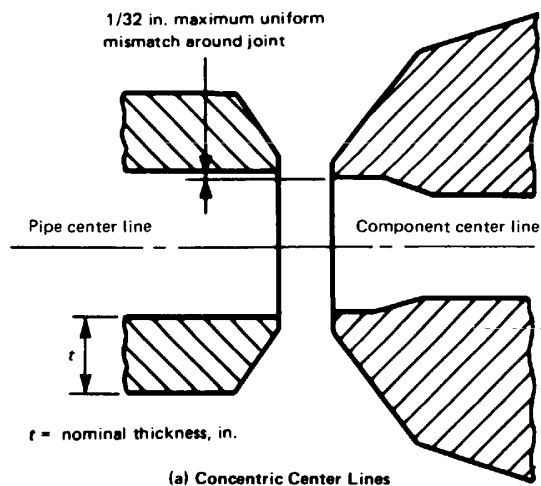
(1)(a) For circumferential joints the inside diameters shall match each other within $\frac{1}{16}$ in (1.6 mm). When the items are aligned concentrically, a uniform mismatch of $\frac{1}{32}$ in. (0.8 mm) all around the joint can result as shown in Fig. ND-4233-1 sketch (a). However, other variables not associated with the diameter of the item often result in alignments

that are offset rather than concentric. In these cases, the maximum misalignment at any one point around the joint shall not exceed $\frac{3}{32}$ in. (2.4 mm) as shown in Fig. ND-4233-1 sketch (b). Should tolerances on diameter, wall thickness, out-of-roundness, etc., result in inside diameter variations

Page 218

Page 219

which do not meet these limits, the inside diameters shall be counterbored, sized, or ground to produce a bore within these limits, provided the requirements of ND-4250 are met.



GENERAL NOTE:

The weld end transitions are typical and are not intended as requirements. Refer to ND-4250 for weld end transition requirements.

FIG. ND-4233-1 BUTT WELD ALIGNMENT AND MISMATCH TOLERANCES FOR UNEQUAL I.D. AND O.D. WHEN COMPONENTS ARE WELDED FROM ONE SIDE AND FAIRING IS NOT PERFORMED

FIG. ND-4233-1 BUTT WELD ALIGNMENT AND MISMATCH TOLERANCES FOR UNEQUAL I.D. AND O.D. WHEN COMPONENTS ARE WELDED FROM ONE SIDE AND FAIRING IS NOT PERFORMED

(b) Offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(2) For longitudinal joints the misalignment of inside surfaces shall not exceed $\frac{3}{32}$ in. (2.4 mm), and the offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(b) Single welded joints may meet the alignment requirements of (1) and (2) above in lieu of the requirements of ND-4232.

ND-4240 REQUIREMENTS FOR WELD JOINTS IN COMPONENTS¹

ND-4241 Category A Weld Joints in Vessels and Longitudinal Weld Joints in Other Components

All Category A weld joints in vessels and longitudinal weld joints in other components shall meet the requirements of (a), (b), and (c) below.

(a) When the design is based on a joint efficiency permitted by ND-3352.1(a) or ND-3352.1(b), all Category A welds in vessels and longitudinal joints in other components shall be Type 1 or Type 2 as described in ND-4245.

(b) When the design is based on a joint efficiency permitted by ND-3352.1(c), any joint Type as described in ND-4245 may be used, provided the limitations of the joint are followed.

(c) When the component is constructed of P-No. 11A, Group 1 material, Type 1 joints as described in ND-4245 shall be used.

ND-4242 Category B Weld Joints in Vessels and Circumferential Weld Joints in Other Components

Category B weld joints in vessels and circumferential weld joints in other components shall meet the requirements of (a) and (b) below, except that piping 2 in. NPS (DN 50) and smaller may be socket welded.

¹ See ND-4246 and ND-4247 for special weld joint requirements in storage tanks.

(a) When the design is based on a joint efficiency permitted by ND-3352.1(a) or ND-3352.1(b), or when P-No. 11A, Group 1 materials are joined, all Category B welds in pressure vessels and circumferential joints in other components shall be Type 1 or Type 2 as described in ND-4245.

(b) When the design is based on a joint efficiency permitted by ND-3352.2(c), any joint Type as described in ND-4245 may be used, provided the limitations of the joint are followed.

ND-4243 Category C Weld Joints in Vessels and Similar Joints in Other Components

Category C weld joints in vessels and similar weld joints in other components shall meet the requirements of (a), (b), and (c) below, except that socket welded flanges NPS 2 (DN 50) and less and slip-on flanges may be used.

(a) Category C and similar weld joints shall be Type 1 or Type 2 as described in ND-4245(a) when a butt weld detail is used and the provisions of ND-3352.1(a) or ND-3352.2(b) apply. These joints must be Type 1 or Type 2 butt welds when the joint is required to be radiographed.

(b) Typical Category C corner joints are shown in Fig. ND-4243-1 and Appendix XI.

(c) All category C joints in P-No. 11A, Group 1 material shall be full penetration welds extending through the entire section of the joint.

ND-4243.1 Flat Heads and Tubesheets With Hubs.

Hubs for butt welding to the adjacent shell, head, or other pressure part, as in Fig. ND-4243.1-1, shall not be machined from rolled plate. The component having the hub shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material, in a direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension test specimen, subsize if necessary, taken in this direction and as close to the hub as is practical.² In no case shall the height of the hub be less than 1.5 times the thickness of the pressure part to which it is welded.

ND-4244 Category D Weld Joints in Vessels and Branch Connection Weld Joints in Other Components

² One test specimen may represent a group of forgings, provided they are of the same nominal dimensions, from the same heat of material, the same heat treatment lot, and forged in the same manner.

Category D weld joints in vessels and branch connection weld joints in other components shall be welded using one of the details of (a) through (g) below except

Page 220

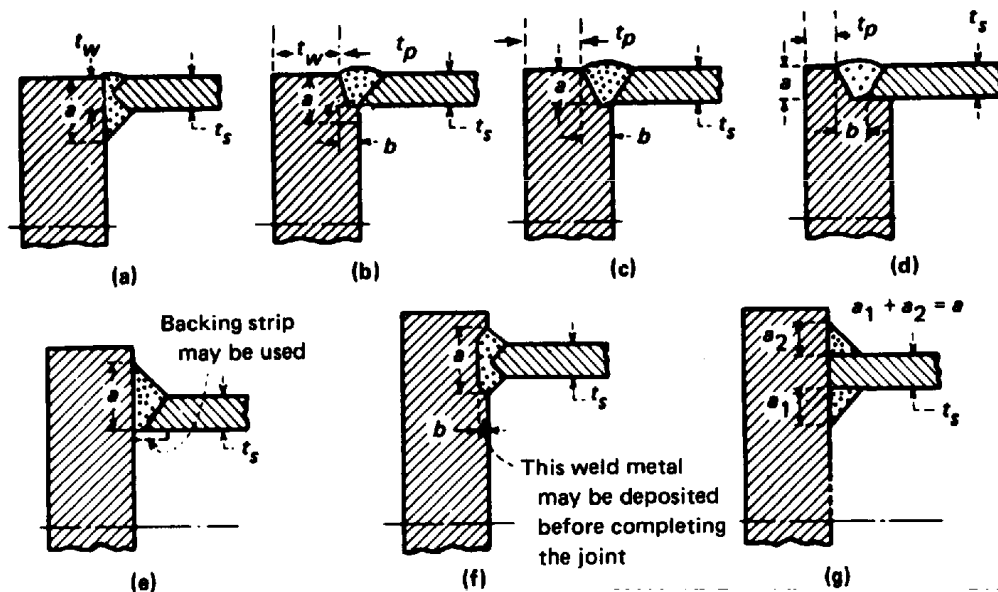
that joints in P-No. 11A, Group 1 material shall be full penetration welds extending through the entire thickness of the component wall or nozzle wall as shown in Figs. ND-4244(a)-1, ND-4244(b)-1, and ND-4244(c)-1.

(a) Butt Welded Nozzles and Branch Piping Connections. Nozzles and branch piping connections shall be attached by full penetration butt welds through the wall of the component nozzle or branch as shown in Fig. ND-4244(a)-1. Backing strips, if used, may be left in place.

(b) Corner Welded Nozzles and Branch Piping Connections. Nozzles and branch piping connections shall be joined to the component by full penetration welds through the wall of the component, nozzle, or branch similar to those shown in Fig. ND-4244(b)-1. When complete joint penetration cannot be verified by visual examination or other means permitted, backing strips or equivalent shall be used with full penetration welds deposited from only one side. Backing strips, if used, may be left in place.

(c) Deposited Weld Metal of Opening for Nozzles and Branch Piping Connections. Nozzles and branch piping connections shall be joined to the component by full penetration weld to built-up weld deposits applied to the component, nozzle, or branch as shown in Fig. ND-4244(c)-1. Backing strips, if used, may be left in place. Fillet welds shall be used only to provide

a transition between the parts joined or to provide a seal. The fillet welds, when used, shall be finished by grinding to
provide a smooth surface having a transition radius at its intersection with either part being joined. Pages 221-221



Typical Unstayed Flat Heads and Side Plates of Rectangular Vessels

GENERAL NOTES [sketches (a) through (g)]:

(1) For unstayed flat heads, see ND-3325.

(2) t_s , t_p , and t_w are defined in ND-3325.1.

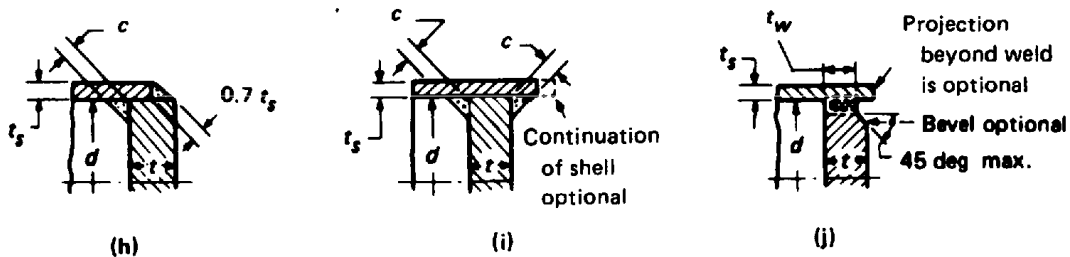
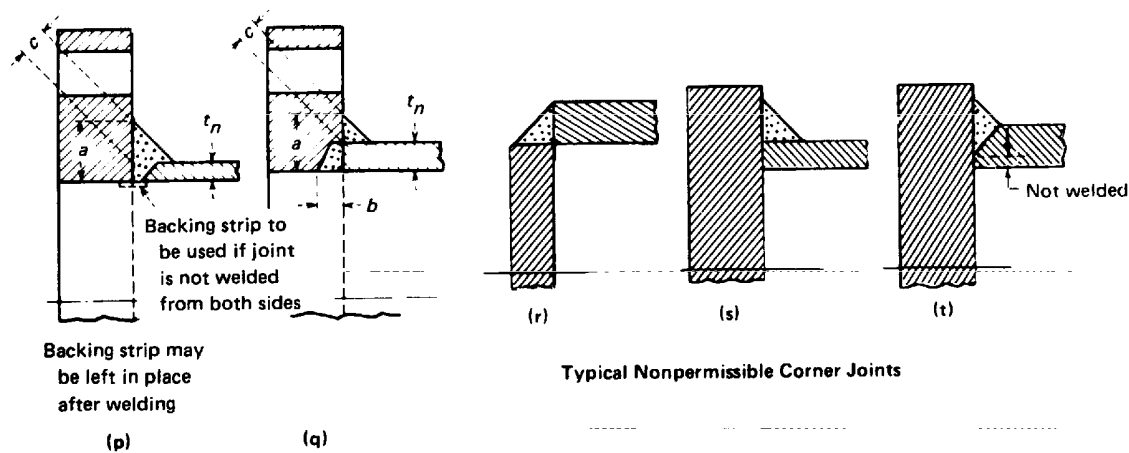
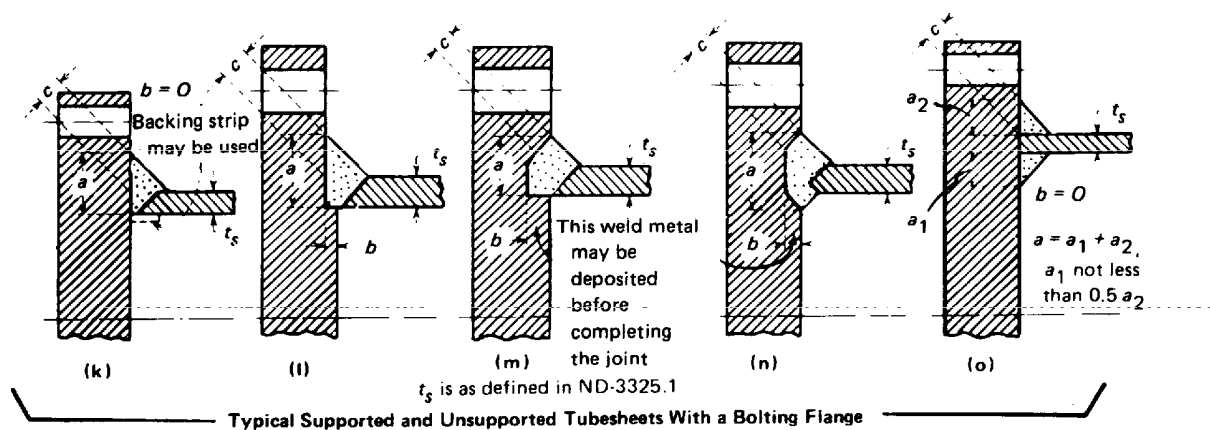


FIG. ND-4243-1 ATTACHMENT OF PRESSURE PARTS TO PLATES TO FORM A CORNER JOINT

FIG. ND-4243-1 ATTACHMENT OF PRESSURE PARTS TO PLATES TO FORM A CORNER JOINT



Typical Bolted Flange Connections
 c and t_n are as defined in XI-3130

FIG. ND-4243-1 ATTACHMENT OF PRESSURE PARTS TO PLATES
 TO FORM A CORNER JOINT (CONT'D)

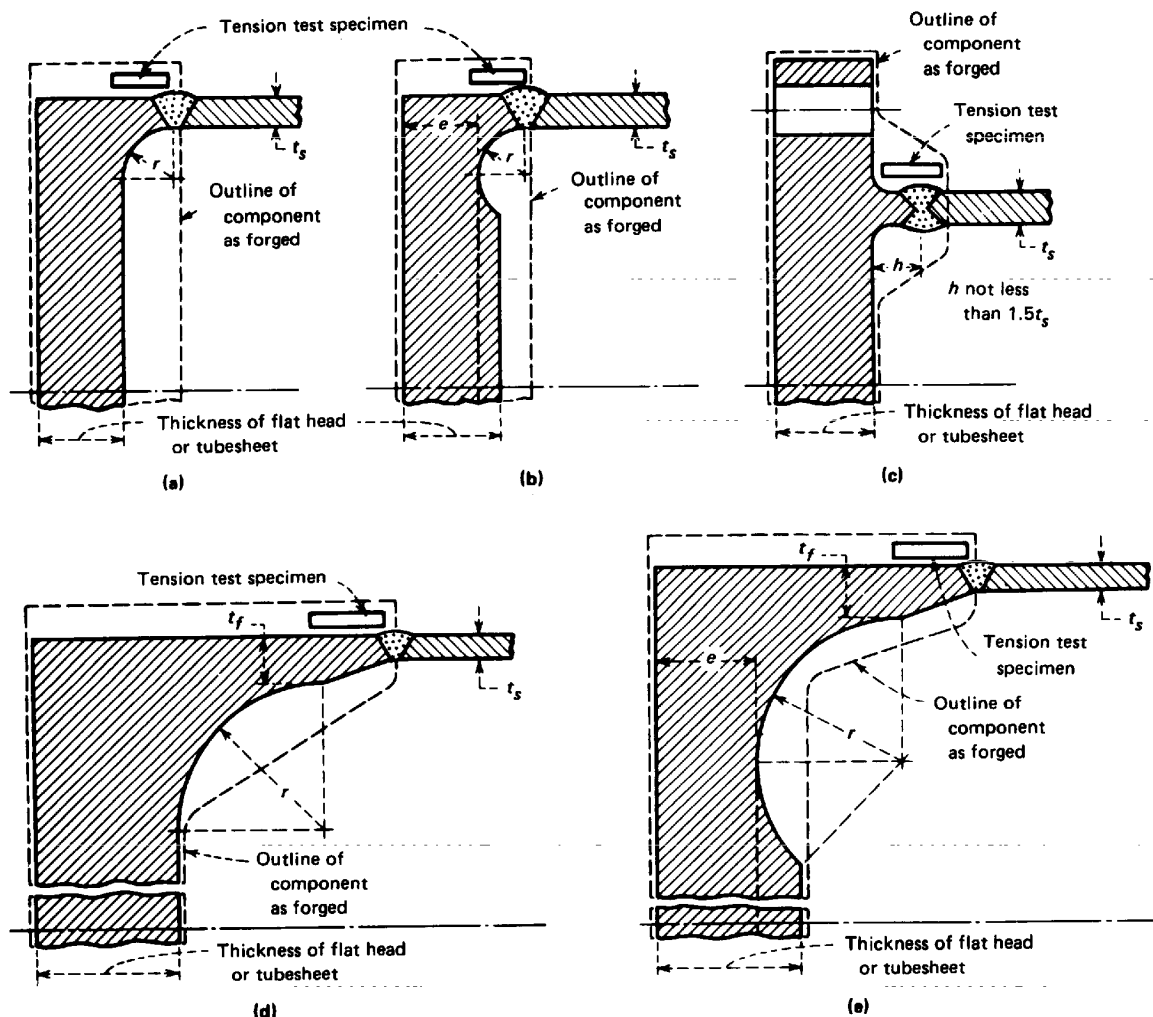
FIG. ND-4243-1 ATTACHMENT OF PRESSURE PARTS TO PLATES TO FORM A CORNER JOINT (CONT'D)

(d) *Partial Penetration Welded Nozzle and Branch Piping Connections.* Partial penetration welds in components and branch piping connections shall meet the weld design requirements of ND-3352.4(d) and ND-3359. Nozzles shall be attached as shown in Fig. ND-4244(d)-1. Reinforcing plates of nozzles attached to the outside of a vessel shall be provided with at least one telltale hole, maximum size $\frac{1}{4}$ in. pipe tap, that may be tapped for a preliminary compressed air and soapsuds test for tightness of welds that seal off the inside of the vessel. These telltale holes may be left open or may be plugged when the vessel is in service. If the holes are plugged, the plugging material used shall not be capable of sustaining pressure between the reinforcing plate and the vessel wall.

³ Written and illustrated with internal threads, but also applicable to externally threaded and socket or butt welded fittings.

(e) *Attachment of Fittings With Internal Threads.*³ Internally threaded fittings shall be attached by a full penetration groove weld or, for NPS 3 (DN 80) and less, by two fillet or partial penetration welds, one on

each face of the vessel wall, or by a fillet groove weld from the outside only as shown in Fig. ND-4244(e)-1 sketch (c-3). Internally threaded fitting and bolting pads not exceeding NPS 3, as shown in Fig. ND-4244(e)-2, may be attached to components having a wall thickness not greater than $\frac{3}{8}$ in. (10 mm) by a fillet weld, deposited from the outside only. The design requirements of ND-3352.4(e) shall be met for all components.



GENERAL NOTE:

Not permissible if machined from rolled plate. The tension test specimen may be located, when possible, inside the forged hub, instead of outside, as shown.

FIG. ND-4243.1-1 TYPICAL FLAT HEADS, AND SUPPORTED AND UNSUPPORTED TUBESHEETS WITH HUBS

FIG. ND-4243.1-1 TYPICAL FLAT HEADS, AND SUPPORTED AND UNSUPPORTED TUBESHEETS WITH HUBS

(f) *Tubed Connections.* Nozzles or tubes recessed into thick-walled components or parts may be welded from only one side, provided the requirements of ND-3352.4(f) are met. Typical connections are shown in Fig. ND-4244(f)-1.

(g) *Nozzles With Integral Reinforcing.* Nozzles and other connections having integral reinforcing in the form of external necks or saddle type pads shall be attached by full penetration welds or by means of a

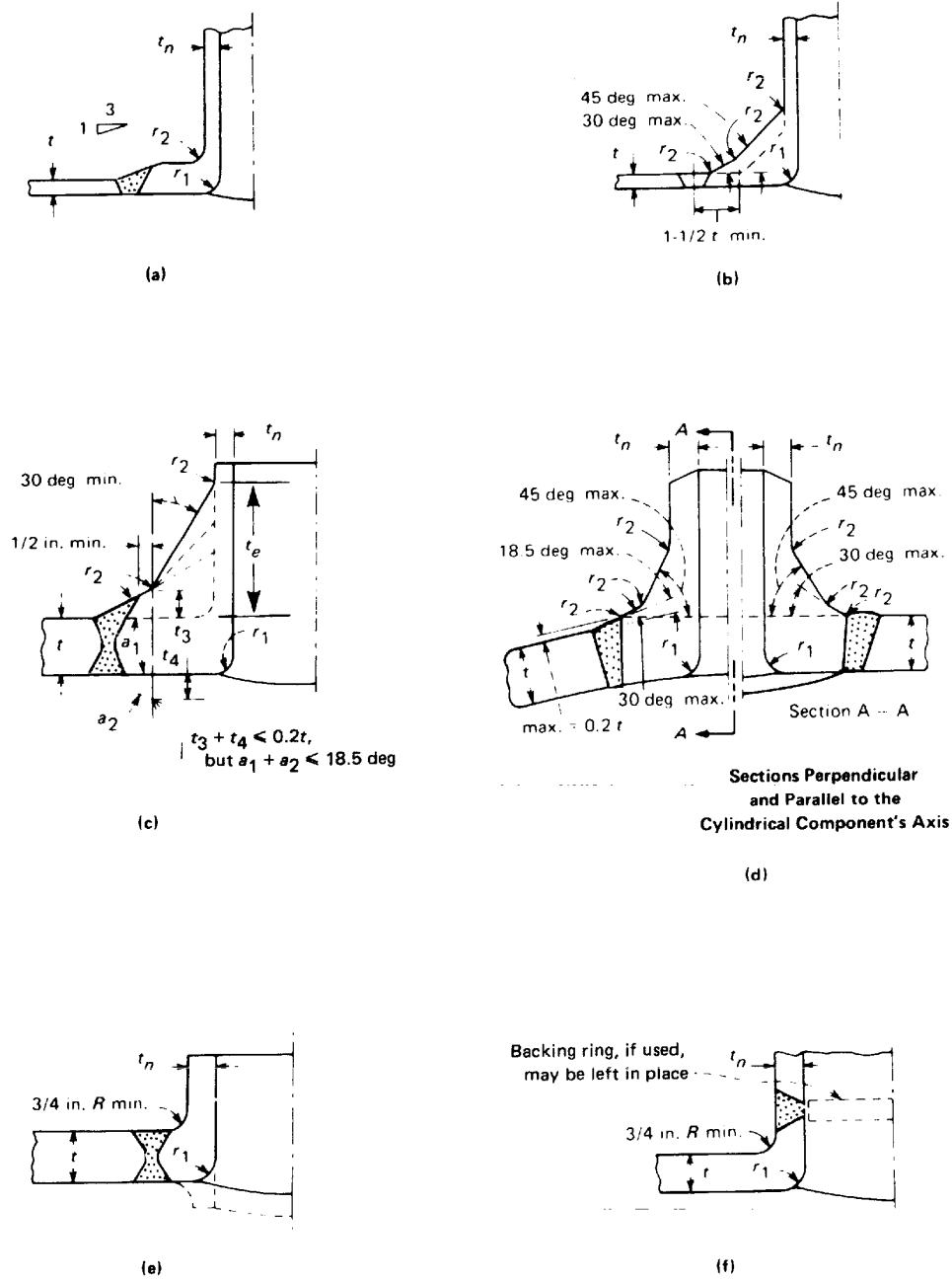


FIG. ND-4244(a)-1 NOZZLES, AND BRANCH AND PIPING CONNECTIONS JOINED BY FULL PENETRATION BUTT WELDS
For Definition of Symbols, See ND-3352(a)

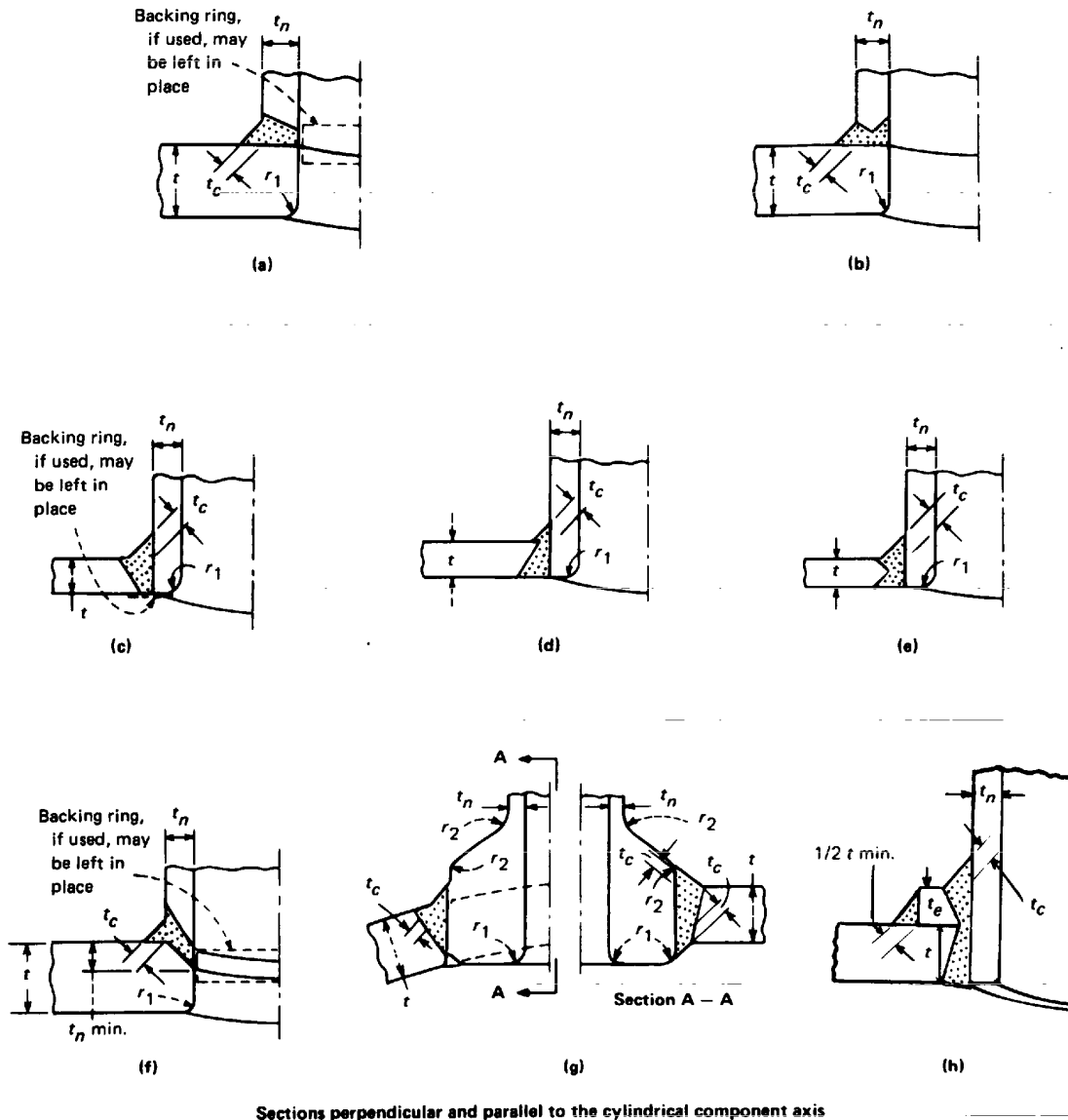


FIG. ND-4244(b)-1 NOZZLES, AND BRANCH AND PIPING CONNECTIONS JOINED BY FULL PENETRATION CORNER WELDS
For Definition of Symbols, See ND-3352.4(b)

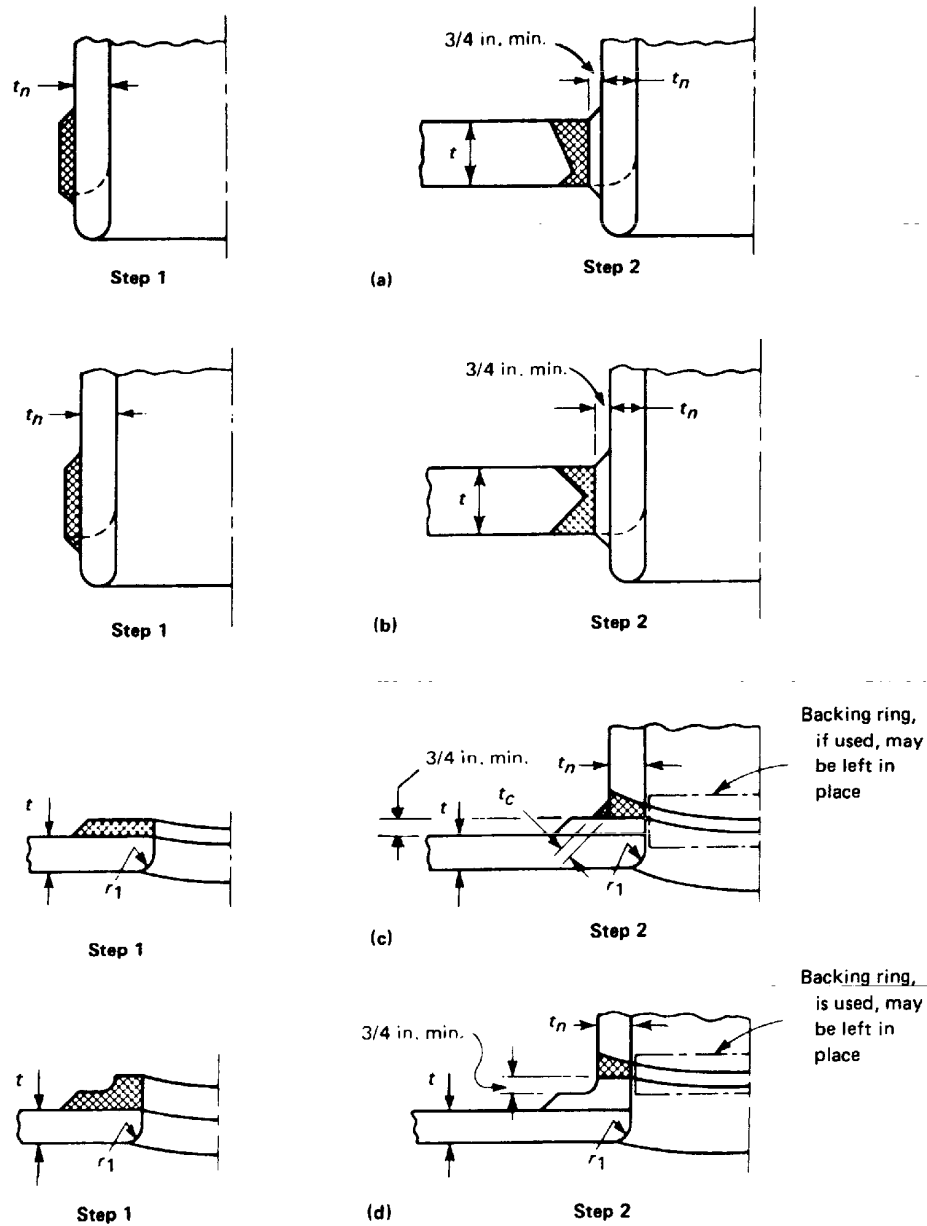


FIG. ND-4244(c)-1 DEPOSITED WELD METAL USED AS REINFORCEMENT OF OPENINGS FOR NOZZLES, AND BRANCH AND PIPING CONNECTIONS
For Definition of Symbols, See ND-3352.4(c)

FIG. ND-4244(c)-1 DEPOSITED WELD METAL USED AS REINFORCEMENT OF OPENINGS FOR NOZZLES, AND BRANCH AND PIPING CONNECTIONS

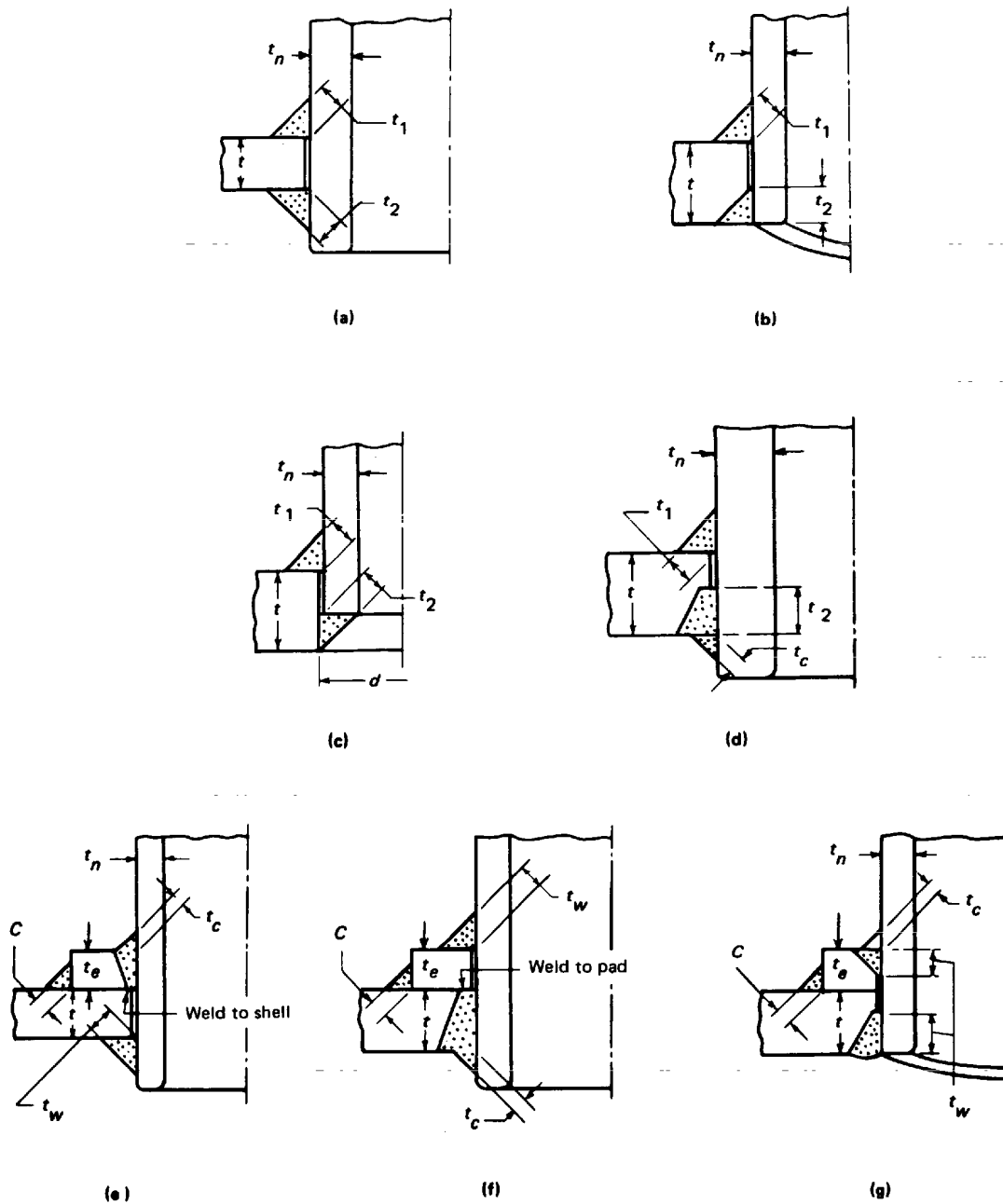


FIG. ND-4244(d)-1 SOME ACCEPTABLE TYPES OF WELDED NOZZLES, AND BRANCH AND PIPING CONNECTIONS
For Definition of Symbols, See ND-3352.4(d)

FIG. ND-4244(d)-1 SOME ACCEPTABLE TYPES OF WELDED NOZZLES, AND BRANCH AND PIPING

CONNECTIONS

fillet weld along the outer attachment having a wall, single bevel, or single J-weld along the inner attachment. Typical connections are shown in Fig. ND-4244(g)-1.

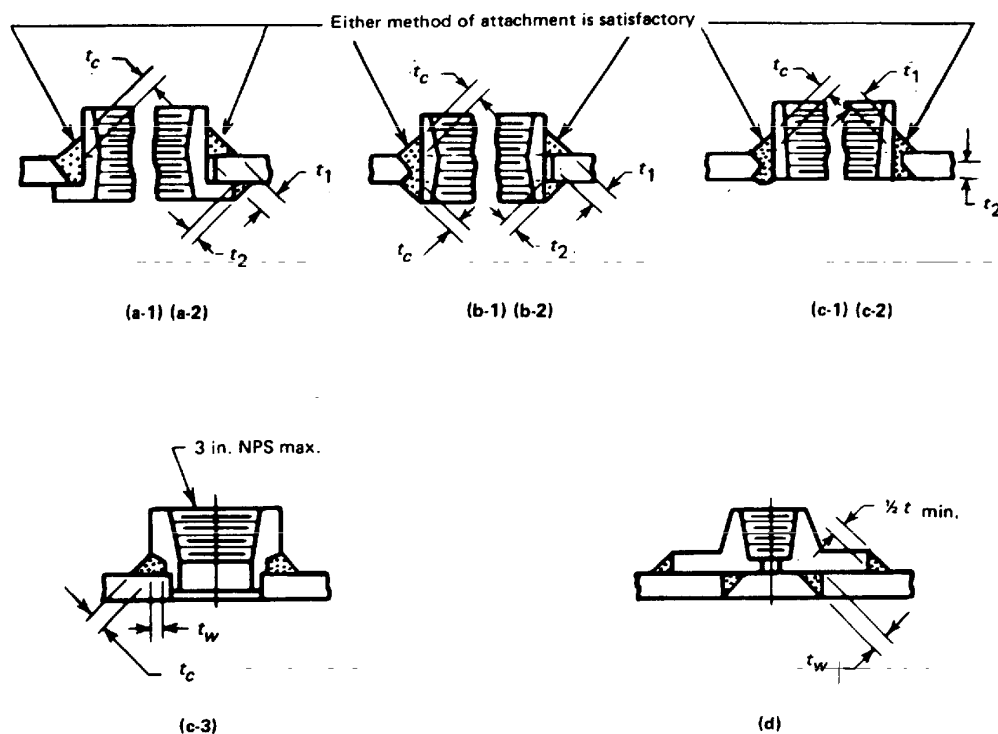


FIG. ND-4244(e)-1 SOME ACCEPTABLE TYPES OF WELDED NOZZLES
For Definition of Symbols, See ND-3352.4(e)

FIG. ND-4244(e)-1 SOME ACCEPTABLE TYPES OF WELDED NOZZLES

ND-4245 Description and Limitations of Joint Types

(a) For components the description of the joint types are as follows:

Type	Description
1	Butt joints as attained by double welded or by other means will obtain the same quality of deposit weld metal on the inside and outside surface to agree with the requirements of ND-4426. Welds using metal backing strips which remain in place are excluded.
2	Single welded butt joints with backing strips other than those included in Type 1
3	Single welded butt joints without the use of a backing strip
4	Double full fillet lap joints
5	Single full fillet lap joints with plug welds conforming to ND-3356.2
6	Single full fillet lap joints without plug welds

(b) The limitations for each Type of weld are as outlined below. Some typical configurations are shown in Fig. ND-4245-1.

Type	Limitations
1	The use of this joint Type is not limited.
2	The use of this joint Type is not limited, except for butt welds with one plate offset which can be used for circumferential joints only and are limited by the provisions of ND-3358.5 [Fig. ND-4245-1 sketch (k)].
3	This joint Type is limited to circumferential joints only, which are not over $\frac{5}{8}$ in. (16 mm) thick and not over 24 in. (610 mm) outside diameter.
4	This joint Type is limited to longitudinal joints not over $\frac{3}{8}$ in. (10 mm) thick and circumferential joints not over $\frac{5}{8}$ in. (16 mm) thick.
5	This joint Type is limited to circumferential joints for attachments of heads other than hemispherical not over 24 in. (610 mm) outside diameter to shells not over $\frac{1}{2}$ in. (13 mm) thick. This joint Type cannot be used for attaching hemispherical heads to shells.
6	This joint Type is limited to attachment of heads convex to pressure to shells not over $\frac{5}{8}$ in. required thickness, using fillet welds on the inside of the shell or for the attachment of heads having pressure on either side, to shells not over 24 in. inside diameter and not over $\frac{1}{4}$ in. required thickness with the fillet welds on the outside of the head flange only.

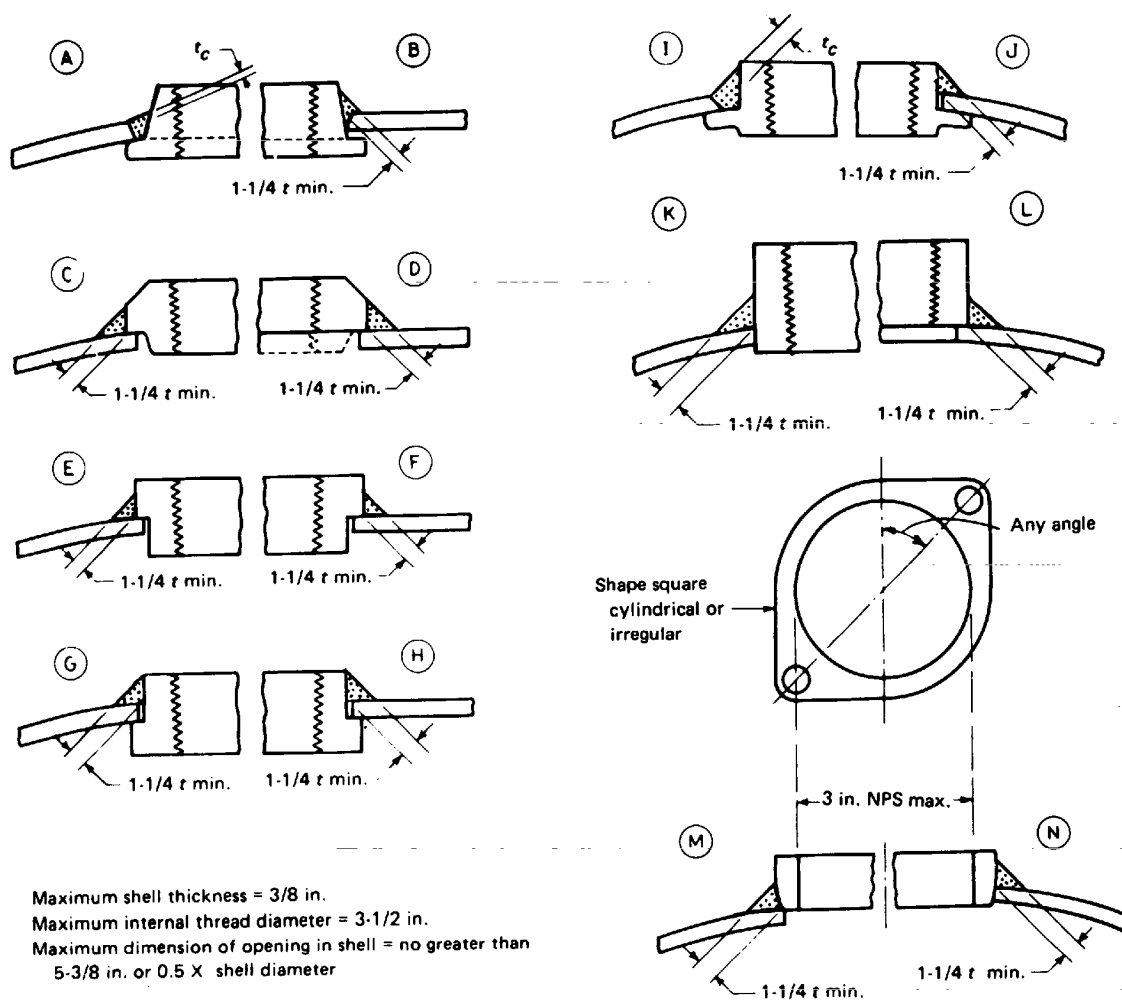
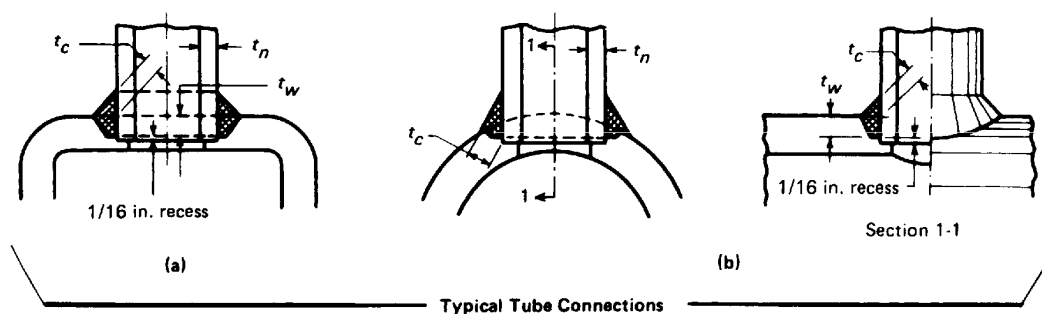


FIG. ND-4244(e)-2 SOME ACCEPTABLE TYPES OF SMALL FITTINGS
 For Definition of Symbols, See ND-3352.4(e)

FIG. ND-4244(e)-2 SOME ACCEPTABLE TYPES OF SMALL FITTINGS

ND-4246 Atmospheric Storage Tank Special Joints

Requirements for special joints for atmospheric storage tanks are given below.



GENERAL NOTE: When used for other than square, round, or oval headers, round off corners.

FIG. ND-4244(f)-1 TUBE CONNECTIONS
For Definition of Symbols, See ND-3352.4(f)

FIG. ND-4244(f)-1 TUBE CONNECTIONS

ND-4246.1 Bottom Plates.

Bottoms shall be built to either one of the alternative methods of construction given in (a) and (b) below.

(a) Lap welded bottom plates shall be reasonably rectangular and square edged. Three plate laps in tank bottoms shall not be closer than 12 in. (305 mm) from each other and also from the tank shell. Bottom plates need be welded on the top side only, with a continuous full fillet weld on all seams [Fig. ND-4246.1(a)-1]. The plates under the bottom ring shell connection shall have the outer ends of the joints fitted and lap welded to form a smooth bearing for the shell plates, as shown in Fig. ND-4246.1(a)-1.

(b) Butt welded bottom plates shall have the parallel edges prepared for butt welding with either square or V-grooves. If square grooves are employed, the root opening shall be not less than $\frac{1}{4}$ in. (6 mm). The butt welds shall be made by applying a backing strip $\frac{1}{8}$ in. thick or heavier by tack welding to the underside of the plate [Fig. ND-4246.1(a)-1]. A metal spacer shall be used, if necessary, to maintain the root opening between the adjoining plate edges. The Certificate Holder may submit other methods of butt welding the bottom for the Owner's approval. Three plate joints in tank bottoms shall not be closer than 12 in. (305 mm) from each other and also from the tank shell.

ND-4246.2 Shell-to-Bottom Attachment.

The attachment between the bottom edges of the lowest course shell plate and the bottom plate shall be a continuous full wall thickness weld with a cover fillet on each side of shell plate [Fig. ND-4246.1(a)-1], or for tanks not exceeding 35 ft (10.6 mm) in diameter the bottom plates may be flanged and butt welded to the bottom shell course. The flanged tank bottom plates shall be butt welded and have a thickness equal to the thickness of the bottom shell course. The inside radius of the bend shall be not less than $1.75t$ nor more than $3t$.

ND-4246.3 Roof-to-Sidewall Attachment.

Roof plates shall be attached to the top angle of the tank with a continuous fillet weld on the top side only (Fig. ND-4246.3-1). Roof plates of supported cone roofs shall not be attached to the supporting members. For cone roofs the fillet weld shall be $\frac{3}{16}$ in. (4.8 mm) or smaller.

ND-4246.4 Roof Plates.

Roof plates shall be attached at least by a continuous full fillet lap joint on the top side (Fig. ND-4246.3-1). The top angle sections for self-supporting roofs shall be joined by full penetration butt welds.

ND-4246.5 Nozzle-to-Tank Joints.

Nozzles, manholes, and outlets shall be attached by full fillet welds as shown in Figs. ND-4246.5-1, ND-4246.5-2, ND-4246.5-3, and ND-4246.5-4.

[98]

ND-4246.6 Special Requirements.

Special weld requirements for storage tanks are given in (a) through (d) below.

(a) The minimum size of fillet welds shall be as follows: plates $\frac{3}{16}$ in. (4.8 mm) thick, full fillet welds; plates over $\frac{3}{16}$ in. (4.8 mm) thick, not less than one-third the thickness of the thinner plate at the joint, with a minimum of $\frac{3}{16}$ in. (4.8 mm).

(b) Lap welded joints, as tack welded, shall be lapped not less than five times the nominal thickness of the thinner plate joined; but in the case of double welded lap joints the lap need not exceed 2 in. (51 mm), and

Page 230

Page 231

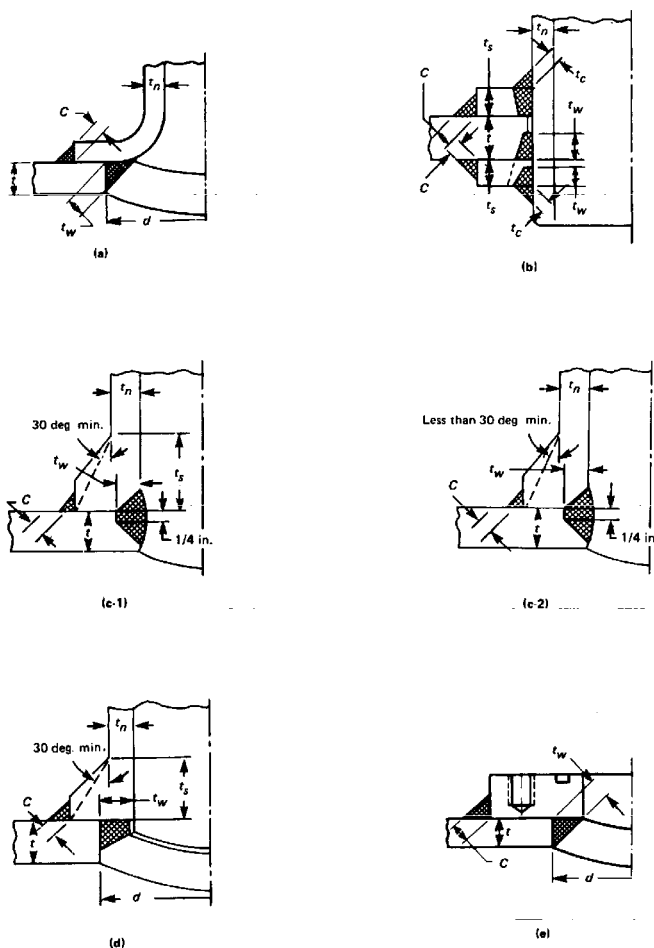


FIG. ND-4244(g)-1 SOME ACCEPTABLE TYPES OF WELDED NOZZLES, AND BRANCH AND PIPING CONNECTIONS
For Definition of Symbols, See ND-3352.4(g)

FIG. ND-4244(g)-1 SOME ACCEPTABLE TYPES OF WELDED NOZZLES, AND BRANCH AND PIPING CONNECTIONS

For Definitions of Symbols, See ND-3352.4(g)

Page 233
Pages 232-232

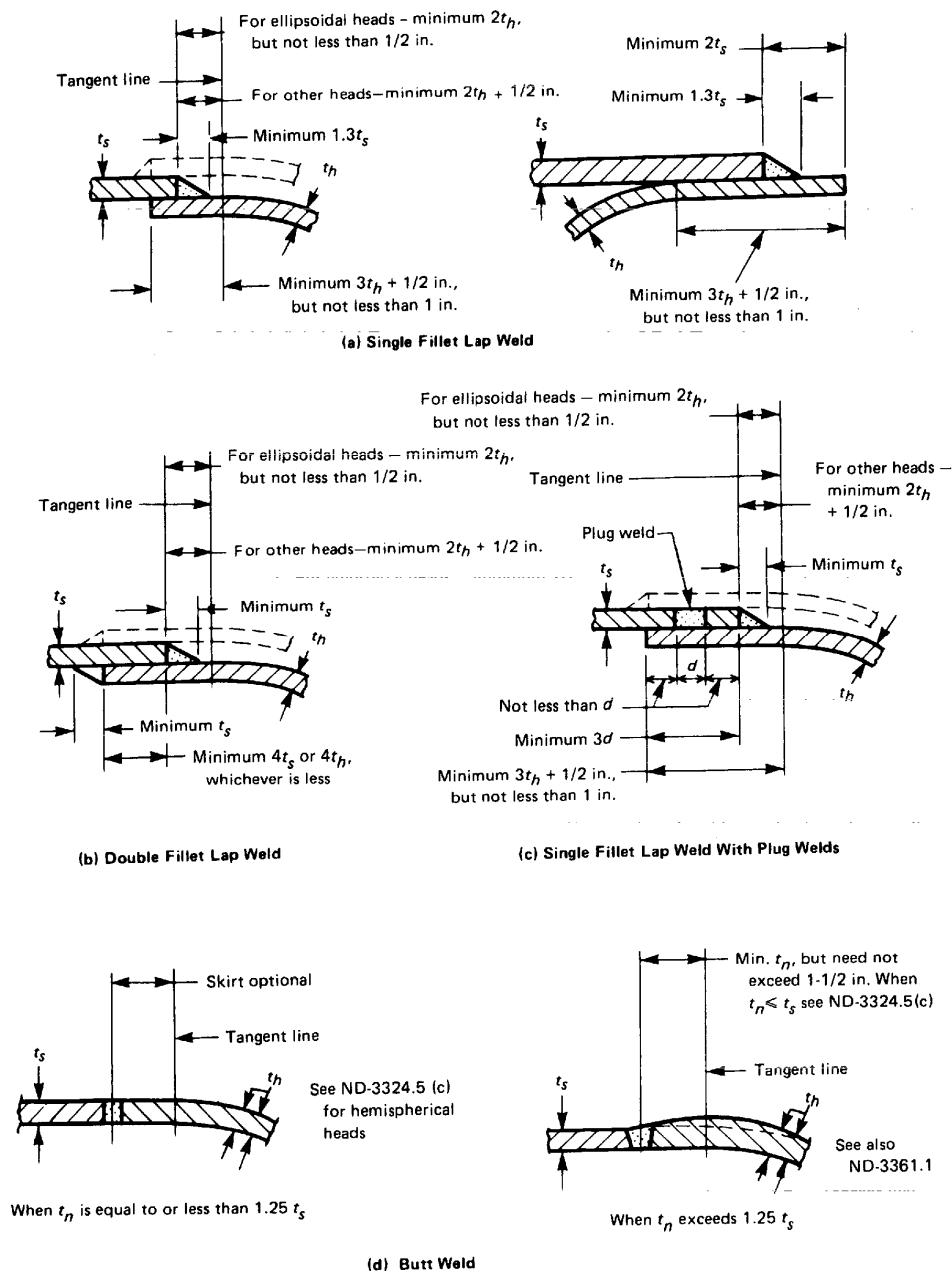


FIG. ND-4245-1 ATTACHMENT WELDS

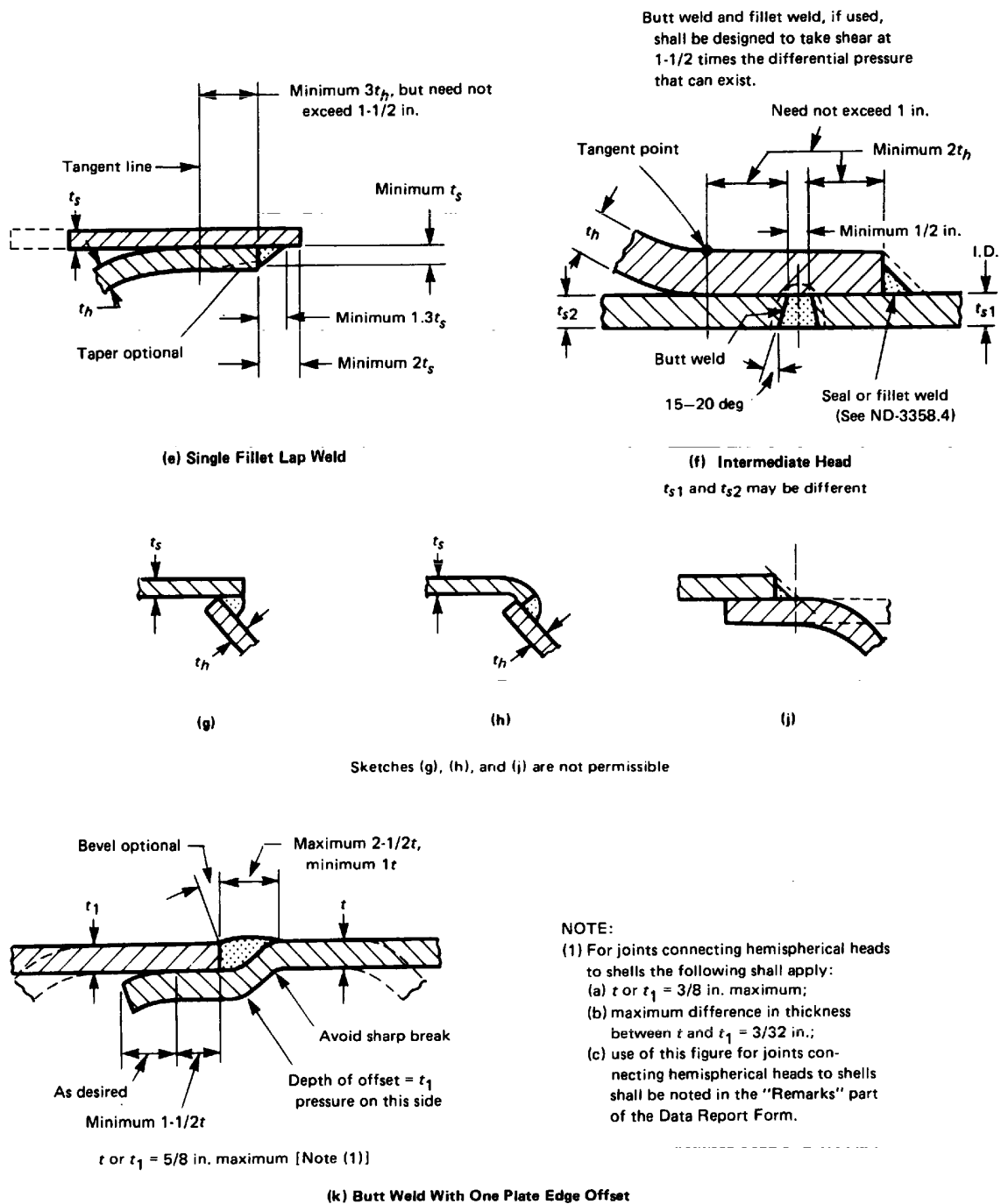


FIG. ND-4245-1 ATTACHMENT WELDS (CONT'D)

FIG. ND-4245-1 ATTACHMENT WELDS (CONT'D)

in the case of single welded lap joints the lap need not exceed 1 in. (25 mm).

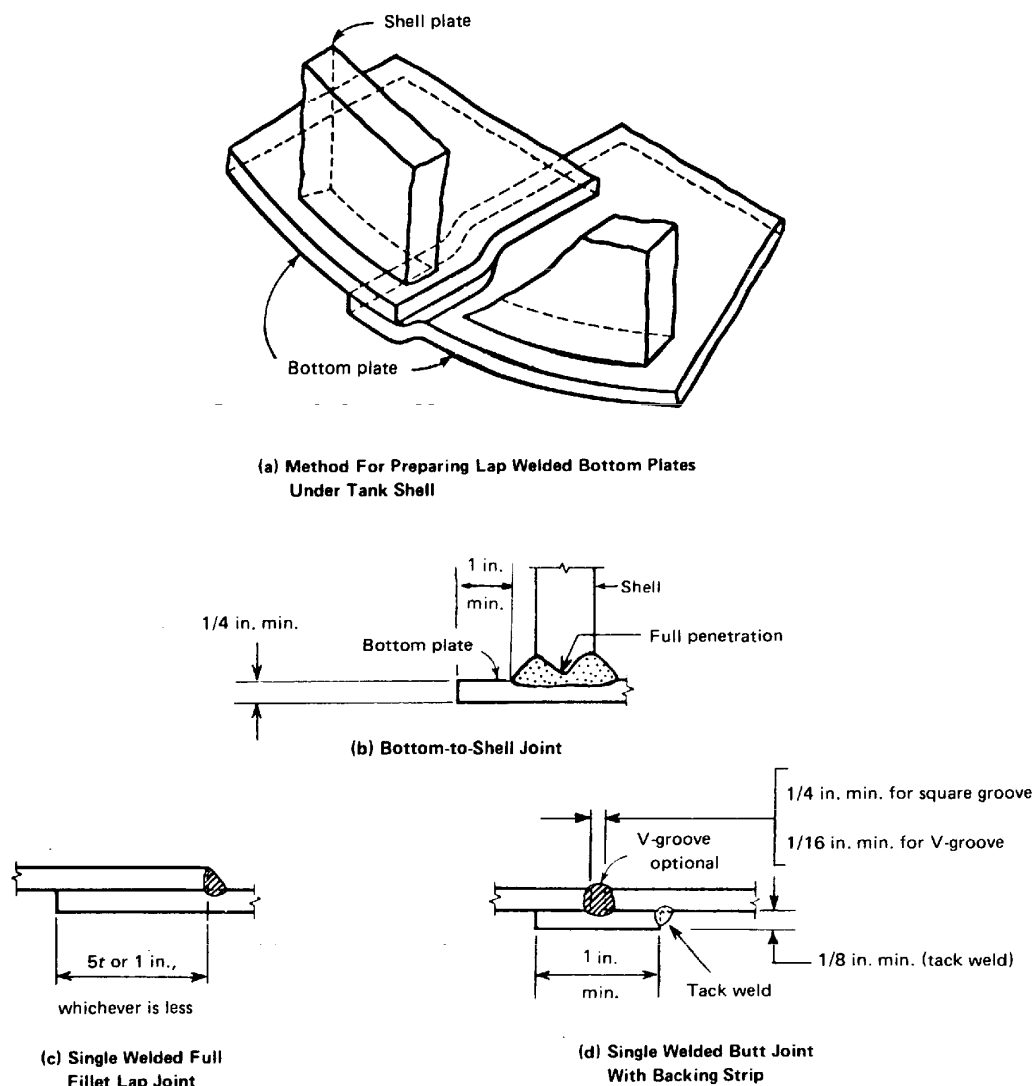


FIG. ND-4246.1(a)-1 TYPICAL BOTTOM AND BOTTOM-TO-SHELL JOINTS

FIG. ND-4246.1(a)-1 TYPICAL BOTTOM AND BOTTOM-TO-SHELL JOINTS

(c) For plates over $\frac{1}{2}$ in. (13 mm) thick in the sidewalls, roof, or bottom of the tank, if the thickness of two adjacent plates which are to be butt welded together differs more than $\frac{1}{8}$ in. (3.2 mm), the thicker plate shall be trimmed to a smooth taper extending for a distance at least three times the offset between the abutting surfaces so that the adjoining edges will be approximately the same thickness (Fig. ND-3361.1-1). The length of the required taper may include the width of the weld.

(d) Top angle sections for self-supporting roofs shall be joined by full penetration butt welds.

[98]

ND-4246.7

weld joints, are the same as given in ND-4240 for Category A, B, and C weld joints for vessels.

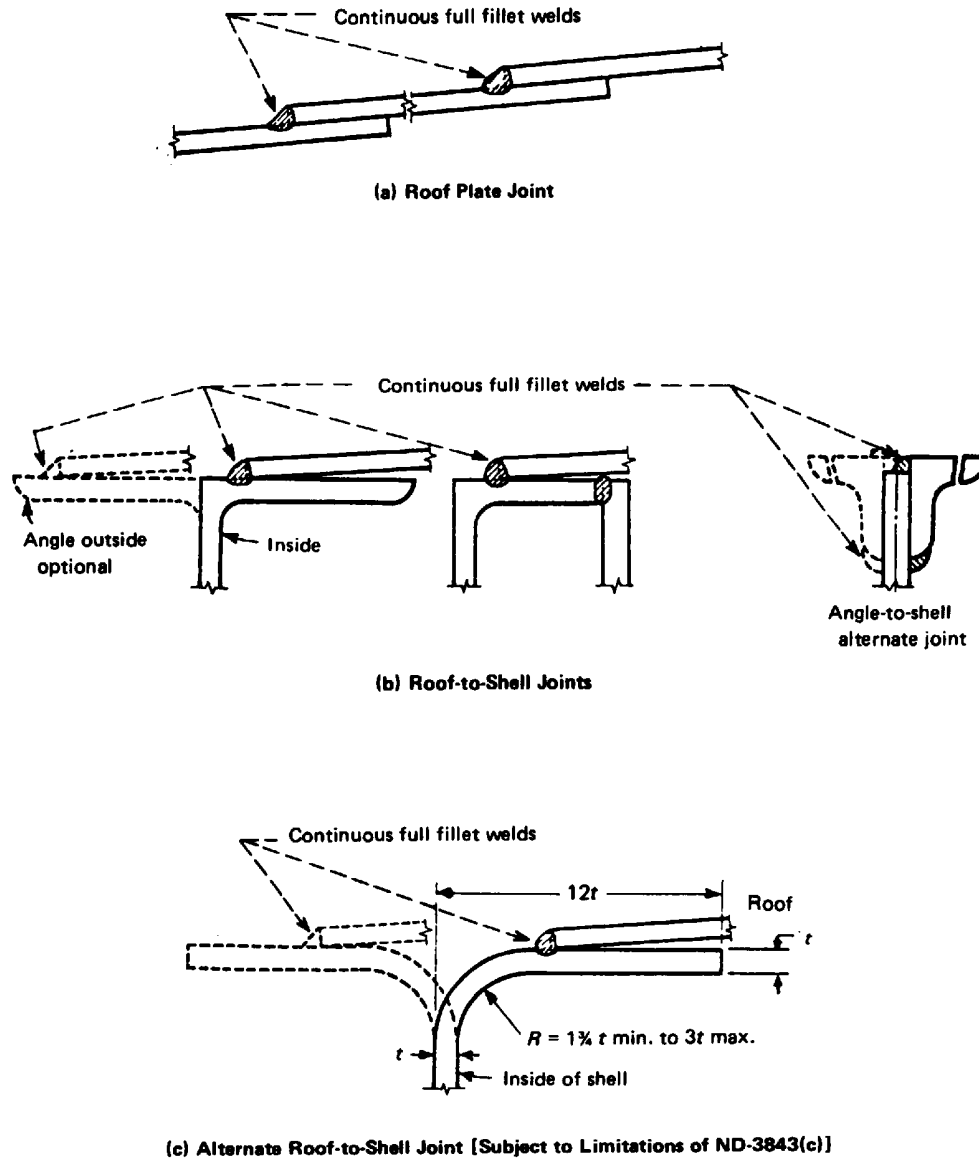


FIG. ND-4246.3-1 TYPICAL ROOF AND ROOF-TO-SHELL JOINTS

FIG. ND-4246.3-1 TYPICAL ROOF AND ROOF-TO-SHELL JOINTS

ND-4247 0-15 psi (0-103 kPa) Storage Tank Special Joints

Requirements for special joints for 0-15 psi (0-103 kPa) storage tanks are given below.

Requirements for special joints for 0-15 psi (0-103 kPa) storage tanks are given below.

ND-4247.1 Bottoms.

All welds in flat bottoms supported directly on foundations shall be single full fillet lap joints as a minimum. For other bottoms, all welds shall be butt welds.

ND-4247.2 Bottom-to-Sidewall.

All welds shall meet the design requirements of ND-3933. Flat bottoms shall be attached to sidewalls by full penetration welds and fillet welds on each side as a minimum.

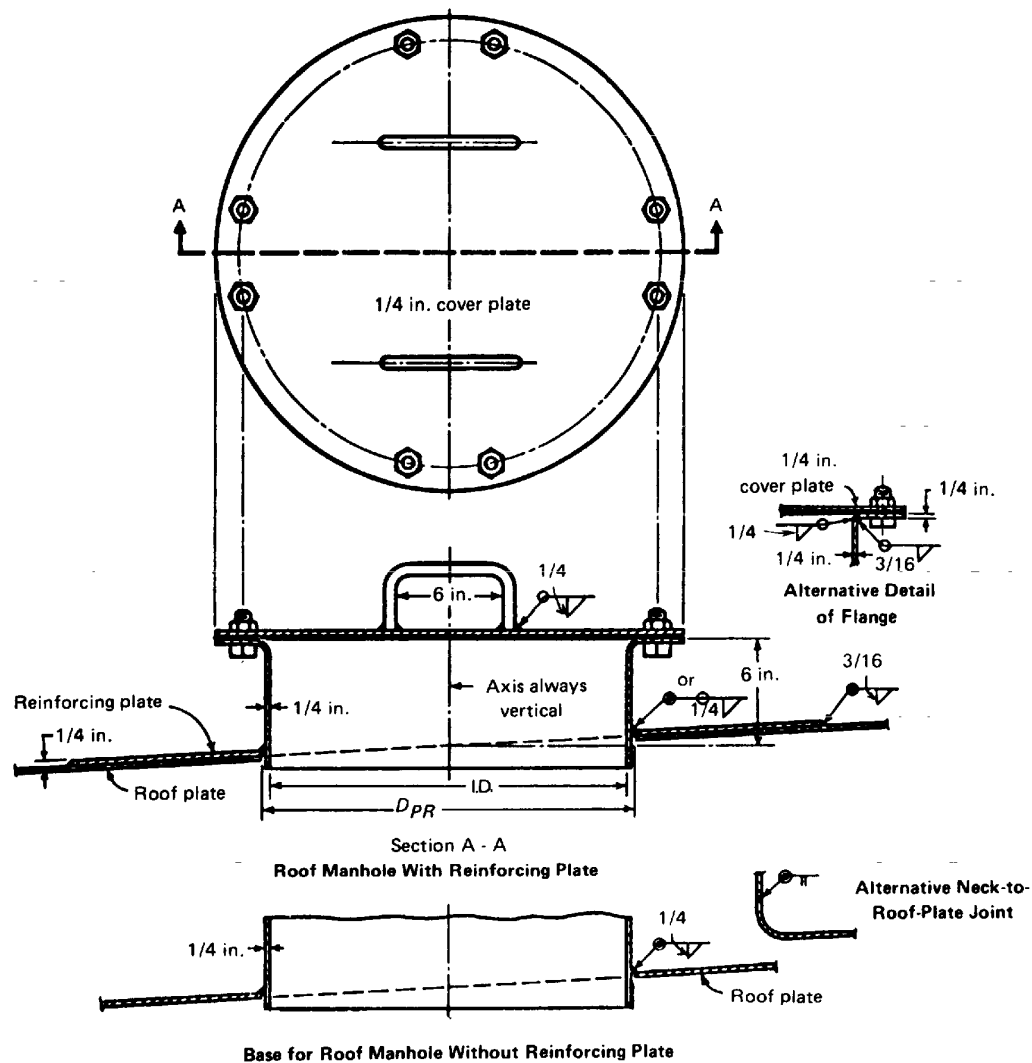


FIG. ND-4246.5-1 ROOF MANHOLES

FIG. ND-4246.5-1 ROOF MANHOLES

ND-4247.3

Roof-to-sidewall joints shall be in accordance with the design requirements of ND-3933. The joints shall have continuous full fillet welds as a minimum.

ND-4247.4 Roofs.

Roofs shall be in accordance with the design requirements of ND-3933 and shall meet the requirements of ND-4241.

ND-4247.5 Nozzles.

Nozzle welds shall meet the requirements of ND-4244.

[98]

ND-4247.6 Special Requirements.

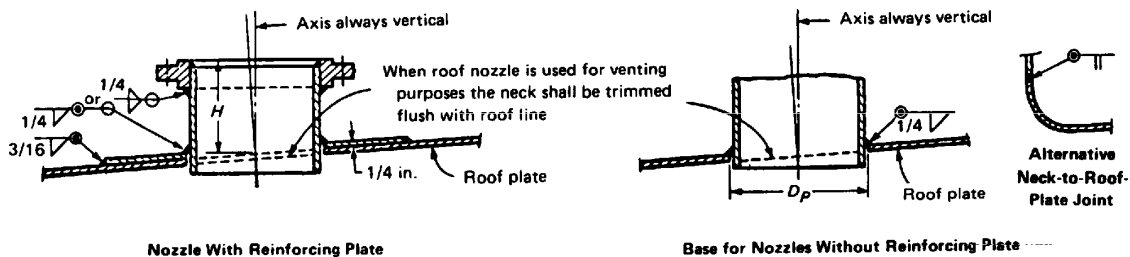
Special weld requirements for storage tanks are given in (a) through (d) below.

(a) The minimum size of fillet welds shall be as follows: plates $\frac{3}{16}$ in. (4.8 mm) thick, full fillet welds; plates over $\frac{3}{16}$ in. (4.8 mm) thick, not less than one-third the thickness of the thinner plate at the joint, with a minimum of $\frac{3}{16}$ in. (4.8 mm)

(b) Lap welded joints, as tack welded, shall be lapped not less than five times the nominal thickness of the thinner plate joined; but in the case of double welded lap joints the lap need not exceed 2 in. (51 mm), and in the case of single welded lap joints the lap need not exceed 1 in. (25 mm).

(c) For plates over $\frac{1}{2}$ in. (13 mm) thick in the sidewalls, roof, or bottom of the tank, if the thickness

Page 236



GENERAL NOTES:

- (a) Slip-on welding and welding neck flanges shall conform to the requirements for 150 lb forged carbon steel raised face flanges as given in ANSI B16.5.
- (b) Plate ring flanges shall conform to all dimensional requirements for slip-on welding flanges, except that the extended hub on the back of the flange may be omitted.

FIG. ND-4246.5-2 FLANGED ROOF NOZZLES

FIG. ND-4246.5-2 FLANGED ROOF NOZZLES

of two adjacent plates which are to be butt welded together differs more than $\frac{1}{8}$ in. (3.2 mm), the thicker plate shall be trimmed to a smooth taper extending for a distance at least three times the offset between the abutting surfaces so that the adjoining edges will be approximately the same thickness (Fig. ND-3361.1-1). The length of the required taper may include the width of the weld.

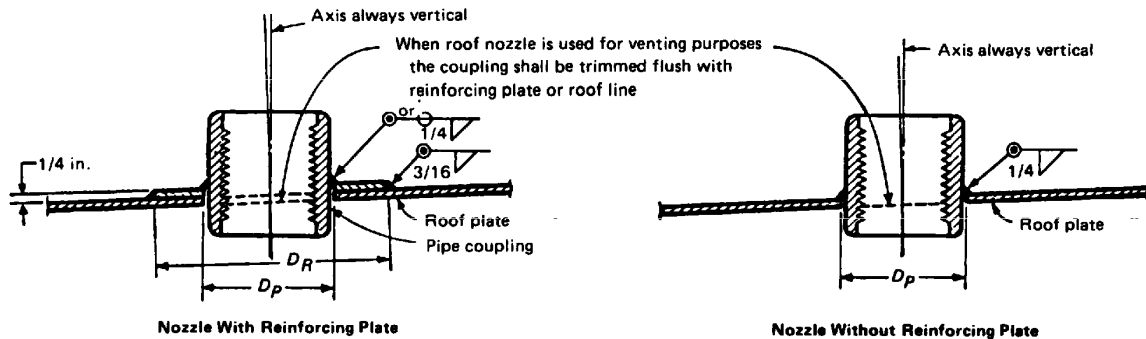


FIG. ND-4246.5-3 SCREWED OR SOCKET WELD ROOF NOZZLES

FIG. ND-4246.5-3 SCREWED OR SOCKET WELD ROOF NOZZLES

(d) The size of any weld along either edge of a compression ring shall not be less than the thickness of the thinner of the two parts joined or $\frac{1}{4}$ in. (6 mm), whichever is less, nor shall the size of the corner welds between the shell and a girder bar, such as shown in sketches (d) and (e) in Fig. ND-3933.5(d)-1, or between the horizontal and vertical members of a compression ring assembly, such as shown in sketches (f) and (i), be less than the applicable value specified in Table ND-4247.6(d)-1.

[98]

ND-4247.7 Other Weld Joints.

The fabrication requirements for weld joints not specifically covered by ND-4247, such as sidewall weld joints and nozzle-to-flange weld joints, are the same as given in ND-4240 for Category A, B, and C weld joints for vessels.

ND-4250 WELDING END TRANSITIONS - MAXIMUM ENVELOPE

The welding ends of items shall provide a gradual change in thickness from the item to the adjoining

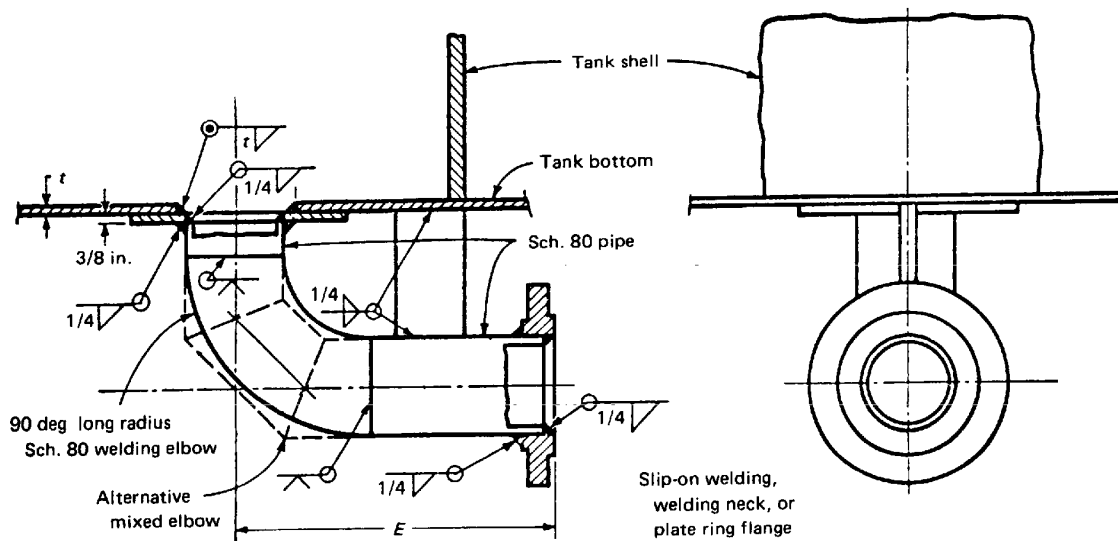


FIG. ND-4246.5-4 WELDED BOTTOM OUTLET ELBOW

FIG. ND-4246.5-4 WELDED BOTTOM OUTLET ELBOW

items. Any welding end transition which lies entirely within the envelope shown in Fig. ND-4250-1 is acceptable, provided that:

**TABLE ND-4247.6(d)-1
MINIMUM SIZE FOR FILLET WELDS**

Thickness of the Thicker of the Two Parts Joined, in.	Minimum Size of Fillet Weld, in.
Not over $\frac{1}{4}$	$\frac{3}{16}$
Over $\frac{1}{4}$ through $\frac{3}{4}$	$\frac{1}{4}$
Over $\frac{3}{4}$ through $1\frac{1}{4}$	$\frac{5}{16}$
Over $1\frac{1}{4}$	$\frac{3}{8}$

TABLE ND-4247.6(d)-1 MINIMUM SIZE FOR FILLET WELDS

- (a) the wall thickness in the transition region is not less than the minimum wall thickness of the adjoining item; and
- (b) sharp reentrant angles and abrupt changes in slope in the transition region are avoided. When the included angle between any two adjoining surfaces of a taper transition is less than 150 deg, the intersection or corner (except for the weld reinforcement) shall be provided with a radius of at least $0.05t_{\min}$.

ND-4300 WELDING QUALIFICATIONS

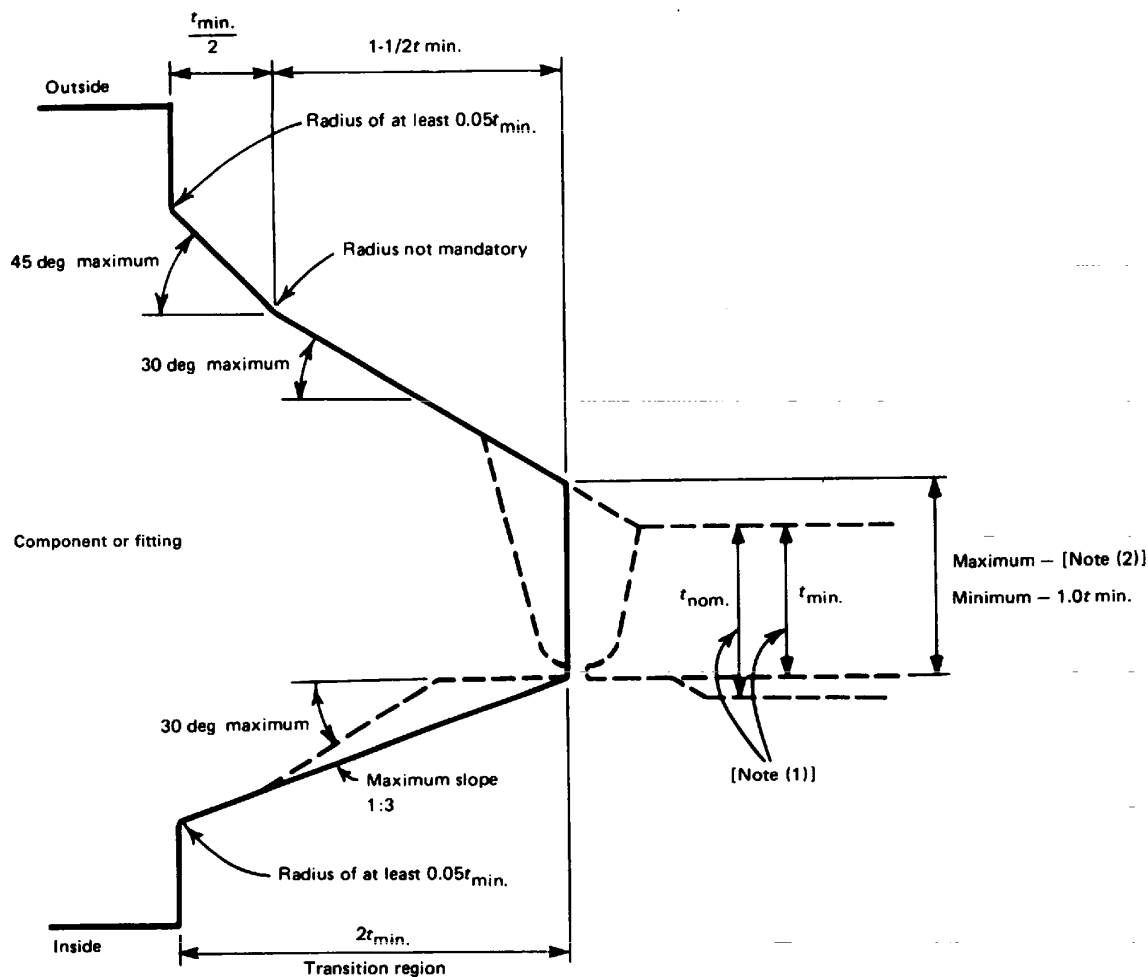
ND-4310 GENERAL REQUIREMENTS

ND-4311 Types of Processes Permitted

Only those welding processes which are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Subsection may be used for welding pressure retaining material or attachments thereto. Any process used shall be such that the records required by ND-4320 can be prepared, except that records for stud welds shall be traceable to the welders and welding operators and not necessarily to each specific weld.

ND-4311.1 Stud Welding Restrictions.

Stud welding is acceptable only for nonstructural and temporary attachments (ND-4435). Studs shall be limited to 1 in. maximum diameter for round studs and an equivalent cross-sectional area for studs of other shapes when welding in the flat position and $\frac{3}{4}$ in. (19 mm) diameter for all other welding positions. Postweld heat treatment shall comply with ND-4600, except that time at temperature need not exceed $\frac{1}{2}$ hr regardless of base material thickness. Welding procedure and performance qualification shall comply with the requirements of Section IX.



GENERAL NOTES:

- (a) Weld bevel is shown for illustration only
- (b) The weld reinforcement permitted by ND-4426 may lie outside the maximum envelope.

NOTES:

- (1) The value of $t_{min.}$ is whichever of the following is applicable:
 - (a) the minimum ordered wall thickness of the pipe
 - (b) 0.875 times the nominal wall thickness of pipe ordered to a pipe schedule wall thickness which has an under tolerance of 12.5%
 - (c) the minimum ordered wall thickness of the cylindrical welding end of a component or fitting (or the thinner of the two) when the joint is between two components
- (2) The maximum thickness at the end of the component is:
 - (a) the greater of $(t_{min.} + 0.15 \text{ in.})$ or $1.15t_{min.}$, when ordered on a minimum wall basis
 - (b) the greater of $(t_{min.} + 0.15 \text{ in.})$ or $1.10t_{nom.}$, when ordered on a nominal wall basis.

FIG. ND-4250-1 WELDING END TRANSITIONS MAXIMUM ENVELOPE

FIG. ND-4250-1 WELDING END TRANSITIONS MAXIMUM ENVELOPE

ND-4311.2 Capacitor Discharge Welding.

Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments provided:

- (a) temporary attachments are removed in accordance with the provisions of ND-4435(b);
- (b) the energy output for permanent nonstructural attachments such as strain gages and thermocouples is limited to 125 W-sec and the minimum thickness of the material to which the attachment is made is greater than 0.09 in. (2.3 mm); and
- (c) a Welding Procedure Specification is prepared describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required.

ND-4311.4 Inertia and Continuous Drive Friction Welding

- (a) Inertia and continuous drive friction welding shall not be used for the fabrication of piping.
- (b) The weld between the two members shall be a full penetration weld.

ND-4312 Production Test Plates

If a vessel of welded unalloyed titanium construction incorporates weld joints of Categories A or B, a production test plate of the same specification, grade, and thickness shall be made of sufficient size to provide at least one face and one root bend specimen. Where longitudinal joints are involved, the test plate shall be attached to one end of the longitudinal joint and welded continuously with the joint. Where circumferential joints only are involved, the test plate need not be attached but shall be welded along with the joint. One test plate is required for each vessel by each welder or welding operator working on the vessel, provided not over 100 ft (30.5 m) of Category A or B weld joints are involved. An additional test plate, meeting the same requirement as outlined above, shall be made for each additional 100 ft (30.5 m) of Category A or B weld joints involved. The bend specimens shall be tested in accordance with Section IX. Failure of either bend specimen constitutes rejection of the weld.

ND-4313 Unalloyed Titanium

Unalloyed titanium shall not be welded to other material.

ND-4320 WELDING QUALIFICATIONS, RECORDS, AND IDENTIFYING STAMPS

ND-4321 Required Qualifications

- (a) Each Certificate Holder is responsible for the welding done by his organization and shall establish the procedure and conduct the tests required by this Article and by Section IX in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures.
- (b) Procedures, welders, and welding operators used to join permanent or temporary attachments to pressure parts and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Article.
- (c) When making procedure test plates for butt welds, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. This applies particularly to material and weld metal of 80.0 ksi (552 MPa) tensile strength or higher and heavy sections of both low and high tensile strength material. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.
- (d) NCA-3131 provides specific additional requirements when welding services are subcontracted to or through organizations not holding an appropriate Certificate of Accreditation.

ND-4322 Maintenance and Certification of Records

The Certificate Holder shall maintain a record of his qualified welding procedures and of the welders and welding operators qualified by him, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and signed by any authorized individual assigned by the Certificate Holder, and they shall be accessible to the Owner and to the Inspector.

ND-4322.1 Identification of Joints by Welder or Welding Operator

(a) Each welder or welding operator shall apply the identification mark assigned to him by the Certificate Holder on or adjacent to all permanent welded joints or series of joints on which he welds. The marking shall be at intervals of 3 ft (0.9 m) or less and shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps. As an alternative, the Certificate Holder shall keep a record of permanent welded joints in each item and of the welders and welding operators used in making each of the joints.

Page 240

(b) When a multiple number of permanent structural attachment welds, nonstructural welds, fillet welds, socket welds, welds of specially designed seals, weld metal cladding, hard surfacing and tube-to-tubesheet welds, are made on an item, the Certificate Holder need not identify the welder or welding operator who welded each individual joint, provided:

(1) the Certificate Holder maintains a system that will identify the welders or welding operators who made such welds on each item so that the Inspector can verify that the welders or welding operators were all properly qualified;

(2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification.

(c) The identification of welder or welding operator is not required for tack welds.

ND-4323 Welding Prior to Qualification

No welding shall be undertaken until after the welding procedures which are to be used have been qualified. Only welders and welding operators who are qualified in accordance with ND-4320 and Section IX shall be used.

ND-4324 Transferring Qualifications

The welding procedure qualifications and performance qualification tests for welders and welding operators conducted by one Certificate Holder shall not qualify welding procedures, and shall not qualify welders or welding operators to weld for any other Certificate Holder, except as provided in Section IX, QW-201 and QW-300.2.

ND-4330 GENERAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION TESTS

ND-4331 Conformance to Section IX Requirements

All welding procedure qualification tests shall be in accordance with the requirements of Section IX as supplemented or modified by the requirements of this Article.

ND-4333 Heat Treatment of Qualification Welds for Ferritic Material

Postweld heat treatment of procedure qualification welds shall conform to the applicable requirements of ND-4600 and Section IX. The postweld heat treatment time at temperature shall be at least 80% of the maximum time to be applied to the component weld material. The postweld heat treatment total time may be applied in one heating cycle.

ND-4334 Preparation of Test Coupons and Specimens

(a) Removal of test coupons from the test weld and the dimensions of specimens made from them shall conform to the requirements of Section IX, except that the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with (b) below.

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test

specimens. When each process cannot be included in the full-size impact test specimen at the $\frac{1}{4}t$ location required by this Section, additional full-size specimens shall be obtained from locations in the test weld that will ensure that at least a portion of each process has been included in full-size test specimens. As an alternative, additional test welds can be made with each process so that full-size specimens can be tested for each process.

ND-4334.1 Coupons Representing the Weld Deposits.

Impact test specimens and testing methods shall conform to ND-2321. The impact specimen shall be located so that the longitudinal axis of the specimen is at least $\frac{1}{4}t$ and, where the thickness of the test assembly permits, not less than $\frac{3}{8}$ in. (10 mm) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified in ND-4620, and the test assembly is cooled at an accelerated rate, the longitudinal axis of the specimen shall be a minimum of t from the edge of the test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the weld. The length of the notch of the Charpy V-notch specimen shall be normal to the surface of the weld.

ND-4334.2 Coupons Representing the Heat Affected Zone.

Where impact tests of the heat affected zone are required by ND-4335.2, specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through (c) below.

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented either parallel to or perpendicular to the principal direction of rolling or forging.

Page 241

(b) The heat affected zone impact test specimens and testing methods shall conform to the requirements of ND-2321. The specimens shall be removed from a location as near as practical to a depth midway between the surface and center thickness. The coupons for heat affected zone impact specimens shall be taken transverse to the axis of the weld and etched to define the heat affected zone. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much heat affected zone as possible in the resulting fracture. Where the material thickness permits, the axis of a specimen may be inclined to allow the root of the notch to align parallel to the fusion line. When a grain refining heat treatment is not performed on welds made by the electroslag or electrogas welding process, the notch for the impact specimens shall be located in the grain coarsened region.

(c) For the comparison of heat affected zone values with base material values [ND-4335.2(b)], Charpy V-notch specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the heat affected zone specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the heat affected zone specimens, and the axis of the notch shall be normal to the surface of the base material.

ND-4335 Impact Test Requirements

When materials are required to be impact tested per ND-2300, impact tests of the weld metal and heat affected zone shall be performed in accordance with the following subparagraphs. Exemption from impact testing under ND-2311(a)(8) does not apply to weld metal unless the specific weld metal used is included in Table ND-2311(a)-1. Exemption from impact testing of the heat affected zone of those base materials exempted by ND-2311(a)(8) is not permitted. The weld procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of ND-2330 and ND-4334. Retests in accordance with the provisions of ND-2350 are permitted.

ND-4335.1 Impact Tests of Weld Metal

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding $\frac{5}{8}$ in. (16 mm) in thickness when the weld will be made on the surface or will penetrate the base material that requires impact testing in accordance with ND-2310. In addition, such testing of the weld metal is required for the welding procedure qualification tests for any weld repair to base material that requires impact testing in accordance with ND-2310, regardless of the depth of the repair. Exemption from impact testing under ND-2311(a)(8) does not apply to weld metal of welding procedure qualification tests for either production weld joints or base material repairs unless the specific weld metal used is included in Table ND-2311-1. Weld metal exemptions are being developed.

(b)

same as specified in ND-2330 for the base material to be welded or repaired. Where two materials are to be joined by welding, and have different fracture toughness requirements, the test requirements and acceptance standards of either material may be used for the weld metal, except where otherwise specified by NCA-1280 or other parts of this Section.

(c) A Welding Procedure Specification qualified to the impact testing requirements of Subsection NB, NC, or NE may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection. Use of this alternative shall be identified on the Welding Procedure Qualification Record.

ND-4335.2 Impact Tests of Heat Affected Zone

(a) Charpy V-notch tests of the heat affected zone of the welding procedure qualification test assembly are required whenever the thickness of the weld exceeds $\frac{5}{8}$ in. and either of the base materials require impact testing in accordance with the rules of ND-2310. Exemption of base materials by ND-2311(a)(8) does not apply to the welding procedure qualification heat affected zone or unaffected base material for such materials. The only exceptions to the requirements are the following:

(1) the qualification for welds in P-Nos. 1 and 3 and SA-336 F12 materials that are postweld heat treated and are made by any process other than electroslag, electrogas, or thermit;

(2) the qualification for weld deposit cladding or hard-facing on any base material.

(b) Impact testing of the procedure qualification test heat affected zone, where required by ND-4335, shall be conducted in accordance with (1) through (3) below, and (c) below, if applicable.

(1) For tests of welding procedure qualifications for materials that require testing in accordance with ND-2331, the three Charpy V-notch heat affected zone specimens and three Charpy V-notch unaffected base material specimens shall be tested at a temperature in accordance with ND-2331(a). The Charpy V-notch impact test of the unaffected base material shall meet the toughness value requirements of Table ND-2331(a)-1

Page 242

or Table ND-2331(a)-2. If the average toughness value of the three heat affected zone specimens is equal to or greater than the average toughness value of the unaffected base material Charpy V-notch specimens, the qualification test shall be considered acceptable, and the values and testing temperature shall be recorded on the Welding Procedure Qualification Record.

(2) If the heat affected zone Charpy V-notch average toughness value of (b)(1) above is less than the unaffected base material value and the qualification test meets the other criteria of acceptance, the Charpy V-notch test results may be recorded on the Welding Procedure Qualification Record. Data shall then be obtained, as specified in (3) below, to provide an additive temperature for the adjustment of the lowest service temperature (LST) of the base material that is to be welded in production with the welding procedure that is being qualified. Alternatively, the welding procedure qualification may be rewelded and retested.

(3) The data for use in (b)(2) above shall be developed by performing additional Charpy V-notch tests on either the welding procedure qualification test heat affected zone or the unaffected base material, or both, at temperatures which provide toughness values that meet or exceed those required for the yield strength and thickness of the material to be welded in production. The average toughness data for the heat affected zone and unaffected base material shall be plotted on a property temperature chart. The temperature at which these two sets of data exhibit a common acceptable value of toughness for the production base material shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the heat affected zone. This difference, if a positive number, shall be used in (b)(2) above as the adjustment temperature. The welding procedure adjustment temperature shall be added to the highest LST established by the tests of ND-2331 for all of the base material to be welded by this procedure in production. If the temperature difference is zero or a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by the tests for ND-2331 will still apply as stated in (b)(2) above. Where the actual LST is not required for the production material to be welded, for example, where a testing temperature is established by the Design Specification to determine that the material has adequate toughness to meet the requirements of Table ND-2331(a)-1 or Table ND-2331(a)-2 at the specified test temperature, the adjustment temperature determined by the curves shall be used to establish a reduction in the specified testing temperature for the production material.

The adjustment temperature shall be used to lower the specified testing temperature for any production material on which the procedure will be used.

(c) Should the unaffected base material Charpy V-notch impact test results fail to meet the applicable requirements referenced in (b)(1) above, additional unaffected base material Charpy V-notch impact tests shall be tested at higher temperatures until the applicable requirements are met. Charpy V-notch impact tests of the heat affected zone shall be tested at the same temperature at which acceptable unaffected base material properties were achieved. The rules governing the average toughness values of the heat affected zone relative to the average toughness values of the unaffected base material shall be followed as in (b)(1) through (3) above, to determine the data which are to be recorded in the Welding Procedure Qualification Record.

(d) A Welding Procedure Specification qualified to the impact testing requirements of Subsection NB, NC, or NE may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection.

ND-4336 Qualification Requirements for Built-Up Weld Deposits

Built-up weld deposits for base metal reinforcement shall be qualified in accordance with the requirements of ND-4331 to ND-4335, inclusive.

ND-4350 SPECIAL QUALIFICATION REQUIREMENTS FOR TUBE-TO-TUBESHEET WELDS

ND-4351 General Requirements

The welding procedure for tube-to-tubesheet welds shall be set up as a new procedure specification and shall be completely requalified when any of the changes listed below are made in the procedure. Changes other than those given may be made in a procedure without the necessity of requalification, provided the procedure specification is amended to show these changes.

ND-4352 Essential Variables for All Welding Processes

Essential variables for all welding processes shall be as stipulated in (a) through (k) below:

(a) a change from one welding process to any other welding process or combination of welding processes;

(b) a change in the P-Number classification of tube material in Section IX, QW-422. A separate qualification

Page 243

is required for each tube material which is not included under any P-Number.

(c) a change in the P-Number of the tubesheet base material. The base material may be a homogeneous material or a cladding material of wrought type or weld overlay type. If welding is performed between the tube and cladding, the cladding shall be considered the base material. A separate qualification is required for welding tubes to base material or cladding material which is not included under any P-Number.

(d) changes in the weld metal analysis of the deposited weld metal as given in (1) or (2) below:

(1) a change from any A-Number in Section IX, QW-422 to any other A-Number or to any F-Number in QW-432 or to any analysis not listed in the tables, except that each AISI type similar to A-No. 7 or A-No. 8 of QW-422 shall require separate qualification;

(2) a change from any F-Number in QW-432 to any other F-Number or to any A-Number in QW-422 or to any analysis not listed in the tables;

(e) for tubes of specified wall thickness of 0.100 in. or less, an increase or decrease of 10% of specified wall thickness or specified diameter;

(f) for specified wall thicknesses greater than 0.100 in., only one qualification test is required;

(g)

- (g) a decrease of 10% or more in the specified width of the ligament between tube holes when the specified width of the ligament is less than the greater of $\frac{3}{8}$ in. (10 mm) or three times the specified tube wall thickness;
- (h) the addition of other welding positions than those already qualified (Section IX, QW-461.1);
- (i) a change in the specified preheating temperature range;
- (j) a change in the specified postweld heat treating temperature;
- (k) a change from multiple pass to single pass or vice versa.

ND-4353 Essential Variables for Shielded Metal-Arc Welding

An additional essential variable for shielded metal-arc welding is an increase in electrode diameter.

ND-4354 Essential Variables for Gas Tungsten-Arc and Gas Metal-Arc Welding

Additional essential variables for gas tungsten-arc and gas metal-arc welding are as given in (a) through (f) below:

- (a) a change in the configuration of the tubesheet at the tube hole edges, including the addition or omission of preplaced metal inserts;
- (b) a change in the size or shape of preplaced metal inserts;
- (c) a change from one shielding gas to another shielding gas or to a mixture of shielding gases;
- (d) when using mixed shielding gas, a change of $\pm 25\%$ or 5 cu ft/hr (0.14 m³/hr), whichever is the larger, in the rate of flow of the minor gas constituent;
- (e) for gas tungsten-arc welding process, the addition or omission of filler metal;
- (f) a change in the nominal diameter of the filler metal.

ND-4355 Essential Variables for Explosive Welding

Additional essential variables for explosive welding are as given in (a) through (e) below:

- (a) an increase or decrease in the specified tube wall thickness or diameter of 10% for all diameters and wall thicknesses instead of the provision of ND-4352(e);
- (b) a change in the method of pressure application;
- (c) a change in the type of explosive or a change in energy content of $\pm 10\%$;
- (d) a change of $\pm 10\%$ in the placement of the charge from the tubesheet face;
- (e) a change in the specified clearance between the tube and the tubesheet of $\pm 10\%$.

ND-4356 Test Assembly

The procedure qualification shall be made on a test assembly which simulates the conditions to be used in production with respect to the tube hole pattern and the essential variables listed in ND-4352 through ND-4354. In addition, the thickness of the tubesheet in the test assembly shall be as thick as the production tube sheet, except it need not exceed 2 in. (51 mm). The minimum required number of weld joints shall be 10.

ND-4357 Examination of Test Assembly

The assembly shall be examined by a liquid penetrant method in accordance with the requirements of ND-5110 and shall meet the acceptance standards of ND-5350. Following this, the assembly shall be sectioned longitudinally through each tube. The thickness of the assembly may be reduced to $\frac{1}{2}$ in. (13 mm) prior to this sectioning. The four faces of each tube exposed by sectioning shall be polished and etched with a suitable etchant and shall be visually examined for

cracks. The weld throat minimum leakage path shall be not less than two-thirds of the specified tube wall thickness, and

cracks. The weld throat minimum leakage path shall be not less than two-thirds of the specified tube wall thickness, and the weld shall be free from cracks on visual examination with $\times 10$ magnification.

ND-4358 Performance Qualification

ND-4358.1 Welders.

The requirements for the performance qualification test for welders shall be the same as those for the procedure qualification, except that the minimum required number of tubes in the test assembly shall be six.

ND-4358.2 Welding Operators.

The requirements for the performance qualification test for welding operators (automatic weld process) shall be the same as those for the procedure qualification except that:

- (a) the essential variables for performance qualification are those detailed in ND-4352(a), (b), (c), (d), and (h);
- (b) the minimum required number of tubes in the test assembly shall be six.

ND-4400 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS

ND-4410 PRECAUTIONS TO BE TAKEN BEFORE WELDING

ND-4411 Identification, Storage, and Handling of Welding Materials

Each Certificate Holder is responsible for control of the welding electrodes and other materials which are used in the fabrication and installation of components (ND-4120). Suitable identification, storage, and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by electrodes and flux.

ND-4412 Cleanliness and Protection of Welding Surfaces

The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

ND-4420 RULES FOR MAKING WELDED JOINTS

ND-4421 Backing Rings

Backup plates and backing rings which remain in place, and compression rings or stiffeners of storage tanks such as angles, bars, and ring girders may be used. Their materials shall be compatible with the base metal, but spacer pins shall not be incorporated into the welds.

ND-4422 Peening

Controlled peening may be performed to minimize distortion. Peening shall not be used on the initial layer root of the weld metal or on the final layer unless the weld is postweld heat treated.

ND-4423 Double Welded Joints, Single Welded Joints, and Plug Welds

ND-4423.1 Double Welded Joints.

Before applying weld metal on the second side to be welded, the root of full penetration double welded joints shall be prepared by suitable methods such as chipping, grinding, or thermal gouging, except for those processes of welding by which proper fusion and penetrations are otherwise obtained and demonstrated to be satisfactory by welding procedure qualifications.

ND-4423.2 Single Welded Joints.

Where single welded joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joint for its full length.

ND-4423.3 Plug Welds.

In welding plug welds, a fillet around the bottom of the hole shall be deposited first.

[98]

ND-4424 Surfaces of Welds

As-welded surfaces are permitted, except for inertia and continuous drive friction welding where the flash shall be removed to sound metal. For piping, the appropriate stress intensification factors given in Table ND-3672(b)-1 shall be applied. However, the surface of welds shall be sufficiently free from coarse ripples, grooves, overlaps, abrupt ridges, and valleys to meet the requirements of (a) through (e) below.

(a) The surface condition of the finished weld shall be suitable for the proper interpretation of radiographic and other required nondestructive examination of the weld. In those cases where there is a question regarding

Page 245

the surface condition on the interpretation of a radiographic film, the film shall be compared to the actual weld surface for interpretation and determination of acceptability.

(b) Reinforcements are permitted in accordance with ND-4426.1 for vessels, pumps, and valves, and with ND-4426.2 for piping.

(c) Undercuts shall not exceed $\frac{1}{32}$ in. (0.8 mm) and shall not encroach on the required section thickness.

(d) Concavity on the root side of a single welded circumferential butt weld is permitted when the resulting thickness of the weld meets the requirements of ND-3000.

(e) If the surface of the weld requires grinding to meet the above criteria, care shall be taken to avoid reducing the weld or base material below the required thickness.

(f) For inertia and continuous drive friction welding, the weld upset shall meet the specified amount within $\pm 10\%$.

[98]

ND-4425 Welding Components of Different Diameters

When components of different diameters are welded together, there shall be a gradual transition between the two surfaces. The length of the transition may include the weld in accordance with ND-3361.

ND-4426 Reinforcement of Welds

ND-4426.1 Thickness of Weld Reinforcement for Vessels, Pumps, and Valves.

The surface of the reinforcement of all butt welded joints in vessels, pumps, and valves may be flush with the base material or may have uniform crowns. The height of reinforcement on each face of the weld shall not exceed the thickness in the following tabulation:

Nominal Thickness, in.	Maximum Reinforcement, in.
Up to 1, incl.	$\frac{3}{32}$
Over 1 to 2, incl.	$\frac{1}{8}$
Over 2 to 3, incl.	$\frac{5}{32}$
Over 3 to 4, incl.	$\frac{7}{32}$
Over 4 to 5, incl.	$\frac{1}{2}$

Over 5

$\frac{5}{16}$ ⁴

ND-4426.2 Thickness of Weld Reinforcement for Piping.

For double welded butt joints, the limitation on the reinforcement given in Column 1 of the following tabulation shall apply separately to both inside and outside surfaces of the joint. For single welded butt joints, the reinforcement given in Column 2 shall apply to the inside surface and the reinforcement given in Column 1 shall apply to the outside surface. The reinforcement shall be determined from the higher of the abutting surfaces involved.

Material Nominal Thickness, in.	Maximum Reinforcement Thickness, in.	
	Column 1	Column 2
Up to $\frac{1}{8}$ incl.	$\frac{3}{32}$	$\frac{3}{32}$
Over $\frac{1}{8}$ to $\frac{3}{16}$ incl.	$\frac{1}{8}$	$\frac{3}{32}$
Over $\frac{3}{16}$ to $\frac{1}{2}$ incl.	$\frac{5}{32}$	$\frac{1}{8}$
Over $\frac{1}{2}$ to 1, incl.	$\frac{3}{16}$	$\frac{5}{32}$
Over 1 to 2, incl.	$\frac{1}{4}$	$\frac{5}{32}$
Over 2	The greater $\frac{1}{4}$ in. or $\frac{1}{8}$ times the width of the weld, in.	$\frac{5}{32}$

ND-4427 Shape and Size of Fillet Welds

(a) Fillet welds may vary from convex to concave. Except as permitted in (b) below, the shape and size of the weld shall be in accordance with the requirements of Fig. ND-4427-1. A fillet weld in any single continuous weld may be less than the specified fillet weld dimension by not more than $\frac{1}{16}$ in. (1.6 mm), provided that the total undersize portion of the weld does not exceed 10% of the length of the weld. Individual undersize weld portions shall not exceed 2 in. (51 mm) in length. In making socket welds, a gap as shown in Fig. ND-4427-1 shall be provided prior to welding. The gap need not be present nor be verified after welding.

(b) Socket welds smaller than those specified in Fig. NC-4427-1 may be used provided the requirements of NC-3000 are met.

ND-4428 Seal Welds of Threaded Joints

Where seal welding of threaded pipe joints is performed, the exposed threads shall be either removed entirely or covered with weld metal.

ND-4430 WELDING OF ATTACHMENTS

ND-4431 Materials for Attachments

Nonpressure-retaining attachments (ND-1132.1) welded to pressure retaining components shall be of materials which meet the requirements of ND-2190.

Page 246

Page 247

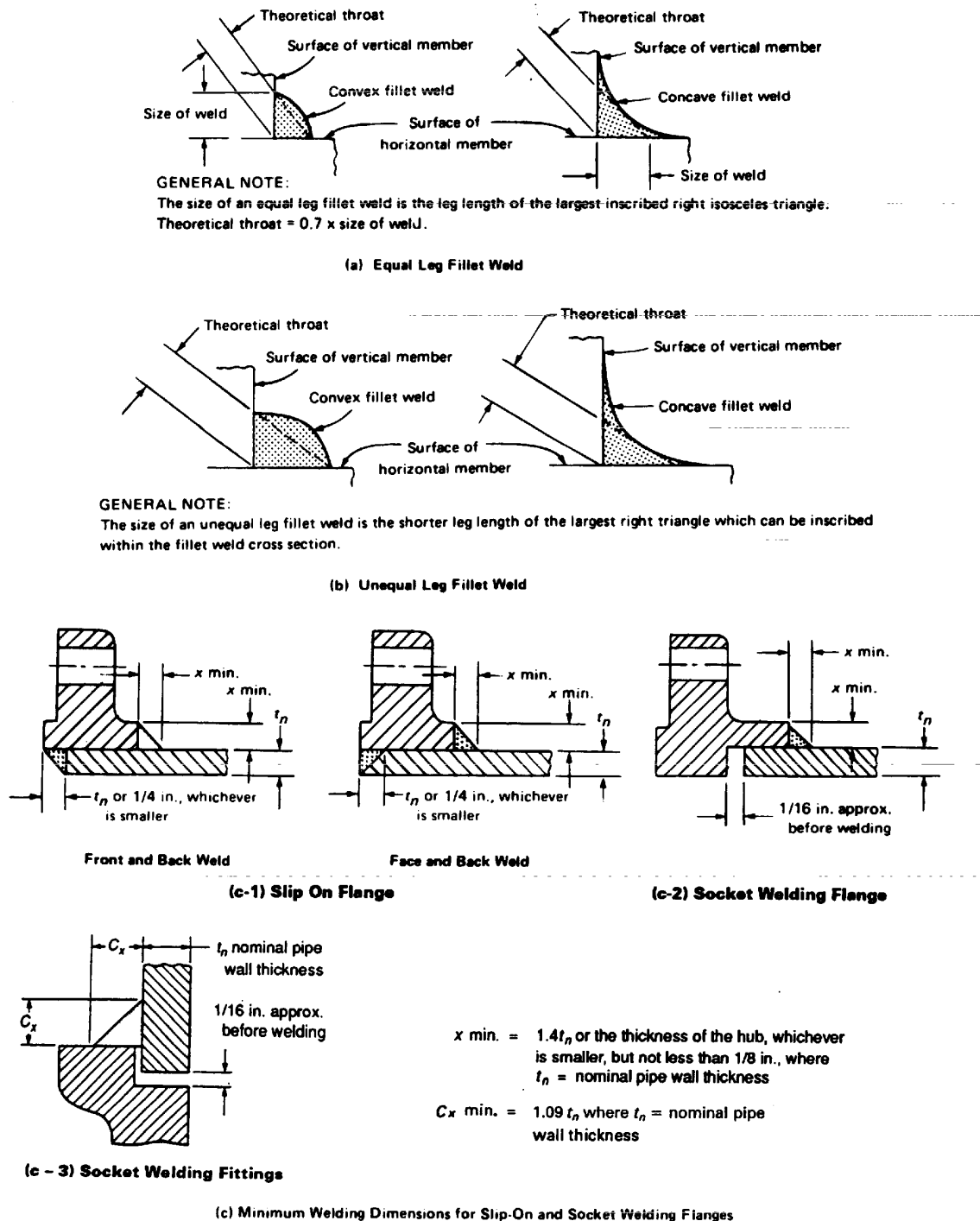


FIG. ND-4427-1 FILLET AND SOCKET WELD DETAILS AND DIMENSIONS

FIG. ND-4427-1 FILLET AND SOCKET WELD DETAILS AND DIMENSIONS

Materials for pressure retaining attachments shall meet the requirements of ND-2120.

ND-4432 Welding of Structural Attachments

The rules of ND-4321 governing welding qualifications shall apply to the welding of structural attachments to pressure retaining material.

ND-4433 Structural Attachments

Structural attachments shall conform reasonably to the curvature of the surface to which they are to be attached and shall be attached by full penetration, fillet, or partial penetration continuous or intermittent welds. Figure ND-4433-1 illustrates some of the typical details for attaching structural attachments to a component using full penetration welds. Valve seats may be attached to the pressure boundary part by fillet or partial penetration welds, provided the valve seat is shouldered against the pressure boundary part.

ND-4434 Types of Permanent Structural Attachments

Internal structural supports on cladding surfaces shall be welded to the base metal and not to the cladding, except for weld overlay cladding.

ND-4435 Welding of Nonstructural and Temporary Attachments and Their Removal

(a) Nonstructural attachments (ND-1132.1) welded to the pressure retaining portion of the component need not comply with ND-2000 and may be welded with continuous or intermittent fillet or partial penetration welds, provided the requirements of (1) through (4) below are met.

(1) The welding procedure and the welders have been qualified in accordance with ND-4321.

(2) The material is identified and is compatible with the material to which it is attached.

(3) The welding material is identified and is compatible with the materials joined.

(4) The welds are postweld heat treated when required by ND-4620.

(b) Removal of nonstructural attachments, when temporary, shall be accomplished as follows:

(1) The temporary attachment is completely removed in accordance with the procedures of ND-4211;

(2) As an alternative to (a)(4) above, postweld heat treatment may be deferred until after removal of the attachment.

ND-4436 Installation of Attachments to Piping Systems After Testing

Attachments may be welded to the piping system after performance of the pressure test provided that:

(a) the welds do not require PWHT as provided in ND-4622.7;

(b) welds shall be restricted to fillet welds not exceeding $\frac{3}{8}$ in. (10 mm) throat thickness and to full penetration welds attaching materials not exceeding $\frac{1}{2}$ in. (13 mm) in thickness;

(c) welds shall not exceed a total length of 24 in. (610 mm) for fillet welds or 12 in. (305 mm) for full penetration welds;

(d) welds shall be examined as required by ND-5000.

ND-4437 Attachments of Stiffener Rings

ND-4437.1 General Requirements.

All permanent and temporary attachments of stiffener rings to shells, including tack welds, shall be made by qualified welders using qualified welding procedures.

ND-4437.2 Attachment of Stiffening Rings to Shell

(a) Stiffening rings, when used, may be placed on the inside or outside of a vessel and shall be attached to the shell by welding or bolting. The ring shall be in contact with the shell.

(b) Stiffening rings may be attached to the shell by either continuous or intermittent welding. The total length of the intermittent welding on each side of the stiffening ring shall be:

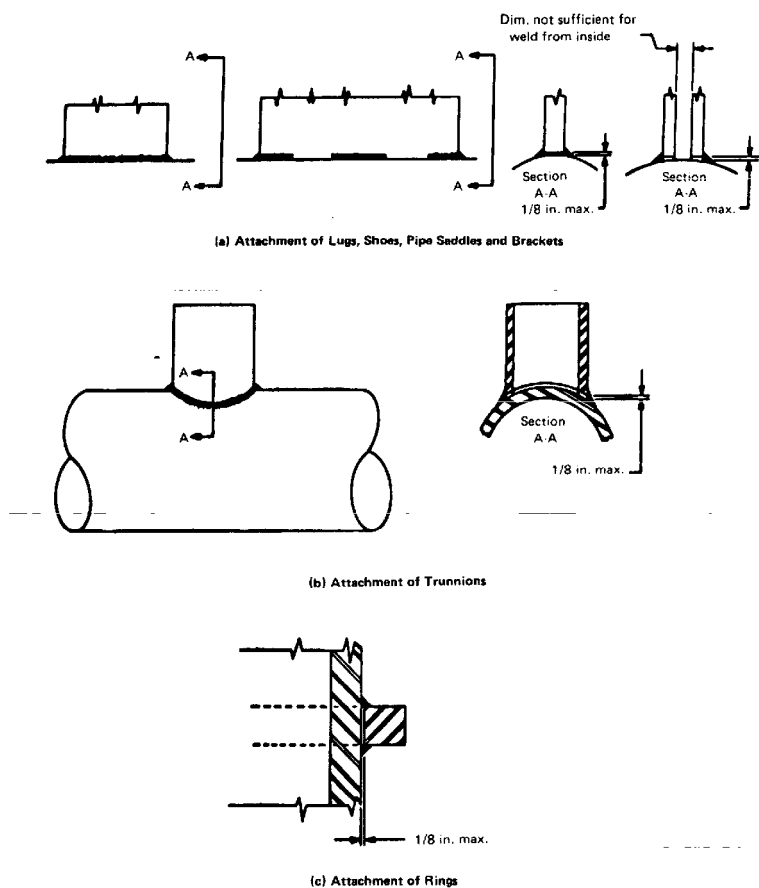
- (1) not less than one-half the outside circumference of the component for rings on the outside; and
- (2) not less than one-third of the circumference of the vessel for rings on the inside.

Acceptable arrangements and spacings of intermittent welds are shown in Fig. ND-4437.2(b)-1. Welds on opposite sides of the stiffener may be either staggered or in-line as indicated.

(c) All welding of stiffening rings shall comply with the requirements of this Subsection. In areas where a corrosion allowance is specified in the Design Specification, stiffening rings shall be attached to the shell with a continuous fillet weld, seal weld, or full penetration weld.

Page 248

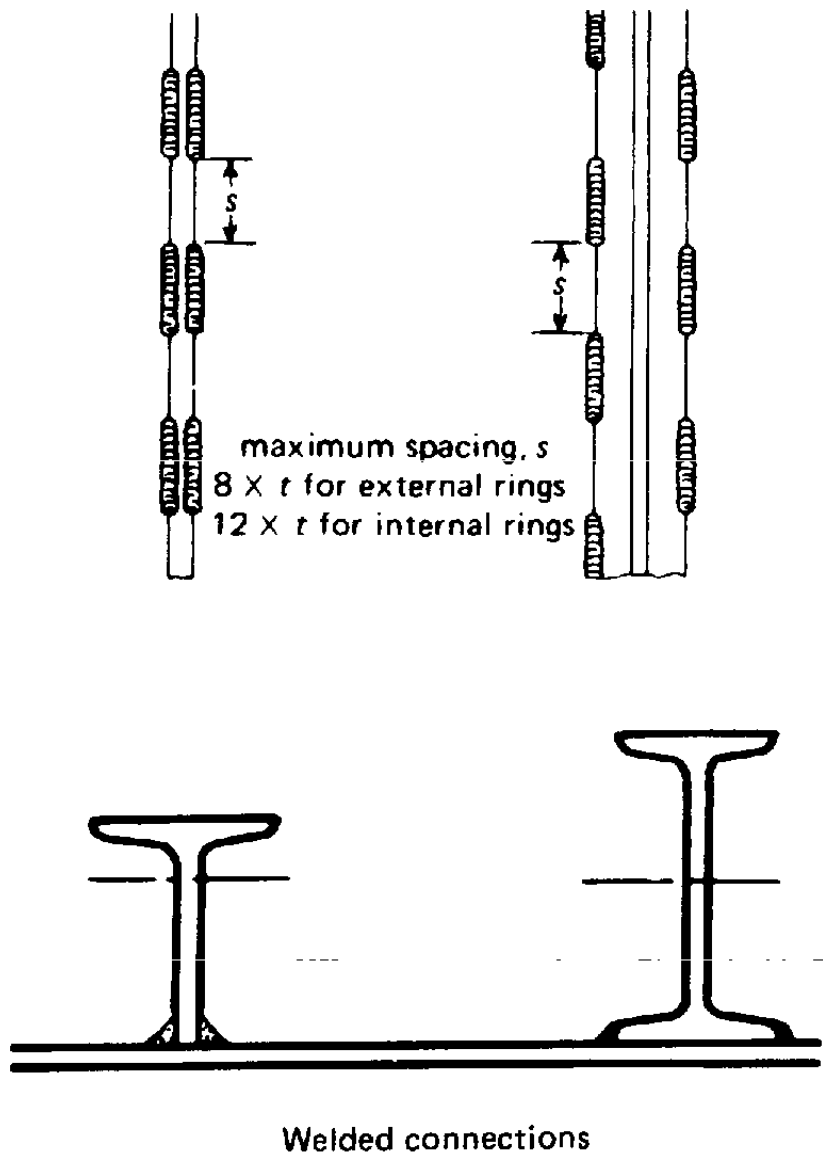
Page 249



GENERAL NOTE:
The welds may be partial penetration or fillet welds.

FIG. ND-4433-1 TYPES OF ATTACHMENT WELDS

FIG. ND-4433-1 TYPES OF ATTACHMENT WELDS



**FIG. ND-4437.2(b)-1 SOME ACCEPTABLE
METHODS OF ATTACHING STIFFENING RINGS
TO SHELLS OF CYLINDRICAL VESSELS
SUBJECTED TO EXTERNAL PRESSURE**

FIG. ND-4437.2(b)-1 SOME ACCEPTABLE METHODS OF ATTACHING STIFFENING RINGS TO SHELLS OF CYLINDRICAL VESSELS SUBJECTED TO EXTERNAL PRESSURE

ND-4450 REPAIR OF WELD METAL DEFECTS

ND-4451 General Requirements

Defects in weld metal detected by the examinations required by ND-5000, or by the tests of ND-6000, shall be eliminated and repaired when necessary.

ND-4452 Elimination of Surface Defects

Weld metal surface defects may be removed by grinding or machining and not repaired by welding, provided that the requirements of (a), (b), and (c) below are met.

(a) The remaining thickness of the section is not reduced below that required by ND-3000.

(b) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(c) The area is examined by a magnetic particle or liquid penetrant method in accordance with ND-5110 after blending and meets the acceptance standards of ND-5300 to ensure that the defect has been removed or the indication reduced to an acceptable limit. Defects detected by visual or volumetric method and located on an interior surface need only be reexamined by the method which initially detected the defect when the interior surface is inaccessible for surface examination.

ND-4453 Requirements for Making Repairs of Welds

Excavations in weld metal, when repaired by welding, shall meet the requirements of the following subparagraphs.

ND-4453.1 Defect Removal.

Defects may be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined by a liquid penetrant or magnetic particle method in accordance with ND-5110 and meet the acceptance standards of ND-5340 or ND-5350. This examination is not required where defect elimination removes the full thickness of the weld and where the backside of the weld joint is not accessible for removal of examination materials.

ND-4453.2 Requirements for Welding Material, Procedures, and Welders.

The weld repair shall be made using welding materials, welders, and welding procedures qualified in accordance with ND-4125 and ND-4300.

ND-4453.3 Blending of Repaired Areas.

After repair the surface shall be blended uniformly into the surrounding surface.

ND-4453.4 Examination of Repair Welds

(a) The examination of a weld repair shall be repeated as required for the original weld, except that it need only be reexamined by the liquid penetrant or magnetic particle method when the unacceptable indication was originally detected by the liquid penetrant or magnetic particle method and when the repair cavity does not exceed the following:

(1) $\frac{1}{3}t$ for $t \leq \frac{3}{4}$ in. (19 mm)

(2) $\frac{1}{4}$ in. (6 mm) for $\frac{3}{4}$ in. (19 mm) $< t \leq 2\frac{1}{2}$ in. (64 mm)

(3) the lesser of $\frac{3}{8}$ in. (10 mm) or $10\%t$ for $t > 2\frac{1}{2}$ in. (64 mm)

where t equals the thickness of the weld.

(b) When repairs to welds joining P-No. 1 and P-No. 3 materials require examination by radiography as required in (a)

above, but construction assembly prevents meaningful radiographic examination, ultrasonic examination may be substituted, provided:

(1) the weld had been previously radiographed and met the applicable acceptance standards:

Page 250

(2) the ultrasonic examination is performed using a procedure in accordance with Section V, Article 5 to the acceptance standards of ND-5330;

(3) the substitution is limited to Category A and B welds in vessels and similar type welds in other items.

The absence of suitable radiographic equipment is not justification for the substitution.

ND-4453.5 Heat Treatment of Repaired Areas.

The area shall be heat treated in accordance with ND-4620.

ND-4460 WELDED TEST PLATES

(a) For welded vessels constructed of Type 405 material which are not postweld heat treated, welded test plates shall be made to include material from each melt of plate steel used in the vessel. Plates from two different melts may be welded together and be represented by a single test plate.

(b) From each welded test plate there shall be taken two face bend test specimens as prescribed in Section IX, QW-161.2 and shall meet the requirements of Section IX, QW-162 and QW-163.

ND-4470 WELDED STAYED CONSTRUCTION

Welded staybolts must be attached using details similar to those shown in Fig. ND-4470-1, where t equals the nominal thickness of the inner stayed plate.

ND-4500 BRAZING

ND-4510 RULES FOR BRAZING

ND-4511 Where Brazing May Be Used

(a) Brazing is permitted for the attachment of tubes to tubesheets and as specified in ND-3671.6. Appurtenances and piping with outside diameter equal to that of NPS 4 and less may be fabricated using brazed joints in accordance with Fig. ND-4511-1.

(b) Valves with inlet piping connections of NPS 4 (DN 100) and less may have seats brazed to the valve body or bonnet, provided the seat is shouldered against the pressure boundary part.

ND-4512 Brazing Material

Where brazing is permitted, the brazing filler material and fluxes shall conform to the rules covering identification in ND-2150 and to the requirements of (a), (b), and (c) below.

(a) The filler material used in brazing shall be a nonferrous metal or alloy with a solidus temperature above 800°F (427°C) and at least 500°F (278°C) above the highest temperature of the joint in service.

(b) The filler material shall melt and flow freely by capillary action within the desired temperature range, and in conjunction with a suitable flux or controlled atmosphere the filler material shall wet and adhere to the surfaces to be joined.

(c) Fluxes that are fluid and chemically active at the brazing temperature shall be used, when necessary, to prevent oxidation of the filler metal and the surfaces to be joined, and to promote free flowing of the filler material.

ND-4520

ND-4520 BRAZING QUALIFICATION REQUIREMENTS

ND-4521 Brazing Procedure and Performance Qualifications

Qualification of the brazing procedure to be used and of the performance of brazers and brazing operators is required and shall comply with the requirements of Section IX, except that validation of the procedure qualification per QB-451.5 Note (1) is not required for the furnace brazing of seat rings to bodies or bonnets of valves having inlet piping connections of 4 in. (DN 100) nominal size and less. When the Design Temperature is greater than 200°F (93°C), tension testing shall be performed at the Design Temperature.

ND-4522 Brazing Requalification Requirements

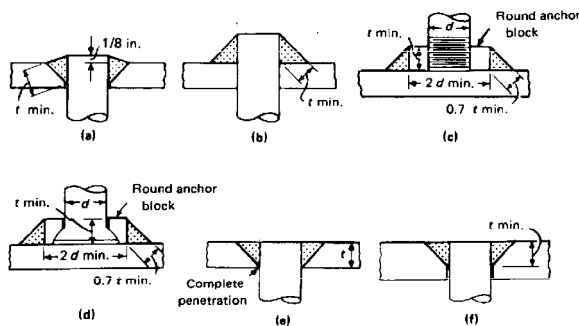
In addition to the requirements of Section IX, the brazing procedure shall be set up as a new procedure specification and shall be completely requalified when the construction of the brazed components includes reheating of any portion of the completed brazed joint to a temperature that is within 300°F (167°C) of the solidus temperature of the filler metal.

ND-4530 FITTING AND ALIGNING OF PARTS TO BE BRAZED

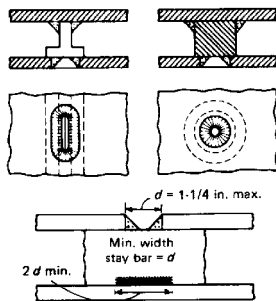
Parts to be joined by brazing shall be fitted, aligned, and retained in position during the brazing operation

Page 251

Page 252



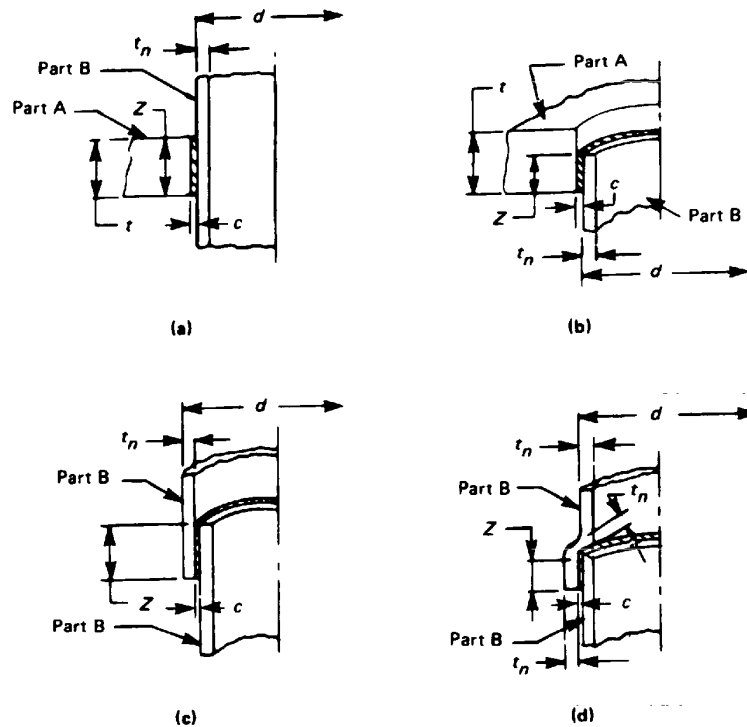
Typical Forms of Welded Staybolts



Use of Plug and Slot Welds for Staying Plates

FIG. ND-4470-1 WELDED STAYED CONSTRUCTION

within the tolerances specified in the brazing procedure specification. Brazed joints shall be assembled in a sequence which will permit the maximum number of joints to be visually examined on both sides of the joint after brazing.



- t = thickness of part penetrated
 t_n = nominal thickness of connecting part
 d = outside diameter of part B
 c = clearance or interference between mating parts and shall be in accordance with the brazing procedure specification
 Z = depth of engagement and shall be the lesser of $3t_n$ or d , but in no case less than 1/4 in.

GENERAL NOTES:

- (a) Part A shall be attached to a component in accordance with the requirements for the component proper.
 (b) Part B shall be attached either to part A or to another part B by the joints shown above, or in accordance with the requirements of the component proper.
 (c) Grooves for preplaced filler metal are permitted, provided the reduction in cross section due to the grooves is considered in the design.

FIG. ND-4511-1 BRAZED CONNECTIONS FOR APPURTENANCES AND PIPING, 4 in. NOMINAL PIPE SIZE AND LESS

FIG. ND-4511-1 BRAZED CONNECTIONS FOR APPURTENANCES AND PIPING, 4 in. NOMINAL PIPE SIZE AND LESS

ND-4540 EXAMINATION OF BRAZED JOINTS

The completed brazed joints shall be visually examined on all accessible surfaces in accordance with ND-5360.

ND-4600 HEAT TREATMENT

ND-4610 WELDING PREHEAT REQUIREMENTS

ND-4611 When Preheat Is Necessary

The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, elevated temperature, physical properties, and material thicknesses. Some practices used for preheating are given in Appendix D as a general guide for the materials listed by P-Numbers of Section IX. It is cautioned that the preheating suggested in Appendix D does not necessarily ensure satisfactory completion of the welded joint and that the preheating requirements for individual materials within the P-Number listing may be more or less restrictive. The Welding Procedure Specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.

ND-4612 Preheating Methods

Preheat for welding or thermal cutting, when employed, may be applied by any method which does not harm the base material or any weld metal already applied or which does not introduce deleterious material into the welding area.

ND-4613 Interpass Temperatures

Consideration shall be given to the limitations of interpass temperatures for quenched and tempered material to avoid detrimental effects on the mechanical properties.

ND-4620 POSTWELD HEAT TREATMENT

ND-4621 Heating and Cooling Methods

Postweld heat treatment (PWHT) may be accomplished by any suitable methods of heating and cooling, provided the required heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control are maintained.

ND-4622 PWHT Time and Temperature Requirements

ND-4622.1 General Requirements.⁴

Except as otherwise permitted in ND-4622.7, all welds, including repair welds, shall be postweld heat treated. During postweld heat treatment, the metal temperature shall be maintained within the temperature range and for the minimum holding time specified in Table ND-4622.1-1, except as otherwise permitted in ND-4622.4(d). For P-No. 11A, Group 1 material, the complete component shall be postweld heat treated within the temperature range specified in Table ND-4622.1-1 and the provisions of ND-4624.2 and ND-4624.3 shall not be applied. P-Number groups in Table ND-4622.1-1 are in accordance with Section IX, QW-420. Except as provided in ND-4624.3, PWHT shall be performed in temperature-surveyed and -calibrated furnaces, or PWHT shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. In addition, the requirements of the following subparagraphs shall apply.

ND-4622.2 Time-Temperature Recordings.

Time-temperature recordings of all postweld heat treatments shall be made available for review by the Inspector. Identification on the time-temperature recording shall be to the weld, item, part, or component. A summary of the

Identification on the time-temperature recording shall be to the weld, item, part, or component. A summary of the time-temperature recording may be provided for permanent records in accordance with NCA-4134.17.

4 Any postweld heat treatment time which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

ND-4622.3 Definition of Nominal Thickness Governing PWHT.

Nominal thickness in Table ND-4622.7(b)-1 is the thickness of the weld, the pressure retaining material for structural attachment welds or the thinner of the pressure retaining materials being joined, whichever is least. It is not intended that nominal thickness include material provided for forming allowance, thinning, or mill overrun when the excess material does not exceed $\frac{1}{8}$ in. (3.2 mm). For fillet welds the

Page 254

Page 255

TABLE ND-4622.1-1
MANDATORY REQUIREMENTS FOR POSTWELD HEAT TREATMENT OF WELDS¹

P-No. (Section IX, QW-420)	Holding Temperature Range, °F [Note (2)]	Minimum Holding Time at Temperature for Weld Thickness (Nominal)			
		$\frac{1}{2}$ in. or less	Over $\frac{1}{2}$ in. to 2 in.	Over 2 in. to 5 in.	Over 5 in.
1, 3	1100–1250	30 min	1 hr/in.	2 hr plus 15 min each additional inch over 2 in.	2 hr plus 15 min each additional inch over 2 in.
4	1100–1250	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
5A, 5B, 5C, 6 except P-No. 6 Gr. 4	1250–1400	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
6 Gr. 4	1050–1150				
7	1300–1400	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
9A Gr. 1	1100–1250	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
9B Gr. 1	1100–1175				
10C Gr. 1 10F Gr. 1	1100–1250	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
10I Gr. 1	1300–1400				
11A Gr. 4	1000–1050	30 min	1 hr/in.	1 hr/in.	1 hr/in.
P-Nos. 8, 10H Gr. 1, 34, 42, 43, 45, and hard surfacing on P-No. 1 base metal whose reported carbon content is not more than 0.30%, and all nonferrous materials	...	PWHT neither required nor prohibited			

NOTES:

- (1) Exemptions to the mandatory requirements of this Table are defined in ND-4622.7.
(2) All temperatures are metal temperatures.

TABLE ND-4622.1-1 MANDATORY REQUIREMENTS FOR POSTWELD HEAT TREATMENT OF WELDS¹

nominal thickness is the throat thickness, and for partial penetration and material repair welds the nominal thickness is the depth of the weld groove or preparation.

TABLE ND-4622.4(c)-1 ALTERNATIVE HOLDING TEMPERATURES AND TIMES¹

Material P-Nos.	Alternative Minimum Holding Temperatures, °F	Alternative Minimum Holding Times
1, 3, 9A Gr.1, 9B Gr.1	1050	2 hr/in. thick
1, 3, 9A Gr.1, 9B Gr.1	1000	4 hr/in. thick

NOTE:

(1) All other requirements of ND-4622 shall apply.

TABLE ND-4622.4(c)-1 ALTERNATIVE HOLDING TEMPERATURES AND TIMES¹

ND-4622.4 Holding Times at Temperature

(a) The holding time at temperature as specified in Table ND-4622.1-1 shall be based on the nominal thickness of the weld. The holding time need not be continuous. It may be an accumulation of the times of multiple postweld heat treat cycles.

(b) Holding time at temperature in excess of the minimum requirements of Table ND-4622.1-1 may be used, provided that specimens so heat treated are tested in accordance with ND-2200, ND-2400, and ND-4300.

(c) Alternatively, when it is impractical to postweld heat treat at the temperature range specified in Table ND-4622.1-1, it is permissible to perform the postweld heat treatment of certain materials at lower temperatures for longer periods of time in accordance with Table ND-4622.4(c)-1 and (1), (2), and (3) below.

(1) Except for P-No. 1 materials, when welds in the materials listed in Table ND-4622.4(c)-1 are to be postweld heat treated at these lower minimum temperatures, the impact test specimens for the welding procedure qualification required by ND-4300 shall be made using the same minimum temperatures and increased minimum holding time. Welding procedures, qualified at the temperature range and minimum holding time specified in Table ND-4622.1-1 and at the lower minimum temperature and increased minimum holding time permitted by Table ND-4622.4(c)-1, are

and at the lower minimum temperature and increased minimum holding time permitted by Table ND-4622.4(c)-1, are also qualified for any temperature in between. When such an in-between temperature is used, the minimum holding time shall be interpolated from Table ND-4622.1-1 and the alternative requirements of Table ND-4622.4(c)-1.

(2) Except for P-No. 1 materials, when welds in the materials listed in Table ND-4622.4(c)-1 are to be postweld heat treated at these lower minimum temperatures, the welding material certification required by ND-2400 shall be made using the same minimum temperature and increased minimum holding times. Welding material certified at the temperature range and minimum holding time specified in Table ND-4622.1-1 and at the lower minimum temperatures and increased minimum holding times permitted by Table ND-4622.4(c)-1 are also certified for any temperature in between.

(3) Base material certified in accordance with ND-2200 may be postweld heat treated at the lower minimum temperatures and increased minimum holding times without recertification. Postweld heat treatment at these lower minimum temperatures and increased minimum holding times may also be the tempering operation, provided a higher tempering temperature is not required by the material specification.

ND-4622.5 PWHT Requirements When Different P-Number Materials Are Joined.

When pressure retaining materials of two different P-Number groups are joined by welding, the applicable postweld heat treatment shall be that specified in Table ND-4622.1-1 for the material requiring the higher PWHT temperature range.

ND-4622.6 PWHT Requirements for Nonpressure-Retaining Parts.

When nonpressure-retaining material is welded to pressure retaining material, the postweld heat treatment temperature range of the pressure retaining material shall control.

ND-4622.7 Exemptions to Mandatory Requirements.

Postweld heat treatment in accordance with this Subarticle is not required for (a) through (d) below:

(a) nonferrous material⁵

(b) welds exempted in Table ND-4622.7(b)-1;

(c) welds subjected to temperatures above the PWHT temperature range specified in Table ND-4622.1-1, provided the Welding Procedure Specification is qualified in accordance with Section IX and the base material and the deposited weld material have been heat treated at the higher temperatures;

(d) welds connecting nozzles to components or branch to run piping, provided the requirements in ND-4622.8 are met;

(e) weld repairs to P-No. 3 material in vessels, provided the requirements of ND-4622.9 are met.

⁵ PWHT shall be performed only by agreement between the Owner and the Certificate Holder, except for casting SB-148 alloy CD954. Agreement shall cover time, temperature, and method of PWHT.

**TABLE ND-4622.7(b)-1
EXEMPTIONS TO MANDATORY PWHT¹**

P-No. (Sect. IX, QW-420)	Type of Weld [Note (5)]	Nominal Thickness (ND-4622.3)	Max. Reported Carbon, % [Note (6)]	Min. Preheat Req'd., °F
1	All welds, where the materials being joined are 1½ in. and less	1¼ in. and less	0.30 and less	...
		Over 1¼ in. to 1½ in.	0.30 and less	200
		¾ in. or less	Over 0.30	...
		Over ¾ in. to 1½ in.	Over 0.30	200
	All welds in material over 1½ in.	¾ in. or less	...	200
1 Gr. 1 or Gr. 2	Cladding or repair of cladding [Note (2)] with A-No. 8 or F-No. 43 filler metal in base material of: 1½ in. or less	...	0.30	100
	Over 1½ in. to 3 in.	...	0.30	200 [Note (3)]
	Over 3 in.	...	0.30	250 [Note (4)]
3	For vessel repair without required PWHT, see NC-4622.9	...	...	350
3 Except Gr. 3	All welds, except repair welds in vessels, provided weld procedure qualification is made using equal or greater thickness base material than production weld	⅝ in. or less	0.25 or less	200
	Attachment welds joining nonpressure-retaining material to pressure retaining material	½ in. or less	0.25 or less	200
	Circumferential butt welds in pipe and tubes	½ in. or less	0.25 or less	200
4	Circumferential butt welds or socket welds in pipe and tubes with nominal O.D. 4 in. or less and attachment welds	½ in. or less	0.15 or less	250
5A, 5B, 5C	Circumferential butt welds or socket welds in pipe and tubes with maximum, reported chromium 3.00% or less and nominal O.D. 4 in. or less and attachment welds	½ in. or less	0.15 or less	300
6 (for type 410) or 7 Gr. 1 (for type 405)	Type 405 and 410S welded with A-No. 8, A-No. 9, or F-No. 43 filler metal	⅜ in. or less	0.08 or less	...

[98]

TABLE ND-4622.7(b)-1 EXEMPTIONS TO MANDATORY PWHT¹

**TABLE ND-4622.7(b)-1 (CONT'D)
EXEMPTIONS TO MANDATORY PWHT¹**

P-No. (Sec. IX, QW-420)	Type of Weld [Note (5)]	Nominal Thickness (ND-4622.3)	Max. Reported Carbon, % [Note (6)]	Min. Preheat Req'd., °F
9A Gr. 1	All welds, provided the procedure qualification is made using equal or greater thickness base material than the production weld	$\frac{5}{8}$ in. or less	...	200
	Attachment welds joining nonpressure-retaining material to pressure retaining material over $\frac{5}{8}$ in.	$\frac{1}{2}$ in. or less	...	200
	Circumferential butt welds or socket welds in pipe and tubes with nominal O.D. 4 in. or less, and attachment welds	$\frac{1}{2}$ in. or less	0.15 or less	250
9B Gr. 1	All welds, provided the procedure qualification is made using equal or greater thickness base material than the production weld	$\frac{5}{8}$ in. or less	...	200
	Attachment welds joining nonpressure-retaining material to pressure retaining material over $\frac{5}{8}$ in.	$\frac{1}{2}$ in. or less	...	200
10C Gr. 1	All welds, including repair welds, in material $1\frac{1}{2}$ in. and less	$1\frac{1}{4}$ in. and less	0.30 and less	...
		Over $1\frac{1}{4}$ in. to $1\frac{1}{2}$ in.	0.30 and less	200
		$\frac{3}{4}$ in. or less	Over 0.30	...
		Over $\frac{3}{4}$ in. to $1\frac{1}{2}$ in.	Over 0.30	200
	Fillet, partial penetration, and repair welds in material over $1\frac{1}{2}$ in.	$\frac{3}{4}$ in. or less	...	200
10I Gr. 1	All welds in material $\frac{1}{2}$ in. and less	$\frac{1}{2}$ in. or less	...	...
11A Gr. 1	All welds in material 2 in. and less	2 in. or less	...	...
11A Gr. 4	All welds in material $\frac{1}{2}$ in. and less	$\frac{1}{2}$ in. or less	...	250

NOTES:

(1) The exemptions noted in this Table do not apply to the following:

(a) electron beam welds in ferritic materials of $\frac{1}{8}$ in. in thickness;

(b) inertia and friction welds in material of any thickness of P-No. 3, P-No. 4, P-No. 5, P-No. 7 (except for Types 405 and 410 S), P-No. 10, and P-No. 11 materials.

(2) Maximum process heat input = 150,000 J/in. The maximum resulting hardness of the heat affected zone in the procedure qualification test plate shall not exceed 35 Rc.

(3) Intermediate postweld soak at not less than 200°F for 2 hr minimum.

(4) Intermediate postweld soak at not less than 300°F for 2 hr minimum.

(5) Where the thickness of material is identified in the Type of Weld column, it is the thickness of the base material at the welded joint.

(6) Carbon level of the pressure retaining materials being joined.

[98]

TABLE ND-4622.7(b)-1 (CONT'D) EXEMPTIONS TO MANDATORY PWHT¹

ND-4622.8 Requirements for Exempting PWHT of Nozzles to Component Welds and Branch-to-Run Piping Welds.

Welds connecting nozzles or branch piping of P-No. 1 materials to components or run piping of P-No. 1 or P-No. 3 materials that are not exempted from PWHT in Table ND-4622.7(b)-1 need not be given a postweld heat treatment if the requirements of (a) below are met for partial penetration and (b) below are met for full penetration welds.

(a) The partial penetration welds are made with A-No. 8 or non-air-hardening nickel-chromium-iron weld metal after:

(1) the ferritic materials to be joined are buttered or built up with A-No. 8 or non-air-hardening nickel-chromium-iron weld metal having a minimum thickness of $\frac{1}{4}$ in., and

(2) the heat affected zones of the buttered or built-up ferritic materials are postweld heat treated in accordance with ND-4620, without the PWHT exemptions being applied, prior to making the final welds.

(b) The full penetration welds are made with A-No. 1 or A-No. 2 weld metal, provided that:

(1) the component or run pipe is built up or buttered in the area of the attachment with A-No. 1 or A-No. 2 metal having a minimum thickness of $\frac{1}{4}$ in.;

(2) the A-No. 1 or A-No. 2 weld metal buildup or buttering is postweld heat treated in accordance with ND-4620 for P-No. 1 or P-No. 3 materials without the PWHT exemptions being applied;

(3) the welds do not penetrate through the component or run pipe thickness;

(4) weld metal with A-No. 1 or A-No. 2 analysis is used to join the nozzle or branch pipe of P-No. 1 material to the weld buildup or buttering;

(5) the nominal thickness of the weld joining the nozzle or branch pipe to the component or run pipe does not exceed $1\frac{1}{2}$ in. (38 mm), and the maximum reported carbon content of the nozzle or branch piping connection does not exceed 0.30%;

(6) a 200°F (93°C) minimum heat is maintained during welding whenever the nominal thickness of the weld exceeds:

(a) $1\frac{1}{4}$ in. (32 mm) and the maximum reported carbon content of the material of the nozzle or branch pipe is 0.30% or less; or

(b) $\frac{3}{4}$ in. (19 mm) and the maximum reported carbon content of material of the nozzle or branch pipe connection exceeds 0.30%.

ND-4622.9 Weld Repair to Vessels.

Limited weld repairs to vessels of P-No. 3 material and A-No. 1, 2, 10, or 11 weld filler metal (Section IX, QW-422) may be made without PWHT or after the final PWHT, provided the following requirements are met.

(a) *Examination of Area to Be Repaired.* Before a repair is made, the area shall be examined by magnetic particle or liquid penetrant method in accordance with ND-5110 and this Subsection and shall meet the acceptance standards of ND-5340 or ND-5350, as appropriate.

(b) *Maximum Extent of Repairs.* A repair shall not exceed 10 sq in. (6452 mm²) in surface area and shall not be greater in depth than 50% of the base metal or weld thickness or $\frac{1}{2}$ in. (13 mm), whichever is less.

(c) *Repair Welding Procedure*

(1) The repairs shall be made using one or more procedures and welders qualified in accordance with Section IX using the shielded metal arc process and low hydrogen covered electrodes.

(2) The largest electrode diameter shall be $\frac{5}{32}$ in. (4 mm), and the bead width shall not exceed four times the electrode diameter.

(3) The repair weld shall be made with a minimum of two layers of weld metal. The last layer shall be limited or ground off so that the weld surface does not extend above the base metal a greater distance than that allowed for reinforcement of butt welds.

(4) A preheat and interpass temperature of 300°F (149°C) minimum shall be used.

(d) *Examination of Repair Welds.* Following the repair and when the area has reached ambient temperature, the area shall again be examined by magnetic particle methods and accepted in accordance with ND-4622.9(a).

ND-4623 PWHT Heating and Cooling Rate Requirements

Above 800°F (427°C) the rate of heating and cooling in any hourly interval shall not exceed 400°F (222°C) divided by the maximum thickness in inches of the material being heat treated, but shall not exceed 400°F (222°C) and need not be less than 100°F (56°) in any hourly interval. During the heating and cooling period there shall not be a greater variation in temperature than 250°F (139°C) within any 15 ft (4.6 mm) interval of weld length. The exceptions of (a) and (b) below are permitted.

(a) P-No. 6 material may be cooled in air from the PWHT holding temperature specified in Table ND-4622.1-1.

(b) For P-No. 7 material the cooling rate at temperatures above 1200°F (649°C) shall not exceed 100°F/hr (56°C), after which the rate of cooling shall be sufficiently rapid to prevent embrittlement.

Page 259

ND-4624 Methods of Postweld Heat Treatment

The postweld heat treatment shall be performed in accordance with the requirements of one of the following subparagraphs.

ND-4624.1 Furnace Heating - One Heat.

Heating the component or item in a closed furnace in one heat is the preferred procedure and should be used whenever practical. The furnace atmosphere shall be controlled so as to avoid excessive oxidation, and direct impingement of flame on the component or item is prohibited.

ND-4624.2 Furnace Heating - More Than One Heat.

The component or item may be heated in more than one heat in a furnace, provided the furnace atmosphere control requirements of ND-4624.1 apply and overlap of the heated sections of the component or item is at least 5 ft (1.5 m). When this procedure is used, the portion of the component or item outside the furnace shall be shielded so that the temperature gradient is not harmful. The cross section where the component or item projects from the furnace shall not intersect a nozzle or other structural discontinuity.

ND-4624.3 Local Heating.

Welds may be locally postweld heat treated when it is not practical to heat treat the entire component or item. Local postweld heat treatment shall consist of heating a circumferential band around the component or item at temperatures within the ranges specified in this Subarticle. The minimum width of the controlled band at each side of the weld, on the face of the greatest weld width, shall be the thickness of the weld or 2 in. (51 mm), whichever is less. The temperature of the component or item from the edge of the controlled band outward shall be gradually diminished so as to avoid harmful thermal gradients. This procedure may also be used for postweld heat treatment after repairs.

ND-4624.4 Heating Components Internally.

The component or item may be heated internally by any appropriate means and with adequate indicating and recording temperature devices to aid in the control and maintenance of a uniform distribution of temperature in the component or item. Previous to this operation, the component or item shall be fully enclosed with insulating material.

ND-4630 HEAT TREATMENT OF WELDS OTHER THAN THE FINAL POSTWELD HEAT TREATMENT

The holding temperature, the time at temperature, the heating rate, and the cooling rate need not conform to the requirements of this Article for heat treatments other than the final postweld heat treatment.

ND-4650 HEAT TREATMENT AFTER BENDING OR FORMING FOR PIPE, PUMPS, AND

VALVES

ND-4651 Conditions Requiring Heat Treatment After Bending or Forming

(a) Ferritic alloy steel pipe or formed portions of pumps or valves that have been heated for bending or other forming operations shall receive a heat treatment in accordance with ND-4620, a full anneal, a normalizing and tempering treatment, or a quenching and tempering treatment.

(b) Carbon steel pipe or formed portions of pumps or valves with a wall thickness greater than $\frac{3}{4}$ in. (19 mm) included in group P-No. 1 in Section IX that have been cold bent or formed shall receive heat treatment in accordance with ND-4620.

(c) Ferritic alloy pipe or formed portions of pumps or valves with an outside diameter greater than 4 in. (102 mm) and a wall thickness greater than $\frac{1}{2}$ in. (13 mm) included in groups P-No. 3 through P-No. 5 in Section IX that have been cold bent or formed shall require a heat treatment in accordance with ND-4620.

ND-4652 Exemptions From Heat Treatment After Bending or Forming

If the conditions described in (a) through (d) below are met, heat treatment after bending or forming is not required.

(a) Carbon steel pipe or portions of pumps and valves that have been bent or formed at a temperature of 1650°F (900°C) or higher shall require no subsequent heat treatment, provided the requirements of ND-4213 have been met.

(b) Austenitic stainless steel pipe or portions of pumps or valves that have been heated for bending or other forming operations may be used in the as-bent condition unless the Design Specifications require a heat treatment following bending or forming.

(c) Austenitic stainless steel pipe or portions of pumps or valves that have been cold bent or formed may be used in the as-bent condition unless the Design Specifications require a heat treatment following bending or forming.

(d) Carbon steel and ferritic alloy steel pipe or portions of pumps or valves with sizes and wall thicknesses less than specified in ND-4651(b) and ND-4651(c)

Page 260

may be cold bent or formed without a heat treatment following bending.

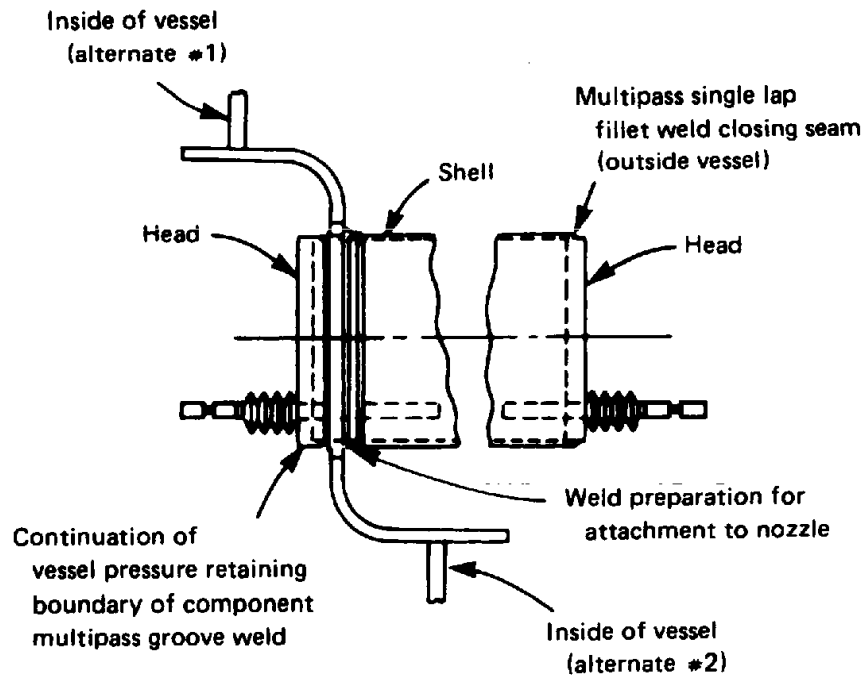


FIG. ND-4730-1 PENETRATION ASSEMBLY

FIG. ND-4730-1 PENETRATION ASSEMBLY

ND-4660 HEAT TREATMENT OF ELECTROSLAG WELDS

Electroslag welds in ferritic material over $1\frac{1}{2}$ in. (38 mm) in thickness at the joints shall be given a grain refining heat treatment.

ND-4700 MECHANICAL JOINTS

ND-4710 BOLTING AND THREADING

ND-4711 Thread Engagement

The threads of all bolts or studs shall be engaged in accordance with the design.

ND-4712 Thread Lubricants

Any lubricant or compound used in threaded joints shall be suitable for the service conditions and shall not react unfavorably with either the service fluid or any component material in the system.

ND-4713 Removal of Thread Lubricants

All threading lubricants or compounds shall be removed from surfaces which are to be seal welded.

ND-4720 BOLTING FLANGED JOINTS

In bolting gasketed flanged joints, the contact faces of the flanges shall bear uniformly on the gasket and the gasket shall be properly compressed in accordance with the design principles applicable to the type of gasket used. All flanged joints shall be made up with relatively uniform bolt stress.

ND-4730 ELECTRICAL AND MECHANICAL PENETRATION ASSEMBLIES

(a) Electrical and mechanical penetration assemblies, except those portions performing an electrical conducting or insulating function, shall be constructed in accordance with the rules for components.

(b) Tubes or pipes of NPS 2 (DN 50) and less may be joined to a penetration assembly in accordance with the rules of ND-4350.

(c) The closing seam for the penetration assembly may be made with a multipass single lap fillet weld as shown in Fig. ND-4730-1, provided the requirements of (1) through (5) below are met.

(1) One of the heads on the penetration assembly shall meet the requirements of ND-3352.3.

(2) The penetration assembly shall not exceed 18 in. (457 mm) outside diameter.

(3) The Design Pressure of the penetration assembly shall not exceed 100 psi (690 kPa), and the Design Temperature shall not exceed 400°F (204°C).

Page 261

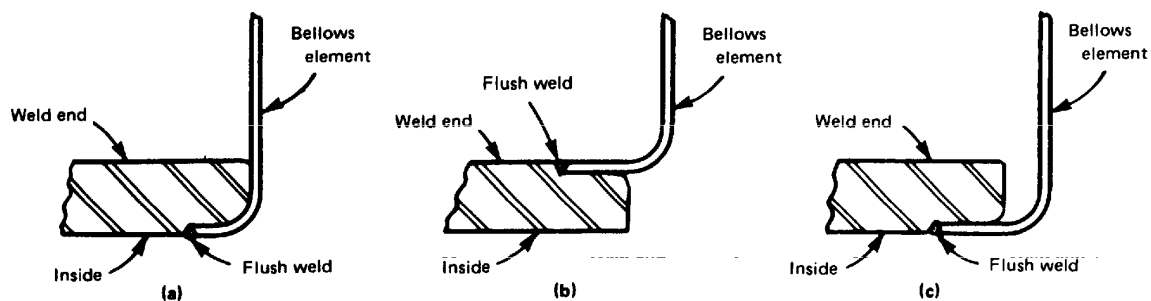


FIG. ND-4810(c)-1 PERMISSIBLE ATTACHMENT WELDS FOR BELLOWS

FIG. ND-4810(c)-1 PERMISSIBLE ATTACHMENT WELDS FOR BELLOWS

(4) Examination of the fillet weld shall be by the liquid penetrant method in accordance with ND-5350.

(5) The fillet weld and closure head shall meet the requirements of ND-3720(b).

ND-4800 EXPANSION JOINTS

ND-4810 FABRICATION AND INSTALLATION RULES FOR BELLOWS EXPANSION JOINTS

For bellows type expansion joints, the requirements of (a) through (f) below shall be met.

(a) All welded joints shall comply with the requirements of ND-4000.

(b) The longitudinal seam weld in the bellows shall be a butt type full penetration weld.

(c) The bellows of the expansion joint shall be attached to the welding ends or flange by circumferential welds of a butt

type having a full penetration through the thickness of the bellows portion, as shown in Fig. ND-4810(c)-1.

(d) Other than the attachment welds, no circumferential welds are permitted in the bellows elements.

(e) Prior to installation of the expansion joint in the system, weld repairs shall not be permitted on parent material of the bellows.

(f) See ND-3649.2 for general requirements applicable to fabrication and installation.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 ND-5000

ARTICLE ND-5000 EXAMINATION

Page 263

ND-5100 GENERAL REQUIREMENTS FOR EXAMINATION

ND-5110 PROCEDURES, QUALIFICATIONS, AND EVALUATION

ND-5111 General Requirements

(a) Nondestructive examinations shall be conducted in accordance with the examination methods of Section V, except as they may be modified by the requirements of this Article. Radiographic examination shall be in accordance with Section V, Article 2, except that the geometric unsharpness shall not exceed the limits of T-285. Ultrasonic examination shall be in accordance with Section V, Article 5; magnetic particle examination shall be in accordance with Section V, Article 7; liquid penetrant examination shall be in accordance with Section V, Article 6; and leak testing shall be in accordance with Section V, Article 10.

(b) The extent of radiography shall meet the requirements of ND-3352 for the joint efficiency used in the design.

(c) The requirements for spot radiography are given in ND-5400.

(d) Nondestructive examination requirements for tanks are given in ND-5280.

(e) The examinations required by this Article or by reference to this Article shall be performed by personnel who have been qualified as required by this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards of this Article.

ND-5112 Nondestructive Examination Procedures

All nondestructive examinations required by this Article shall be performed in accordance with detailed written procedures which have been proven by actual demonstration to the satisfaction of the Inspector. The procedures shall comply with the appropriate Article of Section V for the particular examination method. The digitization of radiographic film and radioscopy images shall meet the requirements of Section V, Article 2, Mandatory Appendix III, "Digital Image Acquisition, Display, and Storage for Radiography and Radioscopy." Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Inspector on request. At least one copy of the procedure shall be readily available to all applicable nondestructive examination personnel for reference and use.

ND-5113 Post-Examination Cleaning

Following any nondestructive examination in which examination material is applied to the piece, the piece shall be thoroughly cleaned in accordance with applicable material or procedure specifications.

ND-5120 TIME OF EXAMINATION OF WELDS AND WELD METAL CLADDING

Acceptance examinations of welds and weld metal cladding required by ND-5200 shall be performed at the times stipulated in (a) through (d) below during fabrication and installation.

(a) Radiographic examination of welds shall be performed after an intermediate¹ or final postweld heat treatment, when required, except as provided in (1) and (2) below.

(1) Radiographic examination of welds in items fabricated of P-No. 1 materials may be performed prior to any required postweld heat treatment.

1 An intermediate postweld heat treatment for this purpose is defined as a postweld heat treatment performed on a weld within a temperature range not lower than the minimum holding temperature range to which the weld shall be subjected during the final postweld heat treatment.

(2) Radiographic examination of welds in P-No. 3 materials may be performed prior to an intermediate

Page 266

or final postweld heat treatment provided the welds are ultrasonically examined after an intermediate or the final postweld heat treatment. The ultrasonic examination and acceptance standards shall be in accordance with this Article.

(b) Magnetic particle or liquid penetrant examinations of welds shall be performed after any required postweld heat treatment, except that welds in P-No. 1 material may be examined either before or after postweld heat treatment.

(c) All dissimilar metal weld joints, such as in austenitic or high nickel to ferritic material or using austenitic or high nickel alloy filler metal to join ferritic materials which penetrate the wall, shall be examined after final postweld heat treatment.

(d) The magnetic particle or liquid penetrant examination of weld surfaces that are to be covered with weld metal cladding shall be performed before the weld metal cladding is deposited. The magnetic particle or liquid penetrant examination of weld surfaces that are not accessible after a postweld heat treatment shall be performed prior to the operation which caused this inaccessibility. These examinations shall be performed before PWHT.

(e) Ultrasonic examination of electroslag welds in ferritic materials shall be performed after a grain refining heat treatment, when performed, or after final postweld heat treatment.

ND-5200 EXAMINATION OF WELDS

ND-5210 CATEGORY A VESSEL WELDED JOINTS IN VESSELS AND SIMILAR WELDED JOINTS IN PIPING, PUMPS, AND VALVES

ND-5211 Vessels

ND-5211.1 General Requirements

(a) Category A welded joints (ND-3351.1) shall be fully radiographed when:

(1) the thickness exceeds the limits of ND-5211.2 or ND-5211.3;

(2) the welds are based on a joint efficiency permitted by ND-3352.1(a);

(3) the butt welds in nozzles or communicating chambers are attached to vessel sections or heads which are required to be fully radiographed by (1) or (2) above;

(4) the welds are made by the electroslag welding process.

(b) Welds not required to be fully radiographed by (a) above shall be examined by spot radiography in accordance with the requirements of ND-5111, except as permitted by (c) below. Spot radiography is required when a joint efficiency described in ND-3352.1(b) is used.

**TABLE ND-5211.2-1
THICKNESS ABOVE WHICH FULL
RADIOGRAPHIC EXAMINATION OF BUTT
WELDED JOINT IS MANDATORY**

P-Number Classification of Material	Nominal Thickness Above Which Butt Welded Joints Shall Be Fully Radiographed, in.
1	1 1/4
3	3/4
4	5/8
5	0
7	5/8
8	1 1/2
10	5/8
11	5/8

TABLE ND-5211.2-1 THICKNESS ABOVE WHICH FULL RADIOGRAPHIC EXAMINATION OF BUTT WELDED JOINT IS MANDATORY

(c) No radiography is required when the vessel or part is designed for external pressure only or when the design complies with ND-3352.1(c).

ND-5211.2 Ferritic Materials.

Complete radiography shall be performed at each butt welded joint at which the thinner of the plate or vessel wall thickness at the welded joint exceeds the thickness limit above which full radiography is required in Table ND-5211.2-1.

ND-5211.3 Nonferrous Materials

(a) Vessels or parts of vessels constructed of nonferrous materials shall be radiographed in accordance with the requirements of ND-3352.

(b) Welded butt joints in vessels constructed of materials covered by specifications SB-163 (Alloy 800 only), SB-333, SB-334, SB-335, SB-336, SB-407, SB-408, SB-409, SB-443, SB-444, and SB-446 shall be examined radiographically for their full length when the thinner of the plate or vessel wall thicknesses at the welded joint exceeds $\frac{3}{8}$ in.

(c) Vessels constructed of unalloyed titanium shall have all welded joints of Categories A and B fully radiographed.

(d) All welds, both groove and fillet, in components constructed with materials SB-333, SB-334, SB-335, and SB-336 shall be examined for the detection of cracks by the liquid penetrant method.

(e) All welded joints in vessels constructed of unalloyed titanium shall be examined by the liquid penetrant method.

Page 267

(f) All welded joints in components or parts constructed with materials SB-163 (Alloy 800 only), SB-407, SB-408, SB-409, SB-443, SB-444, and SB-446 not required to be radiographed shall be examined by the liquid penetrant method.

ND-5212 Piping, Pumps, and Valves

Longitudinal welded joints in piping greater than NPS 2 (DN 50) shall be examined by the requirements of ND-2500. Longitudinal welded joints in pressure retaining parts of pumps and valves greater than NPS 2 (DN 50) shall be examined in accordance with the requirements of ND-2500 for the applicable product form. Butt welds made by the electroslag welding process shall be radiographed for their entire length.

ND-5220 CATEGORY B VESSEL WELDED JOINTS AND CIRCUMFERENTIAL WELDED JOINTS IN PIPING, PUMPS, AND VALVES

ND-5221 Vessels

(a) Category B welded joints (ND-3351.2) shall be fully radiographed when:

- (1) the thickness exceeds the limits of ND-5211.2 or ND-5211.3, except as permitted in (b) below;
- (2) the welds are based on a joint efficiency permitted by ND-3352.1(a), except as permitted in (b) below;
- (3) they are butt welds in nozzles or communicating chambers attached to vessel sections or heads that are required to be radiographed and exceed NPS 10 (254 mm) or $1\frac{1}{8}$ in. (29 mm) wall thickness;
- (4) the welds are made by the electroslag welding process.

(b) In accordance with (a)(2) above, any Category B and similar type welds not required to be fully radiographed by thickness or location as in (a) above shall as a minimum be partially radiographed. This shall consist of a radiographic examination at least 6 in. long of any section of the weld picked at random plus a similar examination of any intersection of the weld with all Category A and similar welds in either of the sections being connected. Acceptance standards for partially examined welds shall be as set forth in ND-5321.

(c) The welds not required to be radiographed by (a) or (b) above shall be examined by spot radiography except as permitted by (d) below. Spot radiography is required when a joint efficiency described in ND-3352.1(b) is used.

(d) No radiography is required when a vessel or part is designed for external pressure only or when a design complies with ND-3352.1(c).

(e) The requirements of ND-5211.2 and ND-5211.3 shall be met.

ND-5222 Piping, Pumps, and Valves

Circumferential welded joints in piping, pumps, and valves greater than NPS 2 (DN 50) shall be examined by either the magnetic particle, liquid penetrant, or radiographic methods. Acceptance standards shall be those stated in ND-5300.

ND-5230 CATEGORY C VESSEL WELDED JOINTS AND SIMILAR WELDED JOINTS IN PIPING, PUMPS, AND VALVES

ND-5231 Vessels

(a) Category C full penetration welds shall be fully radiographed when:

- (1) the thickness exceeds the requirements of ND-5211.2 or ND-5211.3;
 - (2) they are butt welds in nozzles or communicating chambers attached to vessel sections or heads that are required to be radiographed and exceed NPS 10 (254 mm) or $1\frac{1}{8}$ in. (29 mm) wall thickness;
 - (3) the welds are made by the electroslag process.
- (b) Any Category C butt weld not required to be fully radiographed by thickness or location using the joint efficiency of ND-3352.1(a) shall meet the requirements of ND-5221(b).
- (c) The welds not required to be fully radiographed by (a) above shall be examined by spot radiography, except as permitted by (d) below. Spot radiography is required when the butt welds are designed with a joint efficiency as described in ND-3352.1(b).
- (d) No radiography is required when the vessel or part is designed for external pressure only, when the design complies with ND-3352.1(c), or when the joint is not a butt welded joint.

ND-5232 Piping, Pumps, and Valves

The requirements for welded joints similar to Category C shall be the same as given in ND-5222.

Page 268

ND-5240 CATEGORY D VESSEL WELDED JOINTS AND SIMILAR JOINTS IN PIPING, PUMPS, AND VALVES

ND-5241 Vessels

- (a) Full penetration butt welds of Category D (ND-3351.4) shall be fully radiographed when located:
- (1) in a vessel or part that is designed with a joint efficiency as permitted by ND-3352.1(a);
 - (2) in nozzles or communicating chambers that are attached to vessel sections or heads required to be fully radiographed.
- (b) Butt welds not required to be fully radiographed by (a) above shall be examined by spot radiography, except as permitted by (c) below.
- (c) No radiography is required for butt welded joints when the vessel or part is designed for external pressure only or when the design complies with ND-3352.1(c). Radiography is not required for nonbutt-welded joints.

ND-5242 Piping, Pumps, and Valves

The requirements for welded joints similar to Category D welded joints shall be as given in ND-5222.

ND-5260 WELDED STAYED CONSTRUCTION

Welded staybolts need not be radiographed. When welded stays are used to stay jacketed vessels, the inside weld shall be visually examined before closing plates are attached.

ND-5270 SPECIAL WELDS

ND-5272 Weld Metal Cladding

Weld metal cladding shall be examined by the liquid penetrant method.

ND-5273 Hard Surfacing

Hard surfacing shall be examined by the liquid penetrant method in accordance with ND-2546, and the acceptance standards applicable to material less than $\frac{5}{8}$ in. thick shall apply. Penetrant examination is not required for hard surfacing on valves with inlet connections NPS 4 or less.

ND-5274 Tube-to-Tubesheet Welds

Tube-to-tubesheet welds shall be examined by the liquid penetrant method.

ND-5275 Brazed Joints

Flux and flux residue shall be removed from all surfaces prior to examination. Joints shall be visually examined on all accessible surfaces to determine whether there has been adequate flow of brazing metal through the joint. Optical aids may be employed for indirect visual examination of joints which cannot be directly examined.

ND-5276 Inertia and Continuous Drive Friction Welds

When radiographic examination is required by this Article, inertia and continuous drive friction welds shall also be examined by the ultrasonic method to verify bonding over the entire area.

ND-5278 Electroslag Welds

In addition to the requirements for the type of weld being examined, all complete penetration welds made by the electroslag welding process in ferritic materials shall be ultrasonically examined.

ND-5279 Special Exceptions

When the joint detail does not permit radiographic examination of joints attaching penetration assemblies, which are fabricated as appurtenances, or the closing seam within an electrical penetration assembly which is not fabricated as an appurtenance, ultrasonic examination plus liquid penetrant or magnetic particle examination of the completed weld may be substituted for the radiographic examination. The absence of suitable radiographic equipment shall not be justification for such substitution. The substitution of ultrasonic examination can be made, provided the examination is performed using a detailed written procedure which has been proven by actual demonstration to the satisfaction of the Inspector as capable of detecting and locating defects described in this Subsection. The nondestructive examination shall be in accordance with Section V and meet the acceptance standards of ND-5300.

Page 269

ND-5280 WELDED JOINTS IN STORAGE TANKS

ND-5282 Atmospheric Storage Tanks

ND-5282.1 Sidewall Joints.

Sidewall joints shall be examined in accordance with ND-5211 and ND-5221.

ND-5282.2 Roof Joints and Roof-to-Sidewall Joints.

Roof joints and roof-to-sidewall joints shall be examined visually.

ND-5282.3 Bottom Joints.

Bottom joints shall be examined from the inside of the tank by applying soapsuds to the joints and pulling a partial vacuum of at least 3 psi by means of a vacuum box with transparent top.

ND-5282.4 Bottom-to-Sidewall Joints.

Bottom-to-sidewall joints shall be examined by the vacuum box method as required by ND-5282.3. Alternatively, MT or PT examination may be substituted for the vacuum box tests, provided the outside of the joint is accessible for visual examination during the test required by ND-6000.

ND-5282.5 Nozzle-to-Tank Joints.

Nozzle-to-sidewall or bottom joints shall be examined by either the magnetic particle or liquid penetrant method. Nozzle-to-roof joints shall be visually examined.

ND-5282.6 Joints in Nozzles.

All joints in roof nozzles shall be visually examined. Joints in other nozzles shall be examined by the liquid penetrant or magnetic particle method.

ND-5282.7 Other Joints.

Joints not specifically covered by ND-5282 shall be examined in the same manner as similar weld joints in vessels as required by this Subarticle.

ND-5283 Welds in 0-15 psi (0-103 kPa) Storage Tanks

ND-5283.1 Sidewall Joints.

Sidewall joints shall be examined in accordance with ND-5211 and ND-5221.

ND-5283.2 Roof Joints.

Roof joints shall be examined in accordance with ND-5211.

ND-5283.3 Roof-to-Sidewall Joints.

Roof-to-sidewall joints shall be radiographed in accordance with ND-5211 if the design permits. If not radiographed, this joint shall be examined by the magnetic particle or liquid penetrant method.

ND-5283.4 Bottom Joints.

Joints in bottoms supported directly on grade shall be examined by the vacuum box method as detailed in ND-5282.3. Joints not supported directly on grade shall be fully radiographed.

ND-5283.5 Bottom-to-Sidewall Joints.

Bottom-to-sidewall joints shall be examined by the vacuum box method as required by ND-5282.3. Alternatively, MT or PT examination may be substituted for the vacuum box test, provided the outside of the joint is accessible for visual examination during the test required by ND-6000.

ND-5283.6 Nozzle-to-Tank Joints.

Nozzle-to-tank joints shall be examined by either the magnetic particle or the liquid penetrant method.

ND-5283.7 Joints in Nozzles.

Joints in nozzles shall be examined by either the magnetic particle or the liquid penetrant method.

ND-5283.8 Other Joints.

Joints not specifically covered by ND-5283 shall be examined in the same manner as similar weld joints in vessels as required by this Subarticle.

ND-5300 ACCEPTANCE STANDARDS

ND-5320 RADIOGRAPHIC ACCEPTANCE STANDARDS

ND-5321 Evaluation of Indications

Indications shown on the radiographs of welds and characterized as imperfections are unacceptable under the following

conditions:

(a) any indication characterized as a crack or zone of incomplete fusion or penetration;

(b) any other elongated indication which has a length greater than:

(1) $\frac{1}{4}$ in. for t up to $\frac{3}{4}$ in., inclusive

(2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. to $2\frac{1}{4}$ in., inclusive

(3) $\frac{3}{4}$ in. for t over $2\frac{1}{4}$ in.

where t is the thickness of the thinner portion of the weld;

(c) internal root weld conditions are acceptable when the density change as indicated in the radiograph is not abrupt; elongated indications on the radiograph at either edge of such conditions shall be unacceptable as provided in (b) above;

(d) any group of aligned indications having an aggregate length greater than t in a length of $12t$ unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication;

(e) rounded indications in excess of that shown as acceptable in Appendix VI;

Page 270

(f) when a Category B or C butt weld, partially radiographed as required in ND-5221(b) or ND-5231(b), is acceptable in accordance with (a) through (e) above, the entire weld length represented by this partial radiograph is acceptable;

(g) when a Category B or C butt weld, partially radiographed as required in ND-5221(b) or ND-5231(b), has been examined and any radiograph discloses welding which does not comply with the minimum quality requirements of (a) through (e) above, one additional section at least 6 in. long for each radiograph disclosing such defective welding, but a minimum total of two, shall be radiographically examined in the same weld unit at other locations. The location of these additional radiographs shall be acceptable to the Inspector.

(1) If the additional sections examined show welding which meets the minimum quality requirements of (a) through (e) above, the entire weld unit represented by the total number of radiographs is acceptable. The defective welding disclosed by the partial radiographs shall be removed and the area repaired by welding. The weld repaired areas shall be radiographically examined.

(2) If any of the additional sections examined shows welding which does not comply with the minimum quality requirements of (a) through (e) above, the entire unit of weld represented shall be rejected. The entire rejected weld represented shall be rewelded, or the entire unit of weld represented shall be completely radiographed and any part of the weld not meeting the requirements of (a) through (e) above shall be repaired and reexamined radiographically. The rewelded joint shall be partially radiographed as required in ND-5221(b) or ND-5231(b), or the weld repaired areas shall be radiographically reexamined.

ND-5322 Evaluation of Indications (Spot Radiography)

The acceptability of welds examined by spot radiography shall be determined by (a), (b), and (c) below.

(a) Welds in which the radiograph shows any type of crack or zone of incomplete fusion or penetration shall be unacceptable.

(b) Welds in which the radiographs show slag inclusions or cavities shall be unacceptable if the length of any such imperfection is greater than $\frac{2}{3}T$ where T is the thickness of the thinner plate welded. If several imperfections within the above limitations exist in line, the welds shall be judged acceptable if the sum of the longest dimensions of all such imperfections is not more than T in a length of $6T$ or proportionately for radiographs shorter than $6T$ and if the longest imperfections considered are separated by at least $3L$ of acceptable weld metal, where L is the length of the longest imperfection. The maximum length of acceptable imperfections shall be $\frac{3}{4}$ in. Any such imperfections shorter than $\frac{1}{4}$ in. shall be acceptable for any plate thickness.

(c) Rounded indications are not a factor in the acceptability of welds not required to be fully radiographed.

(d) Evaluation and Retests

(1) When an area which is spot radiographed is acceptable in accordance with (a) and (b) above, the entire weld length represented by this radiograph is acceptable.

(2) When a spot has been examined and the radiograph discloses welding which does not comply with the minimum quality requirements of (a) and (b) above, two additional spots shall be radiographically examined in the same weld unit at locations away from the original spot. The locations of these additional spots shall be determined by the Inspector or fabricator as provided for the original spot examination in ND-5420(c).

(a) If the two additional spots examined show welding which meets the minimum quality requirements of (a) and (b) above, the entire weld unit represented by the three radiographs is acceptable. The defective welding disclosed by the first of the three radiographs may be removed and the area repaired by welding, or it may be allowed to remain in the weld joint, at the discretion of the Inspector.

(b) If either of the two additional spots examined shows welding which does not comply with the minimum quality requirements of (a) and (b) above, the entire unit of weld represented shall be rejected. The entire rejected weld shall be removed and the joint shall be rewelded or, at the fabricator's option, the entire unit of weld represented shall be completely radiographed and defective welding only need be corrected.

(c) Repair welding shall be performed using a qualified procedure and in a manner acceptable to the Inspector. The rewelded joint or the weld repaired areas shall be spot radiographically examined at one location in accordance with the foregoing requirements of ND-5420.

ND-5330 ULTRASONIC ACCEPTANCE STANDARDS

All imperfections which produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and

Page 271

evaluate them in terms of the acceptance standards as follows.

(a) Imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths exceeding:

(1) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive

(2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (57 mm), inclusive

(3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm) where t is the thickness of the weld being examined; if a weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses.

(b) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable, regardless of length.

ND-5340 MAGNETIC PARTICLE ACCEPTANCE STANDARDS

ND-5341 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication which is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. After an indication has been verified to be nonrelevant, it is not necessary to reinvestigate repetitive nonrelevant indications of the same type. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

ND-5342 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

- (1) any cracks or linear indications;
- (2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);
- (3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;
- (4) ten or more rounded indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) with the area taken in the most unfavorable location relative to the indications being evaluated.

ND-5350 LIQUID PENETRANT ACCEPTANCE STANDARDS

ND-5351 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities such as may occur from machining marks, surface conditions, or an incomplete bond between base metal and cladding may produce similar indications which are nonrelevant.

(b) Any indication which is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

ND-5352 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

- (1) any cracks or linear indications;
- (2) rounded indications with dimensions greater than $\frac{3}{16}$ in.;
- (3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;
- (4) ten or more rounded indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) with the area taken in the most unfavorable location relative to the indications being evaluated.

Page 272

ND-5360 VISUAL ACCEPTANCE STANDARDS FOR BRAZED JOINTS

Brazing metal shall give evidence of having flowed uniformly through a joint by the appearance of an uninterrupted, narrow, visible line of brazing alloy at the joint.

ND-5380 GAS AND BUBBLE FORMATION TESTING

For gas and bubble formation testing, the test procedure shall be in accordance with Section V, Article 10, T-1030. When vacuum box testing is used, the soak time shall be a minimum of 10 sec. Any indication of leaking, by the formation of bubbles or the breaking of the continuous soap film by leaks, shall be evidence of an unacceptable condition.

ND-5400 SPOT EXAMINATION OF WELDED JOINTS²

ND-5410 GENERAL REQUIREMENTS

Vessels and tanks that have butt welded joints that are not radiographed for their full length and which are required to be spot examined by the rules of this Subsection shall be examined locally by spot radiography in accordance with this Subarticle, except for those vessels or tanks designed for external pressure only.

2 (a) Spot radiographing of a welded joint is recognized as an effective inspection tool. The spot radiography rules are also considered to be an aid to quality control. Spot radiographs made directly after a welder or an operator has completed a unit of weld proves that the work is or is not being done in accordance with a satisfactory procedure. If the work is unsatisfactory, corrective steps can then be taken to improve the welding in the subsequent units, which unquestionably will improve the weld quality.

(b) Spot radiography in accordance with these rules will not insure a fabrication product of predetermined quality level throughout. It must be realized that an accepted vessel or tank under these spot radiography rules may still contain defects which might be disclosed on further examination. If all radiographically disclosed unacceptable weld defects are required to be eliminated from a vessel or tank, then 100% radiography shall be employed.

ND-5420 MINIMUM EXTENT OF SPOT RADIOGRAPHIC EXAMINATION

(a) One spot shall be examined in the first 50 ft of welding in each vessel and one spot shall be examined for each additional 50 ft (15.2 m) of welding or fraction thereof, except that when identical vessels or tanks individually of less than 50 ft (15.2 m) seam length are being fabricated under the rules of this Subsection, 50 ft (15.2 m) increments of welding may be represented by one spot examination.

(b) Such additional spots as may be required shall be selected so that an examination is made of the welding of each welding operator or welder. Under conditions where two or more welders or welding operators make weld layers in a joint or on the two sides of a double welded butt joint, one spot examination may represent the work of both welders or welding operators.

(c) Each spot examination shall be made as soon as practicable after the completion of the increment of weld that is to be examined. The location of the spot shall be chosen by the Inspector, except that when the Inspector has been duly notified in advance and cannot be present or otherwise make the selection, the Certificate Holder may exercise his own judgment in selecting the spots.

ND-5430 STANDARDS FOR SPOT RADIOGRAPHIC EXAMINATION

Spot examination by radiography shall be made in accordance with the technique prescribed in Section V, Article 2. The minimum length of spot radiograph shall be 6 in. (152 mm).

[98]

ND-5440 EVALUATION AND RETESTS

(a) When an area which is spot radiographed is acceptable in accordance with ND-5322(a) and (b), the entire weld length represented by this radiograph is acceptable.

(b) When an area which is spot radiographed has been examined and the radiograph discloses welding which does not comply with the minimum quality requirements of ND-5322(a) and (b), two additional spots shall be radiographically examined in the same weld unit at locations away from the original spot. The locations of these additional spots shall be determined by the Inspector or Certificate Holder as provided for the original spot examination in ND-5420(c).

(1) If the two additional spots examined show welding which meets the minimum quality requirements of ND-5322(a) and (b), the entire weld unit represented by the three radiographs is acceptable. The defective welding disclosed by the first of the three radiographs may be removed and the area repaired by welding, or it may be allowed to remain in the weld joint, at the discretion of the Inspector.

Page 273

(2) If either of the two additional spots examined shows welding which does not comply with the minimum quality requirements of ND-5322(a) and (b), the entire unit of weld represented shall be rejected. The entire rejected weld shall be removed and the joint shall be rewelded, or, at the Certificate Holder's option, the entire unit of weld represented shall be

completely radiographed and defective welding only need be corrected.

(3) Repair welding shall be performed using a qualified procedure and in a manner acceptable to the Inspector. The rewelded joint or the weld repaired areas shall be spot radiographically examined at one location in accordance with the foregoing requirements of ND-5400.

[98]

ND-5500 QUALIFICATIONS AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

ND-5510 GENERAL REQUIREMENTS

Organizations performing Code required nondestructive examinations shall use personnel competent and knowledgeable to the degree specified by ND-5520. When these services are subcontracted by the Certificate Holder or Quality System Certificate Holder, he shall verify the qualification of personnel to the requirements of ND-5520. All nondestructive examinations required by this Subsection shall be performed by and the results evaluated by qualified nondestructive examination personnel.

ND-5520 PERSONNEL QUALIFICATION, CERTIFICATION, AND VERIFICATION

ND-5521 Qualification Procedure

(a) Personnel performing nondestructive examinations shall be qualified in accordance with the recommended guidelines of SNT-TC-1A³⁴ The Employer's⁵ written practice required by paragraph 5 of SNT-TC-1A shall identify his requirements relative to the recommended guidelines. The recommended guidelines of SNT-TC-1A shall be considered minimum requirements, except as modified in (1) through (5) below:

(1) Qualification of Level III nondestructive examination personnel shall be by examination.

(a) The basic and method examinations, paragraphs 8.8(1) and 8.8(2) of SNT-TC-1A, may be prepared and administered by the Employer, ASNT, or an outside agency.

(b) The specific examination, paragraph 8.8(3) of SNT-TC-1A, shall be prepared and administered by the Employer or an outside agency. The Employer or outside agency administering the specific examination shall identify the minimum grade requirement in the written program when the basic and method examinations have been administered by ASNT, which issues grades on a pass/fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(2) The written practice identified in paragraph 5 of SNT-TC-1A and the procedures used for examination of personnel shall be referenced in the Employer's Quality Program.

(3) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform nondestructive examination of limited scope, may be less than that recommended in Table 6.3.1 of SNT-TC-1A. The training and experience times shall be described in the written practice, and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate.

The minimum classroom training times identified in Table 6.3.1 of SNT-TC-1A may be reduced from 8 and 16 hr to 4 and 8 hr, respectively, for visual examination personnel.

3 SNT-TC-1A is a Recommended Practice for Nondestructive Testing Personnel Qualification and Certification published by the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, OH 43228-0518. SNT-TC-1A-1992 is the applicable edition.

4 Personnel qualified by examination and certified to previous editions of SNT-TC-1A are considered to be qualified to the 1992 edition when the recertification is based on continuing satisfactory performance. All reexaminations and new examinations shall be in accordance with the 1992 edition.

5 Employer, as used in this Article, shall include: N Certificate Holders; Quality System Certificate Holders; and Material Organizations that are qualified in accordance with NCA-3862(a)(1); and organizations that provide subcontracted nondestructive examination services to organizations described above.

(4) For visual examination, the Jaeger Number 1 letters shall be used in lieu of the Jaeger Number 2 letters specified in paragraph 8.2(1) of SNT-TC-1A. The use of equivalent type and size letters is permitted.

(5) A Level I individual shall be qualified to perform specific setups, calibrations, and tests, and to record and evaluate data by comparison with specific acceptance criteria defined in written instructions. The Level I individual shall implement these written NDE instructions under the guidance of a Level II or III individual. A Level I individual may independently accept the results of nondestructive examinations when the specific acceptance criteria are defined in the written instructions.

(b) For nondestructive examination methods not covered by SNT-TC-1A documents, personnel shall be qualified to comparable levels of competency by subjection to comparable examinations on the particular method involved.

(c) The emphasis shall be on the individual's ability to perform the nondestructive examination in accordance with the applicable procedure for the intended application.

(d) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use personnel qualified to perform one or more operations. As an example, one person may be used who is qualified to conduct radiographic examination and another may be used who is qualified to interpret and evaluate the radiographic film.

ND-5522 Certification of Personnel

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of Levels I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations [ND-5521(a)(2)], the Employer may use a letter from ASNT as evidence on which to base the certification.

(c) When an outside agency is the examining agent for Level III qualification of the Employer's personnel, the examination results shall be included with the Employer's record.

ND-5523 Verification of Nondestructive Examination Personnel Certification

The Certificate Holder has the responsibility to verify the qualification and certification of nondestructive examination personnel employed by Material Organizations qualified by them in accordance with NCA-3820 and subcontractors who provide nondestructive examination services to them.

ND-5530 RECORDS

Personnel qualification records identified in paragraph 9.4 of SNT-TC-1A shall be retained by the Employer.

ND-5700 EXAMINATION REQUIREMENTS FOR EXPANSION JOINTS

ND-5720 BELLOWS EXPANSION JOINTS

The examinations stipulated in (a) through (f) below are required to verify the integrity of bellows expansion joints for installation in piping systems.

(a) The formed bellows shall be determined by visual examination to be free of defects such as notches, crevices, material buildup or upsetting, or weld spatter, which may serve as points of local stress concentration. Suspect surface areas shall be further examined by liquid penetrant method.

(b) The longitudinal seam weld in the bellows shall be examined by the liquid penetrant method. When the individual ply thickness exceeds $\frac{1}{8}$ in. (3.2 mm), the weld shall also be radiographed. These examinations may be performed either before or after the bellows is formed.

(c) The circumferential attachment weld between the bellows and pipe or flange shall be examined by the liquid penetrant method when the total bellows thickness is $\frac{1}{4}$ in. (6 mm) or less. When the total thickness exceeds this limit, the weld shall be radiographed, except where radiography is not meaningful; for example, when the weld thickness constitutes less than

20% of the total thickness being radiographed, liquid penetrant examination may be substituted.

(d) In the case of liquid penetrant examination of bellows welds, imperfections producing the following indications are unacceptable:

- (1) cracks or linear indications;
- (2) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;
- (3) five or more randomly distributed rounded indications in a weld length of 6 in. (152 mm);
- (4) any rounded indication exceeding the lesser of one-half the bellows thickness or $\frac{1}{16}$ in. (1.6 mm) in diameter.

(e) The examination of all other welds in the expansion joint shall comply with this Article.

Page 275

(f) The variation of the cylindrical end thickness of the formed bellows from the nominal or specified thickness shall not exceed the values given in Table 2 of SA-480. Thinning of the bellows material during forming shall be considered in the design and selection of material thickness but need not be limited to the values specified in Table 2 of SA-480.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 ND-6000

ARTICLE ND-6000 TESTING

Page 277

ND-6100 GENERAL REQUIREMENTS

ND-6110 PRESSURE TESTING OF COMPONENTS, APPURTENANCES, AND SYSTEMS

ND-6111 Scope of Pressure Testing

All pressure retaining components, appurtenances, and completed systems shall be pressure tested, except as specified in (a) through (d) below. Portions of piping systems which are exempt shall be identified in the Design Specification and N-5 Data Report Form. The design specification shall be available to the Authorized Nuclear Inspector when the balance of the system is hydrostatically tested.

(a) Bolts, studs, nuts, washers, and gaskets are exempt.

(b) The following portions of piping systems whose only function is to transport fluids to and from spray ponds, lakes, reservoirs, or tanks which are open to the atmosphere are exempt:

(1) piping downstream of the last isolation valve preceding the pipe discharge to the spray pond, lake, reservoir or tank; and

(2) piping upstream of the intake pump inlet isolation valve.

(c) Where systems discharge into Class 3 vessels or the gaseous regions of MC containment vessels through spargers or spray nozzles, only that portion of the system external to the vessel is required to be pressure tested.

(d) The portion of a Class 3 safety and safety relief valve discharge piping that is submerged below the minimum Design Level in a containment pressure suppression pool of a MC or CC containment vessel is exempt. The minimum Design Level shall be specifically designated in the Design Specification.

ND-6112 Pneumatic Testing

A pneumatic test in accordance with ND-6300 may be substituted for the hydrostatic test when permitted by ND-6112.1

(a).

ND-6112.1 Pneumatic Test Limitations

(a) A pneumatic test may be used in lieu of a hydrostatic test only when any of the following conditions exist:

(1) when components, appurtenances, or systems are so designed or supported that they cannot safely be filled with liquid;¹

(2) when components, appurtenances, or systems which are not readily dried, are to be used in services where traces of the testing medium cannot be tolerated.

(b) A pneumatic test at a pressure not to exceed 25% of the Design Pressure may be applied, prior to either a hydrostatic or a pneumatic test, as a means of locating leaks.

ND-6112.2 Precautions to Be Employed in Pneumatic Testing.

Compressed gaseous fluid is hazardous when used as a testing medium. Therefore, it is recommended that special precautions for protection of personnel be taken when a gaseous fluid under pressure is used as a test medium.

ND-6113 Witnessing of Pressure Tests

Pressure testing required by this Article shall be performed in the presence of the Inspector, except that testing of each line valve and each pump having piping connections of NPS 4 (DN 100) and less need not be witnessed by the Inspector. For line valves and pumps NPS 4 and less, the Inspector's review and acceptance of the Certificate Holder's test records will be authorization to sign the Data Report Form, and takes precedence over NCA-5280.

ND-6114 Time of Pressure Testing

ND-6114.1 System Pressure Test.

The installed system shall be pressure tested prior to initial operation.

¹ These tests may be made with the item being tested partially filled with liquid, if desired.

The pressure test may be performed progressively on erected portions of the system.

ND-6114.2 Component and Appurtenance Pressure Test

(a) Components and appurtenances shall be pressure tested prior to installation in a system, except as permitted in (b) below.

(b) The system pressure test may be substituted for a component or appurtenance pressure test, provided:

(1) the component can be repaired by welding in accordance with the rules of ND-4130 and ND-4450, if required, as a result of the system pressure test;

(2) the component repair weld can be postweld heat treated in accordance with ND-4620, if required, and nondestructively examined in accordance with rules of ND-4130 and ND-4450, as applicable; and

(3) the component is resubjected to the required system pressure test following the completion of repair and examination if the repair is required to be radiographed by ND-4453.4.

(c) Valves require pressure testing prior to installation in a system in accordance with ND-3500.

(d) Items which, when assembled, form a completed pump or valve may be tested in the form of subassemblies, provided:

(1) the test pressure is in accordance with the requirements of ND-6221;

(2)

- (2) the pressure test is performed in a manner which, in the subassembly under test, will simulate the loadings present when the completed pump or valve is assembled and pressurized;
- (3) the component Certificate Holder approves any pressure test of component subassemblies;
- (4) the component Certificate Holder specifies the pressure test requirements and test pressure to be used;
- (5) each subassembly pressure test is performed by a Certificate Holder and is performed in the presence of the Authorized Nuclear Inspector;
- (6) each subassembly pressure tested by other than the component Certificate Holder is stamped with the NPT symbol except as provided in NCA-8330; the test pressure shall be identified on the Partial Data Report Form;
- (7) each subassembly pressure tested by other than the component Certificate Holder is listed on the Code Data Report Form;
- (8) the pressure tested subassemblies of pumps or valves are subsequently assembled by mechanical methods only;
- (9) welds examined during the subassembly pressure test need not be reexamined during the system pressure test.

ND-6114.3 Material Pressure Test.

The component or appurtenance pressure test may be used in lieu of any such test required by the material specification for a part or material used in the component or appurtenance, provided:

- (a) nondestructive examinations, if required by the material specification, can be performed subsequent to the component or appurtenance pressure test;
- (b) the material can be repaired by welding in accordance with rules of ND-4130 if required as a result of the pressure test; and
- (c) postweld heat treatment, when required after repairs, can be performed in accordance with ND-4620.

ND-6115 Machining After Pressure Test

An additional amount of material, not to exceed 10% of the wall thickness or $\frac{3}{8}$ in. (10 mm), whichever is less, is permitted on the completed component during pressure testing, where machining to critical dimensions and tolerances is required.

ND-6120 PREPARATION FOR TESTING

ND-6121 Exposure of Joints

All joints, including welded joints, shall be left uninsulated and exposed for examination during the test.

ND-6122 Addition of Temporary Supports

Components designed to contain vapor or gas may be provided with additional temporary supports, if necessary, to support the weight of the test liquid.

ND-6123 Restraint or Isolation of Expansion Joints

Expansion joints shall be provided with temporary restraints, if required, for the additional pressure load under test.

ND-6124 Isolation of Equipment Not Subjected to Pressure Test

Equipment that is not to be subjected to the pressure test shall be either disconnected from the component or system or isolated during the test by a blind flange or similar means. Valves may be used if the valves with their closures are suitable for proposed test pressure.

ND-6125 Treatment of Flanged Joints Containing Blanks

Flanged joints at which blanks are inserted to isolate other equipment during the test need not be retested.

ND-6126 Precautions Against Test Medium Expansion

If a pressure test is to be maintained for a period of time and the test medium in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure.

ND-6127 Check of Test Equipment Before Applying Pressure

The test equipment shall be examined before pressure is applied to ensure that it is tight and that all low pressure filling lines and other items that should not be subjected to the test have been disconnected or isolated.

ND-6200 HYDROSTATIC TESTS

The requirements of this paragraph apply to all components except tanks, for which ND-6500 applies.

ND-6210 HYDROSTATIC TEST PROCEDURE

ND-6211 Venting During Fill Operation

The component or system in which the test is to be conducted shall be vented during the filling operation to minimize air pocketing.

ND-6212 Test Medium and Test Temperature

(a) Water or an alternative liquid, as permitted by the Design Specification, shall be used for the hydrostatic test.

(b) It is recommended that the test be made at a temperature that will minimize the possibility of brittle fracture. The test pressure shall not be applied until the component, appurtenance or system, and the pressurizing fluid are at approximately the same temperature.

ND-6220 HYDROSTATIC TEST PRESSURE REQUIREMENTS

ND-6221 Minimum Hydrostatic Test Pressure

(a) The installed system shall be hydrostatically tested at not less than 1.25 times the lowest Design Pressure of any component within the boundary protected by the overpressure protection devices which satisfy the requirements of ND-7000.

(b) Valves shall be hydrostatically tested in accordance with the rules of ND-3500.

(c) Other components, excluding piping systems, shall be hydrostatically tested at not less than 1.50 times their Design Pressure.

(d) As an alternative to ND-6221(a) above, piping between the discharge side of a centrifugal pump and the first shutoff valve may be hydrostatically tested at the shutoff head of the pump. The pressure shall be maintained for a sufficient time to permit examination of all joints, connections, and regions of high stress.

ND-6222 Maximum Permissible Pressure

(a) If the minimum test pressure of ND-6221(a) or (d) is to be exceeded by 6% at any location, the upper limit shall be established by analysis using all loadings that may exist during the test.

(b) When testing a system, the test pressure shall not exceed the maximum permissible test pressure of any component in the system.

ND-6223 Hydrostatic Test Pressure Holding Time

The hydrostatic test pressure shall be maintained a minimum of 10 min prior to initiation of the examination for leakage required by ND-6224.

ND-6224 Examination for Leakage After Application of Pressure

Following the application of the hydrostatic test pressure for the required time (ND-6223), all joints, connections, and regions of high stress such as regions around openings and thickness transition sections shall be examined for leakage. Except in the case of pumps and valves, which shall be examined while at test pressure, this examination shall be made at a pressure equal to the greater of the Design Pressure or three-fourths of the test pressure, and it shall be witnessed by the Inspector. Leakage of temporary gaskets and seals, installed for the purpose of conducting the hydrostatic test, and which will be replaced later, may be

Page 284

permitted unless the leakage exceeds the capacity to maintain system test pressure for the required amount of time. Other leaks, such as from permanent seals, seats, and gasketed joints in components, may be permitted when specifically allowed by the Design Specifications. Leakage from temporary seals or leakage permitted by the Design Specification shall be directed away from the surface of the component to avoid masking leaks from other joints.

ND-6230 BELLOWS EXPANSION JOINTS

The hydrostatic test requirements for bellows expansion joints shall be as required in (a) through (c) below.

(a) The completed expansion joint shall be subjected to a hydrostatic test in accordance with the applicable provisions of this Article as supplemented by the Design Specifications.

(b) This test may be performed with the bellows fixed in the straight position, at its neutral length, when the design has been shown to comply with ND-3649.4(e)(1) or (e)(2). If the design is to comply with ND-3649(e)(3), this test shall be performed with the bellows fixed at the maximum design rotation angle or offset movement.

(c) In addition to inspecting the expansion joint for leaks and general structural integrity during the test, the Inspector shall also visually inspect the bellows for evidence of meridional yielding as defined in ND-3649.4(b) and for evidence of squirm as defined in ND-3649.4(c). If the design is to comply with ND-3649.4(e)(3), actual measurements shall be made before, during, and after the pressure test in accordance with ND-3649.4(b) and (c).

ND-6240 PROVISION FOR EMBEDDED OR INACCESSIBLE WELDED JOINTS IN PIPING

When welded joints in piping subassemblies or piping systems will be embedded or otherwise inaccessible for inspection at the time of the system hydrostatic test, either of the following alternatives may be employed. Alternative (b) does not apply to brazed joints.

(a) The piping subassembly, or portion of the piping system which is to be embedded, or will otherwise be inaccessible, shall be hydrostatically tested at some point in the fabrication or installation prior to embedment or inaccessibility.

(b) Radiography shall be performed on all circumferential butt welds, and either magnetic particle or liquid penetrant examination shall be performed on all fillet or socket welds in accordance with the requirements of ND-5000. The longitudinal butt welds shall meet the requirements of ND-2000. The hydrostatic test may then be performed after embedment using maintenance of pressure as the acceptance criterion for those welds only. The system shall be pressurized to the hydrostatic test pressure and then isolated from the pressurizing source for a period of 1 hr/in. of wall thickness but not less than 1 hr. During the test period, there shall be no drop in pressure.²

ND-6300 PNEUMATIC TESTS

ND-6310 PNEUMATIC TESTING PROCEDURES

ND-6311 General Requirements

When a pneumatic test is performed, it shall be conducted in accordance with the requirements of ND-6100 and this Subarticle.

ND-6312 Test Medium and Test Temperature

- (a) The gas used as the test medium shall be non flammable.
- (b) Testing temperature shall be in accordance with ND-6212(b).

ND-6313 Procedure for Applying Pressure

The pressure in the system shall gradually be increased to not more than one-half of the test pressure, after which the pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached.

ND-6320 PNEUMATIC TEST PRESSURE REQUIREMENTS

ND-6321 Minimum Required Pneumatic Test Pressure

- (a) The installed system shall be pneumatically tested at not less than 1.25 times the lowest Design Pressure of any component within the boundary protected by the overpressure protection devices which satisfy the requirements of ND-7000.

2 Temperature fluctuations within the piping system may affect the pressure. Precautions must be taken to ensure that the test is not biased by temperature effects.

Page 285

- (b) Valves shall be pneumatically tested in accordance with the rules of ND-3500.
- (c) Components shall be pneumatically tested at not less than 1.25 times their Design Pressure.

ND-6322 Maximum Permissible Test Pressure

The maximum test pressure shall be limited as defined in ND-6222.

ND-6323 Test Pressure Holding Time

The test pressure of ND-6321 shall be maintained for a minimum total time of 10 min.

ND-6324 Examination for Leakage After Application of Pressure

Following the application of pressure for the time specified in ND-6323, the test pressure shall be reduced to a value equal to the greater of the Design Pressure or three-fourths of the test pressure, and held for a sufficient time to permit examination as defined in ND-6224.

ND-6330 BELLOWS EXPANSION JOINTS

When a pneumatic test is performed on a bellows expansion joint in lieu of a hydrostatic test, the requirements of ND-6230 shall be met.

ND-6400 PRESSURE TEST GAGES

ND-6410 REQUIREMENTS FOR PRESSURE TEST GAGES

ND-6411 Types of Gages to Be Used and Their Location

Pressure test gages used in pressure testing shall be indicating pressure gages and shall be connected directly to the component. If the indicating gage is not readily visible to the operator controlling the pressure applied, an additional indicating gage shall be provided where it will be visible to the operator throughout the duration of the test. For systems with a large volumetric content, it is recommended that a recording gage be used in addition to the indicating gage.

ND-6412 Range of Indicating Pressure Gages

(a) Analog-type indicating pressure gages used in testing shall be graduated over a range not less than $1\frac{1}{2}$ times nor more than 4 times the test pressure.

(b) Digital-type pressure gages may be used without range restriction provided the combined error due to calibration and readability does not exceed 1% of the test pressure.

ND-6413 Calibration of Pressure Gages

All test gages shall be calibrated against a standard dead weight tester or a calibrated master gage. The test gages shall be calibrated before each test or series of tests. A series of tests is that group of tests, using the same pressure test gage or gages, which are conducted within a period not exceeding 2 weeks.

ND-6500 ATMOSPHERIC AND 0-15 psig (0-103 kPa) STORAGE TANKS

ND-6510 TESTING OF ATMOSPHERIC STORAGE TANKS

ND-6511 Testing of Reinforcement Pads

Following the examination specified in ND-5282.5 and before filling the tank with test water, the reinforcement pads shall be tested by applying up to 15 psi (103 kPa) pneumatic pressure between the tank shell and the reinforcement plate on each opening, using the telltale hole; and while each such space is subject to such pressure, soapsuds, linseed oil, or other suitable material for detection of leaks shall be applied to all attachment welding around reinforcement, both inside and outside the tank.

ND-6512 Preparation for Testing

Preparation for testing of storage tanks shall conform to the requirements of ND-6120 as applicable. Flat bottoms supported directly on grade need not comply with ND-6121.

ND-6513 Hydrostatic Testing of Tank Shell

Upon completion of the tank, the shell shall be tested. For tanks with supported cone, self-supported cone, self-supported dome, and self-supported umbrella roofs, the tank shall be filled with water and inspected frequently during the filling operation. The filling height shall be 2 in. (51 mm) above the top leg of the angle.

Page 286

For tanks with flat roofs, the filling height shall be the liquid level for which the tank was designed or the bottom of any overflow which limits the filling height.

ND-6520 TESTING OF 0-15 psig (0-103 kPa) STORAGE TANKS

ND-6521 Testing of Reinforcement Pads

Following the examination specified in ND-5283.6 and before performing the preliminary pneumatic testing, the reinforcement pads shall be tested by using the same procedure as given in ND-6511.

ND-6522 Preparation for Testing

Preparation for testing of storage tanks shall conform to the requirements of ND-6120, as applicable. Flat bottoms supported directly on grade need not comply with ND-6121.

ND-6523 Preliminary Pneumatic Testing

Prior to the application of the hydrostatic or combination hydrostatic-pneumatic test, the tank shall be filled with air to a pressure of 2 psig (13.8 kPa) or one-half the pressure P_G for which the vapor space at the top of the tank is designed, whichever pressure is smaller. Soapsuds shall be applied to all joints in the tank wall above the high liquid design level. If any leaks appear, the defective condition shall be corrected and the applicable preliminary tightness test shall be repeated. In the case of a tank whose bottom rests directly on the tank grade without having anchor bolts provided near the

boundary of contact to hold it down, if the bottom at this boundary rises slightly off the foundation during the tightness test with air pressure in the tank, sand shall be tamped firmly under the bottom, while the tank is under pressure, to fill the gap so formed.

ND-6524 Combination Hydrostatic-Pneumatic Tests

The following requirements apply to tanks which have not been designed to be filled with liquid to a test level higher than their specified capacity level.

ND-6524.1 Pressurizing.

After the preliminary tests specified in ND-6523 have been completed, the pressure relief valve or valves shall be blanked off. With the top of the tank vented to atmosphere to prevent accumulation of pressure, the tank shall be filled with water to its high liquid level. The vents at the top of the tank shall then be closed and air shall be injected slowly into the top of the tank until the pressure in the vapor space is about one-half the pressure P_G for which this space is designed. Thereafter, the test pressure shall be increased in steps of approximately 2 psig (13.8 kPa) or one-fourth of the intended test pressure, whichever is the smaller, until the pressure in the vapor space is 1.25 times the pressure P_G for which this space is designed. Means shall be provided so that the required test pressure will not be exceeded.

ND-6524.2 Time at Pressure.

The pressure in the tank shall be held stationary for a reasonable time after the application of each increment of pressure as specified so as to provide an opportunity to examine the tank carefully for signs of distress. The maximum test pressure of 1.25 times the vapor space design pressure shall be held for at least 1 hr, after which the pressure shall be reduced slowly to the vapor space design pressure.

ND-6524.3 Soap Bubble Test.

The vapor space design pressure shall be held for a sufficient time to permit a close visual examination of all joints in the walls of the tank and of all welding around manways, nozzles, and other connections. In this examination, soapsuds shall be applied to all weld joints located above the high liquid design level for which the tank is designed, including the roof-to-sidewall joint. This examination is not required for welds subject to radiography.

ND-6524.4 Precautions to Be Employed in Pneumatic Testing.

An air test as specified in ND-6523 and in ND-6524 introduces some hazard. In view of the large amount of air which will be present during such a test, it is recommended that no one be permitted to go near the tank while the pressure is being applied for the first time in this test. While the pressure in the tank exceeds the pressure for which the vapor space is designed, the inspections should be made from a reasonable distance from the tank using optical aids, if necessary, for observations of particular areas.

ND-6525 Hydrostatic Test

The following requirements apply to tanks which have been designed and constructed to be filled with liquid to the top of the roof.

ND-6525.1 Filling.

Following the preliminary tests specified in ND-6523 the pressure relief valve or valves shall be blanked off. With the top of the tank vented

Page 287

to atmosphere, the tank shall be filled with water to the top of the roof, while allowing all air to escape in order to prevent accumulation of pressure. The vents on the tank shall be closed and the pressure in the tank shall be increased slowly until the hydrostatic pressure under the topmost point in the roof is 1.25 times the pressure P_G for which the vapor space is designed to withstand when in operation with the tank filled to its specified high liquid level.

ND-6525.2 Pressurizing.

Test pressure may be developed either by (a) or (b) below:

(a) pumping water into the tank with all vents closed;

(b) superimposing a vertical pipe, not less than NPS 6 (DN 150), above the top of the tank with an overflow located at such a height as to give the desired test pressure by static head alone and then filling the pipe to the level of said overflow.

ND-6525.3 Time at Pressure.

Test pressure shall be held for at least 1 hr. The hydrostatic pressure under the roof shall then be reduced to the Design Pressure and shall be held at this level for a sufficient time to permit close visual examination of all joints in the walls of the tank, and of all welding around manways, nozzles, and other connections.

ND-6526 Partial Vacuum Testing Procedure

Following the tests specified in ND-6524 or in ND-6525, the pressure in the tank shall be released and a manometer shall be connected to the vapor space. The ability of that part of the tank to withstand the partial vacuum for which it is designed shall then be checked by withdrawing water from the tank or by air evacuation, with all vents closed, until the design partial vacuum is developed. Careful observations shall be made under the above condition of loading to determine whether any appreciable changes occur in the shape of the tank.

ND-6530 TEST GAGES

ND-6531 Indicating Gage and Its Location

An indicating gage shall be connected directly to the topmost part of the roof on the tank under test, except that, in the case of a tank which is designed for storage of gases or vapors alone and is to be tested only with air, this gage may be connected to the tank at some lower level. If the indicating gage is not readily visible to the operator controlling the pressure applied, an additional indicating gage shall be provided where it will be visible to the operator throughout the duration of the test. Means shall be provided so that the required test pressure will not be exceeded.

ND-6532 Recording Gage and Its Location

A recording gage shall also be used on each tank and a record shall be kept of the pressures during all stages of the tests. This gage shall be connected either to the piping leading to the indicating gage or directly to the tank at a point near the indicating gage connection.

ND-6533 Accumulation of Static Head on Gages

In all cases in which a gage is mounted at a level lower than its connection to the tank or lower than some part of the piping leading to the gage, suitable precautions shall be taken to prevent accumulation of any static head of condensed moisture or water from other sources in the piping leads above the level of the gage.

ND-6534 Calibration of Pressure Test Gages

All test gages shall be calibrated against a standard deadweight tester or a calibrated master gage. The test gages shall be calibrated before each test or series of tests. A series of tests is that group of tests using the same pressure test gage or gages, which are conducted in a period not exceeding 2 weeks.

ND-6600 SPECIAL TEST PRESSURE SITUATIONS

ND-6610 COMPONENTS DESIGNED FOR EXTERNAL PRESSURE

Components designed for external pressure only shall be subjected to an internal test pressure at 1.25 times the design external pressure. The pressure shall be under proper control so that the required test pressure is never exceeded by more

than 6%.

ND-6620 PRESSURE TESTING OF COMBINATION UNITS

ND-6621 Pressure Chambers Designed to Operate Independently

Pressure chambers of combination units that have been designed to operate independently shall be pressure

Page 288

tested as separate vessels; that is, each chamber shall be tested without pressure in the adjacent chamber.

ND-6622 Common Elements Designed for a Maximum Differential Pressure

(a) When pressure chambers of combination units have their common elements designed for the maximum differential pressure that can occur during startup, operation, and shutdown, and the differential pressure is less than the higher of the Design Pressures of the adjacent chambers, the common elements shall be subjected to a pressure test of at least 1.25 times the maximum differential pressure.

(b) Following the test of the common elements as required by ND-6622(a) and their inspection, the adjacent chambers shall be pressure tested (ND-6221). Care must be taken to limit the differential pressure between the chambers to the pressure used when testing the common elements.

ND-6900 PROOF TESTS TO ESTABLISH DESIGN PRESSURE

ND-6910 GENERAL REQUIREMENTS

ND-6911 Establishment by Test of Design Pressure

The Design Pressure for components and piping or component parts for which the strength cannot be computed with a satisfactory assurance of accuracy, shall be established in accordance with the requirements of this Subarticle, using one of the test procedures applicable to the type of loading and to the material used in construction.

ND-6911.1 Types of Proof Tests.

Provision is made in these rules for two types of tests to determine the internal Design Pressure:

(a) tests based on yielding of the part to be tested (these tests are limited to materials with a ratio of specified minimum yield to specified minimum ultimate strength of 0.625 or less);

(b) tests based on bursting of the part.

ND-6911.2 Purpose for Which Proof Tests May Be Used.

The tests in this Subarticle may be used only for the purpose of establishing the Design Pressure of those elements or component parts for which the thickness cannot be determined by means of the design rules given in this Subsection. The Design Pressure of all other elements or component parts shall not be greater than that determined by means of the applicable design rules.

ND-6911.3 Permissible Previous Pressurization of Component or Part.

The component or component part for which the Design Pressure is to be established shall not previously have been subjected to a pressure greater than $1\frac{1}{2}$ times the desired or anticipated Design Pressure adjusted for Design Temperature as provided in ND-6911.9.

ND-6911.4 Test Requirements for Duplicate Components or Parts.

When the Design Pressure of a component or component part has been established by a proof test, duplicate parts of the same materials, design, and construction need not be proof tested but shall be given a hydrostatic test in accordance with ND-6200 or a pneumatic test in accordance with ND-6300. The dimensions and minimum thickness of the structure

to be tested shall not vary materially from those actually used. A geometrically similar part may be qualified by a series of tests covering the complete size range of the pressure part.

ND-6911.5 Application of Pressure.

In the procedures given in ND-6921, ND-6923, and ND-6924, the hydrostatic pressure in the component or component part shall be increased gradually until approximately one-half the anticipated Design Pressure is reached. Thereafter, the test pressure shall be increased in steps of approximately one-tenth or less of the anticipated Design Pressure until the pressure required by the test procedure is reached. The pressure shall be held stationary at the end of each increment for a sufficient time to allow the observations required by the test procedure to be made and shall be released to zero to permit determination of any permanent strain after any pressure increment that indicates an increase in strain or displacement over the previous equal pressure increment.

ND-6911.6 Check of Measurements.

As a check that the measurements are being taken on the most critical areas, the Inspector may require a lime wash or other brittle coating to be applied on all areas of probable high stress concentrations in the test procedures given in ND-6923 and ND-6924. The surfaces shall be suitably cleaned before the coating is applied in order to obtain satisfactory adhesion. The technique shall be suited to the coating material.

ND-6911.7 Determination of Design Pressure for Components or Parts Having Corrosion Allowance.

The test procedures in this Subarticle give the Design Pressure for the thickness of material tested. When the

Page 289

thickness as tested includes extra thickness as provided in ND-3121, the Design Pressure at which the component shall be permitted to operate shall be determined by multiplying the Design Pressure obtained from the test by the ratio:

$$(t - c)/t$$

where

t	= nominal thickness of the material at the weakest point, in.
c	= allowance added for corrosion, erosion, and abrasion, in.

ND-6911.8 Determination of Yield Strength and Tensile Strength

(a) For proof tests based on yielding (ND-6921, ND-6923, or ND-6924), the yield strength (or yield point for those materials which exhibit that type of yield behavior indicated by a "sharp-kneed" portion of the stress-strain diagram) of the material in the part tested shall be determined in accordance with the method prescribed in the applicable material specification and as described in ASTM E 8-1972. For proof tests based on bursting, ND-6922, the tensile strength instead of the yield strength of the material in the part tested shall be similarly determined.

(b) Yield or tensile strength so determined shall be the average from three or four specimens cut from the part tested after the test is completed. The specimens shall be cut from a location where the stress during the test has not exceeded the yield strength. The specimens shall not be flame cut because this might affect the strength of the material. If yield or tensile strength is not determined by test specimens from the pressure part tested, alternative methods are given in ND-6921, ND-6922, ND-6923, and ND-6924 for evaluation of proof test results to establish the Design Pressure.

(c) When excess stock from the same piece of wrought material is available and has been given the same stress relieving heat treatment as the pressure part, the test specimens may be cut from this excess stock. The specimens shall not be removed by flame cutting or any other method involving sufficient heat to affect the properties of the specimen.

ND-6911.9 Design Pressure at Higher Temperatures.

The Design Pressure for components and component parts that are to operate at temperatures at which the allowable stress value of the material is less than at the test temperature shall be determined by the following formula:

where

P_o	= Design Pressure at the Design Temperature, psig
P_t	= Design Pressure at test temperature, psig
S_o	= maximum allowable stress value at the Design Temperature, psi
S_t	= maximum allowable stress value at test temperature, psi

ND-6912 Retests

A retest shall be allowed on a duplicate component or component part if errors or irregularities are obvious in the test results.

ND-6913 Witnessing of Tests by Inspector

Tests to establish the Design Pressure of components or component parts shall be witnessed and approved by the Inspector.

ND-6914 Safety Precautions

Safety of testing personnel should be given serious consideration when conducting proof tests, and particular care should be taken during bursting tests in ND-6922.

ND-6920 PROCEDURES

[98]

ND-6921 Brittle Coating Test Procedure

(a) Subject to the limitations of ND-6911.1(a), this procedure may be used only for components and component parts under internal pressure, constructed of materials having a definitely determinable yield point. The component parts that require proof testing shall be coated with a lime wash or other brittle coating in accordance with ND-6911.6. Pressure shall be applied in accordance with ND-6911.5. The parts being proof tested shall be examined between pressure increments for signs of yielding as evidenced by flaking of the brittle coating or by the appearance of strain lines. The application of pressure shall be stopped at the first sign of yielding or, if desired, at some lower pressure.

(b) The Design Pressure P in psig at test temperature for components or component parts tested under ND-6921 shall be computed as stipulated in (1) through (4) below.

Page 290

(1) If the average yield strength is determined in accordance with ND-6911.8:

$$P = 0.5H \frac{Y_s}{Y_a}$$

(2) To eliminate the necessity of cutting tensile specimens and determining the actual yield strength of the material under test, one of the following equations may be used to determine the Design Pressure.

(a) For carbon steel meeting an acceptable specification in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 with a specified minimum tensile strength of not over 70.0 ksi:

$$P = 0.5H \left(\frac{S}{S + 5000} \right) \quad (1)$$

(1)

(b) For any other acceptable material listed in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3:

$$(2) P = 0.4H$$

where

H	= hydrostatic test pressure at which the test was stopped, psig
Y_s	= specified minimum yield strength, psi
Y_a	= actual average yield strength from test specimens, psi
S	= specified minimum tensile strength, psi

(3) When Eq. (1) or (2) is used, the material in the pressure part shall have had no appreciable cold working or other

treatment that would tend to raise the yield strength above the normal value.

(4) The Design Pressure at other temperatures shall be determined as provided in ND-6911.9.

[98]

ND-6922 Bursting Test Procedure

(a) This procedure may be used for components or component parts under internal pressure when constructed of any material permitted to be used under the rules of this Subsection. The Design Pressure of any component part proof tested by this method shall be established by a hydrostatic test to failure by rupture of a full-size sample of such pressure part. The hydrostatic pressure at which rupture occurs shall be determined.

(b) The Design Pressure P in psig at test temperature for parts tested under ND-6922 shall be computed as stipulated in (1) through (3) below.

(1) Parts constructed of materials other than cast materials:

$$P = \frac{B}{5} \times \frac{SE}{S_{ave}} \quad \text{or} \quad P = \frac{B}{5} \times \frac{SE}{S_{max}} \quad (3)$$

(3)

(2) Parts constructed of cast materials, except cast iron and cast nodular iron which are not permitted:

$$P = \frac{Bf}{5} \times \frac{SE}{S_{ave}} \quad \text{or} \quad P = \frac{Bf}{5} \times \frac{SE}{S_{max}} \quad (4)$$

(4)

where

B	= bursting test pressure, psig
E	= efficiency of welded joint, if used (ND-3352-1)
f	= casting quality factor (ND-3115)
S	= specified minimum tensile strength, psi
S_{ave}	= average actual tensile strength of test specimens, psi

$S_{\max}$

= maximum tensile strength of range of specification, psi

(3) The Design Pressure at other temperatures shall be determined as provided in ND-6911.9.

ND-6923 Strain Measurement Test Procedure

(a) Subject to limitations of ND-6911.1(a), this procedure may be used for components or component parts under internal pressure, constructed of any material permitted to be used under the rules of this Subsection. Strains shall be measured in the direction of the maximum stress at the most highly stressed parts (see ND-6911.6) by means of strain gages of any type capable of indicating strains to 0.00005 in./in. Pressure shall be applied as provided in ND-6911.5.

(b) After each increment of pressure has been applied, readings of the strain gages and the hydrostatic pressure shall be taken and recorded. The pressure shall be released and any permanent strain at each gage shall be determined after any pressure increment that indicates an increase in strain for this increment over the previous equal pressure increment. Only one application of each increment of pressure is required.

(c) Two curves of strain against test pressure shall be plotted for each gage line as the test progresses, one showing the strain under pressure and one showing the permanent strain when the pressure is removed. The test may be discontinued when the test pressure reaches the value H which will, by the equation, justify the desired Design Pressure, but shall not exceed the pressure at which the plotted points for the most highly

Page 291

strained gage line reach the value given below for the material used:

(1) 0.2% permanent strain for aluminum-base and nickel-base alloys

(2) 0.2% permanent strain for carbon low alloy and high alloy steels

(3) 0.5% strain under pressure for copper-base alloys

(d) The Design Pressure P in psig at test temperature for parts tested under this paragraph shall be computed as stipulated in (1) through (3) below.

(1) If the average yield strength is determined in accordance with ND-6911.8:

$$P = 0.5H \left(\frac{Y_s}{Y_a} \right) \quad (5)$$

(5)

(2) If the actual average yield strength is not determined by test specimens:

$$(6) P = 0.4H$$

where

H

= hydrostatic test pressure at which the test was stopped in accordance with (c) above, psig

Y_s

= specified minimum yield strength, psi

Y_a

= actual average yield strength from test specimens, psi

(3) The Design Pressure at other temperatures shall be determined as provided in ND-6911.9.

[98]

ND-6924 Displacement Measurement Test Procedure

(a) Subject to the limitations of ND-6911.1(a), this procedure may be used only for components and component parts under internal pressure, constructed of materials having a definitely determinable yield point. Displacement shall be measured at the most highly stressed parts (ND-6911.6) by means of measuring devices of any type capable of measuring to 0.001 in. The displacement may be measured between two diametrically opposed reference points in a symmetrical structure or between a reference point and a fixed base point. Pressure shall be applied as provided in ND-6911.5.

(b) After each increment of pressure has been applied, readings of the displacement and hydrostatic test pressure shall be taken and recorded. The pressure shall be released, and any permanent displacement shall be determined after any pressure increment that indicates an increase in measured displacement for this increment over the previous equal pressure increment. Only one application of each increment is required. Care must be taken to assure that the readings represent only displacements of the parts on which measurements are being made, and do not include any slip of the measuring devices or any movement of the fixed base points or of the pressure part as a whole.

(c) Two curves of displacement against test pressure shall be plotted for each reference point as the test progresses, one showing the displacement under pressure and one showing the permanent displacement when the pressure is removed. The application of pressure shall be stopped when it is evident that the curve through the points representing displacement under pressure has deviated from a straight line.

(d) The pressure coincident with the proportional limit of the material shall be determined by noting the pressure at which the curve representing displacement under pressure deviates from a straight line. The pressure at the proportional limit may be checked from the curve of permanent displacement by locating the point where the permanent displacement begins to increase regularly with further increases in pressure. Permanent deformation at the beginning of the curve that results from the equalization of stresses and irregularities in the material may be disregarded.

(e) The Design Pressure P in psig at test temperature for parts tested under this paragraph shall be computed as stipulated in (1) through (4) below.

(1) If the average yield strength is determined in accordance with ND-6911.8:

$$P = 0.5H \frac{Y_s}{Y_a} \quad (7)$$

(7)

(2) To eliminate the necessity of cutting tensile specimens and determining the actual yield strength of the material

under test, Eq. (8) or (9) may be used to determine the Design Pressure.

(a) For carbon steel, meeting an acceptable specification in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 with a specified minimum tensile strength of not over 70.0 ksi:

$$P = 0.5H \left(\frac{S}{S + 5000} \right) \quad (8)$$

(8)

(b) For any other acceptable material listed in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3:

Page 292

$$(9) P = 0.4H$$

where

H	= hydrostatic test pressure coincident with the proportional limit of the weakest element of the component part test, psig
Y_s	= specified minimum yield strength, psi
Y_a	= actual average yield strength from test specimens, psi
S	= specified minimum tensile strength, psi

(3) When Eq. (8) or (9) is used, the material in the pressure part shall have had no appreciable cold working or other treatment that would tend to raise the yield strength above the normal value.

(4) The Design Pressure at other temperatures shall be determined as provided in ND-6911.9.

[98]

ND-6930 PROCEDURE FOR COMPONENTS HAVING CHAMBERS OF SPECIAL SHAPE SUBJECT TO COLLAPSE

(a) Pressure chambers of components, portions of which have a shape other than that of a complete circular cylinder or formed head, and also jackets of cylindrical vessels which extend over only a portion of the circumference, which are not fully staybolted as required by ND-3133 and ND-3329, shall withstand without excessive deformation a hydrostatic test of not less than 3 times the desired Design Pressure.

(b) The Design Pressure at other temperatures shall be determined as provided in ND-6911.9.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 ND-7000

ND-7100 GENERAL REQUIREMENTS

ND-7110 SCOPE

(a) A system¹ shall be protected from the consequences arising from the application of conditions of pressure and coincident temperature that would cause the Design Pressure specified in the Design Specification to be exceeded.

(b) Pressure relief devices are required when the operating conditions considered in the Overpressure Protection Report would cause the Service limits specified in the Design Specification to be exceeded.

(c) Protection of components in the system from the effects of pressure increases of extremely short duration, such as water hammer resulting from the rapid closing of a valve, is beyond the scope of this Article and should be included in the Design Specification.

ND-7111 Definitions

(a) Overpressure, as used in this Article, can consist of either one of the following pressure changes:

(1) an increase in system fluid pressure, resulting from thermal imbalances, excess pump flow, and other similar phenomena, capable of causing a system pressure increase of a sufficient duration to be compatible with the dynamic response characteristics of the pressure relief devices listed in this Article; or

(2) changes in differential pressure resulting from thermal imbalances, vapor condensation, and other similar phenomena, capable of causing an internal or external pressure increase of sufficient duration to be compatible with the dynamic response characteristics of the pressure relief devices.

(b) The definitions of pressure relief devices as specified in this Article are in accordance with ASME PTC 25-1994.

¹ Wherever the word system appears in this Article it refers to the component or group of components for which overpressure protection is provided as described in the Overpressure Protection Report.

(c) *Primary pressure* is the pressure of the fluid at the inlet of the pressure relief device.

(d) *Secondary pressure* is that value of pressure existing in the passage between the actual discharge area and the outlet for which the discharge system of the pressure relief devices shall be designed.

ND-7120 INTEGRATED OVERPRESSURE PROTECTION

Overpressure protection of the component shall be provided by one of the following methods as an integrated overpressure protection:

(a) the use of pressure relief devices and associated pressure sensing elements;

(b) a component design not exceeding the service limits specified in the Design Specification [ND-7111(b)].

ND-7130 PROVISIONS FOR CHECKING OPERATION OF PRESSURE RELIEF DEVICES

ND-7131 Design Provisions

Reclosing pressure relief devices shall be designed so that potential impairment of the overpressure protection function from service exposure to fluids can be determined by test or examination.

ND-7132 Construction Provisions

Reclosing pressure relief devices shall be so constructed and installed that their correct operation and the reliability of their associated pressure sensing elements under Service or Test Conditions can be demonstrated as may be required by regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

ND-7140 INSTALLATION PROVISIONS

ND-7141 Installation of Pressure Relief Devices

(a) Pressure relief devices shall be installed at a location as close as practicable to the major source of overpressure anticipated to arise within the pressure retaining boundary of the system under the conditions summarized in the Overpressure Protection Report (ND-7200).

(b) The connection between a component and its pressure relief valve shall have a minimum inside diameter equal to or greater than the nominal inside diameter of the pressure relief valve inlet. The opening in the connection shall be designed to provide direct and unobstructed flow between the component and the pressure relief valve.

(c) The connection between a safety valve and the component it protects shall be not longer than the face-to-face dimension of the corresponding tee fitting of the same diameter and pressure rating listed in ANSI B16.5, ANSI B16.9, or ANSI B16.11, or any length that would cause cumulative line losses of 2% of the relieving pressure. The connection between a safety relief valve or a relief valve and the component it protects shall be such that the accumulated line losses do not exceed 3% of the relieving pressure.

(d) Safety, safety relief, and relief valves shall be installed in an upright position.

(e) The inside areas of the discharge piping from a pressure relief device shall not be less than the inside area of the valve outlet. The size and length of the discharge piping shall be such that any back pressure that may exist or develop will not reduce the relieving capacity of the relieving device(s) below that required to protect the component(s). In the determination of the back pressure, potential for flashing shall be considered.

(f) Valve installation not in accordance with (c), (d), and (e) above may be used provided:

(1) the NV Certificate Holder confirms that the valve design is satisfactory for the valve installation and satisfies the requirements of the valve Design Specification;

(2) the valves are adjusted for acceptable performance and in conformance with the requirements of the valve Design Specification;

(3) technical justification for the adequacy of the installation is provided in the Overpressure Protection Report, including verification that the requirements of (1) and (2) above have been met.

(g) When a rupture disk device is used as the sole pressure relief device, the nominal pipe size of the connections on either side of the rupture disk device shall not be less than the nominal size of the rupture disk device, unless the smaller size connecting pipe is taken into account in determining the capacity of the device.

(h) Rupture disk devices used as the sole pressure relieving device may be installed in any position provided the medium is such that any accumulation of material at the inlet of the rupture disk devices will not impair the proper burst and opening of the rupture disk.

ND-7142 Provisions When Stop Valves Are Used

No stop valve or other device shall be placed relative to a pressure relief device so that it could reduce the overpressure protection below that required by the rules of this Article, unless such stop valves are constructed and installed with controls and interlocks so that the relieving capacity requirements of ND-7300 are met under all conditions of operation of both the system and the stop valves. Means shall be provided such that the operation of controls and interlocks can be verified.

ND-7143 Provisions for Draining Pressure Relief Devices

(a) A pressure relief device installation, whose design is such that liquid or residue can collect on the discharge side of the device and where such liquid or residue could interfere with proper relieving operation, shall be fitted with a drain at the lowest point where the liquid or residue may collect.

(b) If the design of a pressure relief valve is such that liquid or residue can collect on the discharge side of the disk and could interfere with proper relieving operation, the valve shall be fitted with a drain at the lowest point where liquid or residue may collect.

ND-7150 ACCEPTABLE PRESSURE RELIEF DEVICES²

ND-7151 Pressure Relief Valves³

Pressure relief valves may be used in accordance with ND-7170 and ND-7500.

2 A pressure relief device is designed to open to prevent a rise of internal fluid pressure in excess of a specified value due to exposure to emergency or upset conditions. It may be a pressure relief valve, a nonreclosing pressure relief device, or a vacuum relief valve.

3 A pressure relief valve is a pressure relief device which is designed to reclose and prevent the further flow of fluid after normal conditions have been restored.

Page 299

ND-7152 Vacuum Relief Valves

Vacuum relief valves may be used in accordance with ND-7170 and ND-7500.

ND-7153 Nonreclosing Pressure Relief Devices⁴

Nonreclosing pressure relief devices may be used in accordance with ND-7170 and ND-7600.

ND-7160 UNACCEPTABLE PRESSURE RELIEF DEVICES

ND-7161 Deadweight Pressure Relief Valves

Deadweight valves shall not be used.

ND-7170 PERMITTED USE OF PRESSURE RELIEF DEVICES

ND-7171 Valve Types Permitted for Steam Service

Any of the following types or combination of types of pressure relief devices may be used to provide the required relieving capacity:

- (a) safety valves⁵ meeting the requirements of ND-7510;
- (b) pilot operated pressure relief valves⁶ meeting the requirements of ND-7520;
- (c) power actuated pressure relief valves⁷ meeting the requirements of ND-7530;
- (d) safety valves with auxiliary actuating devices meeting the requirements of ND-7540;
- (e) safety relief valves,⁸ meeting the requirements of ND-7510.

4 A nonreclosing pressure relief device is a pressure relief device designed to remain open after operation.

5 A safety valve is a pressure relief valve actuated by inlet static pressure and characterized by rapid opening or pop action.

6 A pilot operated pressure relief valve is a pressure relief valve in which the major relieving device is combined with and controlled by a self-actuated auxiliary pressure relief valve.

7 A power actuated pressure relief valve is a pressure relief valve in which the major relieving device is combined with and controlled by a device requiring an external source of energy.

8 A safety relief valve is a pressure relief valve characterized by rapid opening or pop action, or by opening generally proportional to the increase in pressure over the opening pressure.

ND-7172 Valve Types Permitted for Air and Gas Service

(a) Safety, safety relief, pilot operated, or power actuated pressure relief valves may be used, provided that they comply with the requirements of ND-7500.

(b) Pilot operated or power actuated pressure relief valves may be used, provided that the design is such that the main valve will open automatically at not over the set pressure and will discharge its full rated capacity if some essential part of the pilot or actuator should fail.

(c) Vacuum relief valves⁹ may be used, provided that they comply with the requirements of ND-7500.

ND-7173 Valve Types Permitted for Liquid Service

Safety relief, relief,¹⁰ pilot operated, or power actuated pressure relief valves may be used, provided that they comply with the requirements of ND-7500.

ND-7174 Nonreclosing Devices

(a) Rupture disk devices¹¹ may be used on liquid, air, gas, or steam service, except for main steam service, in accordance with ND-7600.

(b) Application on liquid service shall be evaluated to ensure that the design of the rupture disk device and that the fluid energy of the system on which it is installed will provide adequate opening to meet the requirements of ND-7300.

ND-7200 OVERPRESSURE PROTECTION REPORT

ND-7210 RESPONSIBILITY FOR REPORT

The provisions intended to meet the requirements of this Article shall be the subject of an Overpressure Protection report prepared by the Owner or his Designee.

9 A vacuum relief valve is a pressure relief device designed to admit fluid to prevent an excessive internal vacuum; it is designed to reclose and prevent further flow of fluid after normal conditions have been restored.

10 A relief valve is a pressure relief valve actuated by inlet static pressure and having a gradual lift generally proportional to the increase in pressure over the opening pressure.

11 A rupture disk device is a nonreclosing pressure relief device actuated by inlet static pressure and designed to function by the bursting of a pressure containing disk.

Page 300

ND-7220 CONTENT OF REPORT

The Overpressure Protection Report shall define the protected systems and the integrated overpressure protection provided. As a minimum, the Report shall include (a) through (f) below:

(a) identification of the specific ASME Code Section III, Article ND-7000, Edition and Addenda and applicable Code Cases used in the design of the overpressure protection system;

(b) drawings showing arrangement of the protected systems, including the pressure relief devices employed;

(c) the range of operating conditions, including the effect of discharge piping back pressure under which the pressure relief devices are required to function;

(d) an analysis of the conditions that give rise to the maximum pressure or vacuum relieving requirements, except where the basis for establishing relieving capacity is the loss of the heat sink of the protected system when the thermal input to the system is at a maximum;

(e) consideration of burst pressure tolerance and manufacturing design range of the rupture disk device;

(f) the relief capacity required to prevent a pressure or vacuum rise in any component from exceeding the limitations of ND-7300;

(g) the redundancy and independence of the pressure relief devices and their associated pressure or vacuum sensors and controls employed to preclude a loss of overpressure protection in the event of a failure of any pressure relief device, sensing element, associated control, or external power source.

ND-7230

The report, after it has been reconciled with the requirements of this Subsection, shall be certified by one or more Registered Professional Engineers competent in the applicable field of design and qualified in accordance with the requirements of Appendix XXIII of Section III Appendices.

ND-7240 REVIEW OF REPORT AFTER INSTALLATION

(a) Any modification of the installation from that used for preparation of the Overpressure Protection Report shall be reconciled with the Overpressure Protection Report.

(b) Modifications shall be documented in an addendum to the Overpressure Protection Report. The addendum shall contain a copy of the as-built drawing and shall include either:

- (1) a statement that the as-built system meets the requirements of the Overpressure Protection Report; or
- (2) a revision to the Overpressure Protection Report to make it agree with the as-built system; or
- (3) a description of the changes made to the as-built system to make it comply with the Overpressure Protection Report.

(c) The addendum shall be certified by one or more Registered Professional Engineers competent in the applicable field of design and qualified in accordance with the requirements of Appendix XXIII of Section III Appendices.

ND-7250 FILING OF REPORT

A copy of the Overpressure Protection Report shall be filed at the nuclear power plant site prior to the Inspector signing the Owner's Data Report. The report shall be made available to the Authorized Inspector and the enforcement authorities having jurisdiction at the plant site.

ND-7300 RELIEVING CAPACITY REQUIREMENTS

ND-7310 TOTAL RATED RELIEVING CAPACITY FOR SYSTEM UPSET CONDITIONS

ND-7311 Relieving Capacity of Pressure Relief Devices

(a) The total rated relieving capacity of the pressure relief devices (certified in accordance with ND-7700, intended for overpressure protection within the scope of this Subsection, and credited in conformance with ND-7500 or ND-7600) shall take into account any limitations due to fluid flow through piping and other components.

(b) The total rated relieving capacity shall be sufficient to prevent a rise in pressure of more than 10% above the Design Pressure of any component within the pressure retaining boundary of the protected system under any system upset conditions.

(c) The rated capacity of each vacuum relief valve shall not be less than that required to prevent a differential pressure in excess of the value specified in the Design Specification.

Page 301

ND-7312 Relieving Capacity of Pressure Relief Devices Used With Pressure Reducing Devices

When pressure reducing devices are used, the relieving capacity of the pressure relief devices shall be based on (a) and (b) below.

(a) Pressure reducing devices shall be considered fully open, including open bypass piping, if provided.

(b) The discharge from the low pressure portion shall be considered blocked downstream of the pressure reducing device.

ND-7313 Required Number and Capacity of Pressure Relief Devices

(a) Systems or components requiring individual protection may be served by one or more devices.

(b) When more than one device is used, no device shall have a capacity less than 50% of the device with the largest capacity.

ND-7314 Required Number and Capacity of Pressure Relief Devices for Isolatable Components Requiring Overpressure Protection

(a) The required relieving capacity for overpressure protection of an individual component that is isolatable shall be secured by the use of at least one pressure relief device meeting the requirements of ND-7500 or ND-7600, as applicable.

(b) Certain types of valves have the capability of trapping liquid in the body or bonnet cavity. If such a cavity accumulates liquid and there is an increase in the adjacent system temperature, an increase in pressure in the body or bonnet cavity may result (ND-3511).

ND-7315 Relieving Capacity of Vacuum Relief Valves

(a) The rated capacity of each vacuum relief valve shall not be less than that required to prevent a differential pressure in excess of the value specified in the Design Specification.

(b) At least two independent vacuum relief valves shall be provided on each system. The capacity of each vacuum relief valve shall not be less than that required to protect the system.

(c) Systems designed to withstand the maximum differential pressure do not require vacuum relief valves.

ND-7320 TOTAL RATED RELIEVING CAPACITY FOR SYSTEM EMERGENCY CONDITIONS

ND-7321 Relieving Capacity of Pressure Relief Devices

(a) The total rated relieving capacity of the pressure relief devices (certified in accordance with ND-7700, intended for overpressure protection within the scope of this Subsection, and credited in conformance with ND-7500 or ND-7600) shall take into account any limitations due to fluid flow through piping and other components.

(b) The total rated relieving capacity shall be sufficient to prevent a rise in pressure of more than 10% above the Design Pressure of any component within the pressure retaining boundary of the protected system under any system emergency conditions.

ND-7322 Relieving Capacity of Vacuum Relief Valves

(a) The rated capacity of each vacuum relief valve shall not be less than that required to prevent a differential pressure in excess of the value specified in the Design Specification.

(b) At least two independent vacuum relief valves shall be provided on each system. The capacity of each vacuum relief valve shall not be less than that required to protect the system.

(c) Systems designed to withstand the maximum differential pressure do not require vacuum relief valves.

ND-7330 SYSTEM FAULTED CONDITIONS

This Article does not provide rules for overpressure protection of system faulted conditions.

ND-7400 SET PRESSURES OF PRESSURE RELIEF DEVICES

ND-7410 SET PRESSURE LIMITATIONS FOR UPSET CONDITIONS

The set pressure of at least one of the pressure relief devices connected to the system shall not be greater than the Design Pressure of any component within the pressure retaining boundary of the protected system. Additional pressure relief devices may have higher pressure settings, but in no case shall these settings be such that the total accumulated pressure exceeds the system limitations specified in ND-7310.

ND-7420 SET PRESSURE FOR EMERGENCY CONDITIONS

The establishment of set pressure shall take into account the requirements of ND-7320.

ND-7500 OPERATING DESIGN REQUIREMENTS FOR PRESSURE AND VACUUM RELIEF VALVES

ND-7510 SAFETY, SAFETY RELIEF, AND RELIEF VALVES

ND-7511 General Requirements

ND-7511.1 Spring-Loaded Valves.

Valves shall open automatically by direct action of the fluid pressure as a result of forces acting against a spring.

ND-7511.2 Balanced Valves.

Balanced valves, whose operation is independent of back pressure, may be used if means are provided to verify the integrity of the balancing devices.

ND-7512 Safety Valve Operating Requirements

ND-7512.1 Antichattering and Lift Requirements.

Safety valves shall be constructed to operate without chattering and to attain rated lift at a pressure which does not exceed the set pressure by more than 3% or 2 psi, whichever is greater.

ND-7512.2 Opening Pressure Tolerance

(a) The opening pressure tolerance plus or minus shall not exceed the following: 2 psi (13.8 kPa) for pressures up to and including 70 psi (483 kPa); 3% for pressures over 70 psi (483 kPa) to 300 psi (2070 kPa); 10 psi (69 kPa) for pressures over 300 psi (2070 kPa) to 1000 psi (6900 kPa); and 1% for pressures over 1000 psi (6900 kPa). The set pressure tolerance shall apply unless a greater tolerance is established as permissible in the Overpressure Protection Report (ND-7200) and in the safety valve Design Specification (NCA-3250).

(b) Conformance with the requirements of (a) above shall be established for each production valve by test. Steam valves shall be tested on steam.

ND-7512.3 Blowdown Requirements.

Safety valves shall be adjusted to close after blowing down to a pressure not lower than that specified in the valve Design Specification (NCA-3250) and the basis for the setting is covered in the Overpressure Protection Report (NB-7200). The adjustment shall be determined by test or by proration from the Certificate Holder's blowdown test data.

ND-7513 Safety Relief and Relief Valve Operating Requirements

Safety relief and relief valves shall be constructed to attain rated lift at a pressure which does not exceed the set pressure by more than 10% or 3 psi (20.6 kPa), whichever is greater.

ND-7513.1 Opening Pressure Tolerance

(a) The opening pressure tolerance plus or minus from the set pressure of safety relief and relief valves shall not exceed 2 psi (13.8 kPa) for pressures up to and including 70 psi (483 kPa) and 3% for pressures above 70 psi (483 kPa). The set pressure tolerance shall apply unless a greater tolerance is established as permissible in the Overpressure Protection Report (ND-7200) and in the valve Design Specification (NCA-3250).

(b) Conformance with the requirements of (a) above shall be established for each production valve by test. Steam

valves shall be tested on steam, air or gas valves on air or gas, and liquid valves on liquid.

ND-7513.2 Blowdown Requirements.

Safety relief and relief valves shall be adjusted to close after blowing down to a pressure not lower than that specified in the valve Design Specification (NCA-3250) and the basis for the setting shall be covered in the Overpressure Protection Report (ND-7200). The adjustment shall be determined by test or by proration from the Certificate Holder's blowdown test data.

ND-7514 Relieving Capacity

The relieving capacity of pressure relief valves of the types permitted in this Subarticle shall be based on the stamped relieving capacity and proration of capacity as determined by ND-7700.

ND-7515 Sealing of Adjustments

Means shall be provided in the design of all valves for sealing all adjustments or access to adjustments which can be made without disassembly of the valve. For a pilot operated pressure relief valve, an additional seal shall be provided to seal the pilot and main valve together. Seals shall be installed by the Certificate Holder at the time of initial adjustment. Seals shall be installed in a manner to prevent changing the adjustment or disassembly of the valve without breaking the seal.

Page 303

The seal shall serve as a means of identifying the Certificate Holder making the initial adjustment.

ND-7520 PILOT OPERATED PRESSURE RELIEF VALVES

ND-7521 General Requirements

Pilot operated pressure relief valves shall operate independently of any external energy source.

ND-7522 Operating Requirements

ND-7522.1 Actuation.

The pilot control device shall be actuated directly by the fluid pressure of the protected system.

ND-7522.2 Response Time.

The Overpressure Protection Report (ND-7200) shall include the effects of divergence between opening (set) and closing (blow down) pressures of the pilot valve and the pressures at which the main valve attains rated lift and closes. These divergences are caused by the inherent time delay (i.e., response time) between the operation of the pilot and the main valve, and the rate of the system pressure change. The limits for response time shall be specified in the valve Design Specification (NCA-3250).

ND-7522.3 Main Valve Operation.

The main valve shall operate in direct response to the pilot control device. The valve shall be constructed to attain rated lift under stable conditions at pressures that do not exceed the set pressure by more than 3% or 2 psi, whichever is greater, for steam, and 10% or 3 psi, whichever is greater, for air, gas, or liquid service.

ND-7522.4 Sensing Mechanism Integrity.

For other than spring loaded direct acting pilot control devices, means shall be provided to detect failure of the pressure sensing element, such as bellows, when operation of the pilot control device is dependent upon the integrity of a pressure sensing element.

ND-7522.5 Set Pressure Tolerance

(a) The set pressure tolerance shall apply only to the pilot valve.

(b) The set pressure tolerance plus or minus shall not exceed the following: 2 psi (13.8 kPa) for pressures up to and including 70 psi (483 kPa); 3% for pressures over 70 psi (483 kPa) for liquid valves and 3% for pressures over 70 psi (483 kPa) up to and including 300 psi (2070 kPa); 10 psi (69 kPa) for pressures over 300 psi (2070 kPa) up to and including 1000 psi (6900 kPa); and 1% for pressures over 1000 psi (6900 kPa) for steam, air, and gas valves. The set pressure tolerance as stated shall apply unless a greater tolerance is established as permissible in the Overpressure Protection Report (ND-7200) and in the valve Design Specification (NCA-3250).

(c) Conformance with the requirements of (b) above shall be established for each production valve by test. Steam valves shall be tested on steam, air, or gas valves on air or gas, and liquid valves on liquid.

ND-7522.6 Blowdown

(a) The blowdown requirements shall only apply to the pilot valve.

(b) Pilot operated valves shall be adjusted to close after blowing down to a pressure not lower than that specified in the valve Design Specification (NCA-3250) and the basis for the setting is covered in the Overpressure Protection Report (ND-7200).

(c) The adjustment shall be determined by test or by proration from the Certificate Holder's blowdown test data.

ND-7523 Credited Relieving Capacity

The credited relieving capacity of pilot operated pressure relief valves shall be based on the certified relieving capacity. In addition, the capacity may be prorated as permitted in ND-7700.

ND-7524 Sealing of Adjustments

The sealing requirements of ND-7515 shall apply.

ND-7530 POWER ACTUATED PRESSURE RELIEF VALVES

ND-7531 Use

Power actuated pressure relief valves, which depend upon an external energy source such as electrical, pneumatic, or hydraulic systems and which respond to signals from pressure or temperature sensing devices, may be used, provided the requirements of this Subsubarticle are met.

ND-7532 Minimum Required Number

At least two valves shall be used to contribute to the required relieving capacity.

ND-7533 Sensors and Controls

(a) The sensors, controls, and external energy sources for valve operation shall have redundancy and independence

Page 304

at least equal to that required for the control and safety protection systems associated with the system.

(b) The relief valve and its auxiliary devices treated as a combination shall comply with the following requirements.

(1) The valve opening pressure shall be controlled within a tolerance as specified in ND-7512.2 of the set pressure when the automatic control is in use.

(2) The valve blowdown shall be controlled to a pressure not lower than that specified in the valve Design Specification (NCA-3250).

ND-7534 Relieving Capacity

ND-7534.1 System Upset Conditions.

For system upset conditions, the relieving capacity with which these valves are credited shall be not more than:

- (a) the stamped relieving capacity of the smaller one when two valves are installed;
- (b) one-half of the total stamped relieving capacity when three or more valves are installed.

ND-7534.2 System Emergency Conditions.

For system emergency conditions, the relieving capacity with which these valves are credited shall not be more than:

- (a) the relieving capacity of the valve with the smaller stamped capacity where two valves are installed;
- (b) the relieving capacity of all except the valve with the largest stamped capacity for valves where three through ten valves are installed;
- (c) the relieving capacity of all except two valves of the largest stamped capacity where more than ten valves are installed.

ND-7535 Response Time

In systems protected by power operated pressure relief valves, consideration shall be given to the time lapse between the signal to open and achieving the fully opened position and to the time lapse between the signal to close and achieving the fully closed position.

ND-7540 SAFETY AND SAFETY RELIEF VALVES WITH AUXILIARY ACTUATING DEVICES

ND-7541 Use

Safety and safety relief valves with auxiliary actuating devices which operate independently of the spring loading of the valve may be used, provided the requirements of ND-7510 are met except as modified by this Subsubarticle.

ND-7542 Construction and Design

- (a) The construction shall be such that the valve opens automatically by direct action of the fluid at a pressure not higher than the safety valve set pressure and relieves at the rated relieving capacity in the event of failure of any essential part of the valve's auxiliary devices.
- (b) The design of the auxiliary actuating device shall be such that the safety valve will not be prevented from operating as defined in ND-7510 when the auxiliary actuating device is deenergized.

ND-7550 VACUUM RELIEF VALVES

Vacuum relief valves shall meet the construction requirements applicable to Class 3 valves and the additional requirements of this Article.

ND-7552 Types Permitted

- (a) Balanced self-actuating horizontally installed swinging disk valves.
- (b) Vertically installed vacuum disk or pallet-type valves.
- (c) All vacuum relief valves shall have provisions for adjustment of the differential pressure.

ND-7753 Operating Requirements

Vacuum relief valves, which are operated by indirect means depending on an external energy source, such as electrical, pneumatic, or hydraulic systems, are not acceptable unless at least two independent external power operated valves and

control systems are employed so that the required relieving capacity is obtained if any one of the valves or systems should fail to operate.

ND-7600 REQUIREMENTS FOR NONRECLOSING PRESSURE RELIEF DEVICES

ND-7610 GENERAL REQUIREMENTS

ND-7611 Use of Rupture Disk Devices

Rupture disk devices certified in accordance with ND-7720 and ND-7750 are subject to the following.

Page 305

(a) Rupture disk devices may be used as the sole pressure relief device for services where release of the contents of the protected system is acceptable to the enforcement authority having jurisdiction at the nuclear power plant site.

(b) Rupture disk devices may be used on the inlet side of pressure relief valves only when such valves are of the full bore¹² type (ND-7623).

(c) Rupture disk devices may be used in conjunction with pressure relief valves on the outlet side (ND-7624).

ND-7612 Burst Pressure Tolerance

The burst pressure tolerance at the specified disk temperature¹³ shall not exceed ± 2 psi (± 13.8 kPa) for stamped burst pressure up to and including 40 psi (276 kPa) and $\pm 5\%$ for stamped burst pressure above 40 psi (276 kPa) as established by the rules of ND-7613, unless other values have been established in the Design Specification and are covered in the Overpressure Protection Report.

ND-7613 Tests to Establish Stamped Burst Pressure

(a) Every rupture disk shall have a stamped burst pressure established by rules of ND-7612 within a manufacturing design range,¹⁴ at a specified disk temperature, and shall be stamped with a lot number.

(b) Each lot of rupture disks shall be tested in accordance with one of the following methods. All tests of disks for a given lot shall be made in a holder of the same form and pressure area dimensions as that being used in service.

(1) At least two sample rupture disks from each lot of rupture disks¹⁵ shall be burst at the specified disk temperature. The stamped burst pressure shall be determined so that the sample rupture disk burst pressures are within the tolerance specified by ND-7612.

12 A pressure relief valve which has no protrusions in the bore and wherein the valve disk lifts to an sufficient for the minimum area, at any section at or below the body seat, to become the controlling orifice.

13 The specified disk temperature supplied to the rupture disk manufacturer shall be the temperature of the disk is expected to burst.

14 The manufacturing design range is a range of pressure within which the stamped burst pressure must fall. This range is included in the Design Specification and the Overpressure Protection Report.

15 A lot of rupture disks is those disks manufactured of material at one time, of the same size, thickness, type, heat, and manufacturing process including heat treatment.

(2) At least four sample rupture disks, but not less than 5% from each lot of rupture disks, shall be burst at four different temperatures distributed over the applicable temperature range for which the disks will be used. This data shall be used to establish a smooth curve of burst pressure versus temperature for the lot of disks. The burst pressure for each data point shall not deviate from the curve more than the burst pressure tolerance specified in ND-7612.

The value for the stamped burst pressure shall be established from the curve for a specified disk temperature.

(3) For prebulged solid metal disks or graphite disks only, at least four sample rupture disks using one size of disk from each lot of material shall be burst at four different temperatures, distributed over the applicable temperature range for which this material will be used. This data shall be used to establish a smooth curve of burst pressure versus temperature for the lot of material. The burst pressure for each data point shall not deviate from the curve more than the burst pressure tolerance specified in ND-7612.

At least two disks from each lot of disks, made from this lot of material and of the same size as those to be used, shall be burst at the ambient temperature to establish the room rating of the lot of disks. The curve shall be used to establish the stamped rating at the specified disk temperature for the lot of disks.

ND-7614 Burst Pressure in Relation to Pressure Relief Valve Set Pressure

The burst pressure of a rupture disk may be either lower or higher than the set pressure of the associated pressure relief valve, but in no case shall the rupture disk burst pressure and valve set pressure be such that the total accumulated pressure during full capacity relief exceeds the permitted limit (ND-7400).

ND-7620 INSTALLATION REQUIREMENTS

ND-7621 Provisions for Venting or Draining

The space between the rupture disk and the associated pressure relief valve shall be vented and/or drained. This space shall be provided with means to monitor its internal pressure during service periods.

ND-7622 System Obstructions

When the release of rupture disk material may occur, piping and other components downstream of the rupture disk shall be constructed such that no obstruction can

Page 306

be caused nor the function of a pressure relief valve impaired.

ND-7623 Rupture Disk Devices at the Inlet Side of Pressure Relief Valves

A rupture disk device may be installed at the inlet side of a pressure relief valve if the provisions of (a) through (c) below are met.

(a) The combination of the pressure relief valve and the rupture disk device capacity shall meet the requirements of ND-7300.

(b) The stamped burst pressure at the specified disk temperature of the rupture disk does not exceed the limits of ND-7400.

(c) The opening provided through the rupture disk after burst is sufficient to permit a flow equal to the capacity of the valve, and there is no chance of interference with proper functioning of the valve; but in no case shall this area be less than the area of the inlet of the valve unless the capacity and functioning of the specific combination of rupture disk and valve have been established by test in accordance with ND-7700.

ND-7624 Rupture Disk Devices at the Outlet Side of Pressure Relief Valves

A rupture disk device may be installed at the outlet side of pressure relief valves if the provisions of (a) through (d) below are met.

(a) The valve operation is independent of back pressure; or for unbalanced valves the set pressure of the valve plus the stamped bursting pressure of the rupture disk plus any pressure in the outlet piping does not exceed the limits of ND-7400.

(b) The relieving capacity meets the requirements of ND-7300.

(c) The stamped bursting pressure of the rupture disk at the specified disk temperature plus any pressure in the outlet piping from the rupture disk device shall not exceed the secondary Design Pressure of the outlet portion of the pressure relief valve and any pipe or fittings between the valve and the rupture disk device. However, in no case shall the stamped bursting pressure of the rupture disk at the operating temperature plus any pressure in the outlet piping from the rupture disk device exceed the limits of ND-7400.

(d) The opening provided through the rupture disk device after burst is sufficient to permit a flow equal to the rated capacity of the pressure relief valve.

ND-7700 CERTIFICATION REQUIREMENTS

ND-7710 RESPONSIBILITY FOR CERTIFICATION OF PRESSURE AND VACUUM RELIEF VALVES

(a) The Certificate Holder shall be responsible for having the relieving capacity of valves certified as prescribed in this Subarticle.

(b) Capacity certification which is obtained in compliance with other Subsections and which complies with this Subsection may be considered as qualified for capacity certification under these rules, and the valve may be stamped with the appropriate symbol of this Subsection.

ND-7720 RESPONSIBILITY FOR CERTIFICATION OF NONRECLOSING PRESSURE RELIEF DEVICES

(a) When rupture disk devices are used as the sole pressure relief device, the rupture disk device manufacturer shall be responsible for having the relieving capacity of the rupture disk device determined (ND-7760).

(b) When rupture disk devices are used at the inlet of pressure relief valves, the manufacturer of the rupture disk devices or the pressure relief valves shall be responsible for having the relieving capacity of the combination determined (ND-7760).

ND-7730 CAPACITY CERTIFICATION OF PRESSURE RELIEF VALVES - COMPRESSIBLE FLUIDS

ND-7731 General Requirements

ND-7731.1 Capacity Certification

(a) Capacity certification procedures shall be as required in ND-7732 through ND-7736.

(b) For steam at pressures over 1500 psig and up to 3200 psig, the value of K used to determine the certified relieving capacity shall be multiplied by:

$$(0.1906P - 1000)/(0.2292P - 1061)$$

where

P = set pressure, psig

This correction is also applicable to the certified relieving capacity as determined by the curve method.

Page 307

ND-7731.2 Test Media

(a) Capacity certification tests of pressure relief valves for steam service shall be conducted with dry saturated steam. For test purposes, the limits of 98% minimum quality and 20°F (11°C) maximum superheat shall apply. Capacity shall be corrected to the dry saturated condition from within these limits.

(b) Capacity certification tests for pressure relief valves for air and gas service shall be conducted with air, gas, or dry saturated steam.

ND-7731.3 Test Pressure

(a) Capacity certification tests of pressure relief valves for main steam service shall be conducted at a pressure which does not exceed the set pressure by more than 3% or 2 psi (13.8 kPa), whichever is greater.

(b) Capacity certification tests of pressure relief valves for air, gas, or steam service other than main steam service shall be conducted at a pressure which does not exceed the set pressure by more than 10% or 3 psi (20.6 kPa), whichever is greater.

ND-7731.4 Blowdown.

Valves having an adjustable blowdown construction shall be adjusted prior to testing so that the blowdown does not exceed 5% of the set pressure.

ND-7731.5 Drawings.

Prior to tests, the Certificate Holder shall submit drawings showing the valve construction to the Authorized Observer. The Authorized Observer shall submit the drawings and test results to the ASME designee for review and acceptance.

ND-7731.6 Design Changes.

When changes are made in the design of a pressure relief valve in such a manner as to affect the flow path, lift, or performance characteristics of the valve, new tests in accordance with this Article shall be performed.

ND-7732 Flow Model Test Method - Pilot or Power Operated Valves

ND-7732.1 Flow Capacity.

In those cases where test facility limitations make it impossible to perform capacity tests of the full-scale pressure relief valves, flow models of three different sizes may be utilized as a basis for capacity certification. Such flow models shall be sized consistent with the capabilities of the approved test laboratory at which the tests will be conducted and shall accurately model those features, such as orifice size, valve lift, and internal flow configuration, which affect flow capacity. The test models need not be functional pressure relief valves, provided that other tests to demonstrate proper function of the valve design are conducted as prescribed in ND-7732.2. The relieving capacity of valve designs certified by use of flow models shall be established by the coefficient of discharge method similar to that outlined in ND-7734. The certified relieving capacity of all sizes and pressures of a given design for which the value of K has been established, based on flow model tests in accordance with the method of ND-7734, shall not exceed the value calculated by the appropriate formula in ND-7734.2 multiplied by the coefficient K .

ND-7732.2 Demonstration of Function.

The function of three valves of the design to be certified shall be demonstrated by tests. Such tests may be performed in conjunction with the capacity certification tests outlined above or as separate tests using production valves. The purpose of these tests is to demonstrate to the satisfaction of a designated representative of the ASME that the valve will open at set pressure within the required opening pressure tolerance, will achieve full lift, and will reclose within required blowdown. If required by test facility limitations, these tests may be conducted at reduced flow capabilities. Measurement of valve blowdown may not be possible.

ND-7733 Slope Method

(a) For pressure relief valves of a specific design, four valves of each combination inlet size and orifice size shall be tested. These four valves shall be set at pressures that will cover the appropriate range of pressures for which the valves are to be used or within the range of the authorized test facility.

(b) The instantaneous slope of each test point shall be calculated and averaged, where slope is defined as the measured capacity divided by the absolute inlet pressure. If any of the experimentally determined slopes fall outside of a range of $\pm 5\%$ of the average slope, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average slope shall be determined, excluding the replaced valve test results. If any individual slope is now outside of the $\pm 5\%$ range, then the tests shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design. The certified capacity shall be 90% of the average slope multiplied by the flow rating pressure, psia.

ND-7734 Coefficient of Discharge Method

A coefficient K may be established for a specific pressure relief valve design according to the procedure given in the

ND-7734.1 Number of Valves to Be Tested.

For each design, at least three valves for each of three different sizes shall be submitted for test. Each valve of a given size shall be set at a different pressure.

ND-7734.2 Establishment of Coefficient of Discharge

(a) Tests shall be made on each pressure relief valve to determine its lift, opening, and blowdown pressures, and capacity in terms of the fluid used in the test. A coefficient of discharge K_D shall be established for each test run as follows:

$$K_D = \frac{\text{Actual Flow}}{\text{Theoretical Flow}} = \text{Coefficient of Discharge}$$

where Actual Flow is determined quantitatively by test, and the Theoretical Flow is calculated by the following formula.

For test with dry saturated steam:

Pressures up to 1500 psig

$$W_T = 51.5AP$$

Pressures over 1500 psig and up to 3200 psig the value of W_T , calculated by the above equation, shall be corrected by being multiplied by the following factor:

$$\frac{(0.1906P - 1000)}{(0.2292P - 1061)}$$

For test with air:

$$W_T = 356AP \sqrt{\frac{M}{T}}$$

For test with gas:

$$W_T = CAP \sqrt{\frac{M}{ZT}}$$

where

W_T

= Theoretical Flow, lb/hr

A

= actual discharge area through the valve at developed lift, sq in.

C

= constant for gas or vapor which is a function of the ratio of specific heats

P

= (set pressure $\times$ 1.03) plus atmospheric pressure, psia, or set pressure plus 2 psi plus atmospheric pressure, whichever is greater, for test pressures determined by ND-7731.3(a)

= (set pressure $\times$ 1.10) plus atmospheric pressure, psia, or set pressure plus 3 psi plus atmospheric pressure, whichever is greater, for test pressures determined by ND-7731.3(b)

M

= molecular weight

T	= absolute temperature at inlet, °F + 460
k	= c_p/c_v ratio of specific heats (see Fig. XVIII-1110-1)
Z	= compressibility factor corresponding to P and T

The average of the coefficients of discharge K_D of the tests required shall be multiplied by 0.90 and their product shall be taken as the coefficient K of that design. The coefficient of the design shall not be greater than 0.876 (the product of 0.9×0.975).

(b) If any of the experimentally determined coefficients fall outside of a range of $\pm 5\%$ of the average coefficient, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average coefficient shall be determined, excluding the replaced valve test results. If any individual coefficient is now outside of the $\pm 5\%$ range, then the test shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design.

ND-7734.3 Calculation of Certified Capacity

(a) The certified capacity of all sizes and pressures of a given design, for which the value of K has been established under the provisions of ND-7734.2 and which are manufactured subsequently, shall not exceed the value calculated by the appropriate formula multiplied by the coefficient K .

(b) The coefficient shall not be applied to valves whose beta ratio (the ratio of valve throat and inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that individual coefficients of discharge, K_d , for valves of the extreme ends of a larger range is within $\pm 5\%$ of the average coefficient, K . For designs where lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio (L/D).

ND-7735 Single Valve Method

ND-7735.1 Valve Capacity Within Test Facility Limits

(a) Where a single valve is to be capacity tested, the certified capacity may be based on three separate tests associated with each set pressure for which capacity certification is required.

(b) The certified capacity associated with each set pressure shall not exceed 90% of the average capacity established by the tests. Failure of the individual test capacities to fall within $\pm 5\%$ of the average capacity

Page 309

associated with each set pressure shall be cause for rejection of the test. The reason for the failure shall be determined and the test repeated.

(c) Should additional valves of the same design be constructed at a later date, the results of the tests on the original valve may be included as applicable to the particular test method selected.

ND-7735.2 Valve Capacity in Excess of Test Facility Limits

(a) For valves whose capacity exceeds that of the test facility, the certified capacity may be based on a flow coefficient K (ND-7734.2) determined from either blocked open flow tests or flow model tests, provided the orifice area is such that choked flow conditions are obtained. The certified capacity shall be calculated as directed in ND-7734.3.

(b) The proper operation of the valve shall be demonstrated as prescribed in ND-7732.2.

ND-7736 Proration of Capacity

(a) The capacity of a pressure relief valve applied to a system may be prorated to an overpressure greater than the overpressure for which the valve is certified. This overpressure shall be within the allowable limits of the system.

(b) Depending on the method used for the initial capacity certification:

(1) the prorated capacity shall be 90% of the average slope determined in ND-7733 multiplied by the prorated relieving

pressure (psia), or;

(2) the prorated capacity shall be calculated using the appropriate formula from ND-7734.2 (where P is the prorated relieving pressure (psia) multiplied by the coefficient K).

ND-7737 Capacity Conversions

The rated pressure relieving capacity of pressure relief valves for fluids other than the fluid used for certification shall be determined by the method of conversion given in Appendix XVIII-1000 except that valves for steam service shall be tested on steam.

ND-7738 Laboratory Acceptance of Pressure Relieving Capacity Tests

Tests shall be conducted at a place where the testing facilities, methods, procedures, and Authorized Observer (person supervising the tests) meet the applicable requirements of ASME PTC 25-1994. The tests shall be made under the supervision of and certified by an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation of an ASME designee. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designee for review and acceptance.¹⁶

ND-7739 Laboratory Acceptance of Demonstration of Function Tests

The NV Certificate Holder shall assure that the tests are conducted at a place where the testing facilities, methods, and procedures provide for sufficient testing capacity and range of fluid properties so that the testing requirements of ND-7732.2 are met.

ND-7740 CAPACITY CERTIFICATION OF PRESSURE RELIEF VALVES - INCOMPRESSIBLE FLUIDS

ND-7741 General Requirements

ND-7741.1 Capacity Certification.

Capacity certification procedures shall be as required in ND-7742 through ND-7744.

ND-7741.2 Test Media.

The test medium to be used shall be water at a temperature between 40°F and 125°F (4°C and 52°C).

ND-7741.3 Test Pressure.

Tests shall be conducted at pressures which does not exceed the set pressure by more than 10% or 3 psi (20.6 kPa), whichever is greater.

ND-7741.4 Blowdown.

Blowdown shall be recorded at the time of the test.

ND-7741.5 Drawings.

Prior to tests, the Certificate Holder shall submit drawings showing the valve construction to the ASME designee for review and acceptance.

ND-7741.6 Design Changes.

When changes are made in the design of a pressure relief valve in such a manner as to affect the flow path, lift, or performance characteristics of the valve, new tests in accordance with this Article shall be performed.

¹⁶ Valve capacities published in "Pressure Relief Device Certifications." This publication may be obtained from the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue,

ND-7742 Single Valve Method

Where a single valve at a single pressure is to be capacity tested, the capacity rating may be based on three separate tests of the single valve at the specified set pressure. The certified capacity rating of the valve shall not exceed 90% of the average capacity established by the tests. Failure of the individual test capacities to fall within $\pm 5\%$ of the average capacity may be cause for rejection of the test. The reason for the failure shall be determined and the test repeated.

Should additional valves of the same design be constructed at a later date, the results of the tests on the original valve may be included as applicable to the particular test method selected.

ND-7743 Slope Method

Four valves of each combination of pipe size and orifice size shall be tested. These four valves shall be set at pressures which cover the appropriate range of pressures for which the valves are to be used or within the range of the test facility. The instantaneous slope of each test point shall be calculated and averaged, where slope is defined as the measured capacity divided by the square root of the difference between the flow rating pressure and the valve discharge pressure. If any of the experimentally determined slopes fall outside of a range of $\pm 5\%$ of the average slope, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average slope shall be determined, excluding the replaced valve test results. If any individual slope is now outside of the $\pm 5\%$ range, then the tests shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design. The certified capacity shall be 90% of the average slope multiplied by the square root of the difference between the flow rating pressure and the valve discharge pressure.

ND-7744 Coefficient of Discharge Method

Instead of individual capacity tests or the capacity curve method, a coefficient K may be established for a specific pressure relief valve design in accordance with the following subparagraphs.

ND-7744.1 Number of Valves to Be Tested.

For each design, three valves for each of three different sizes shall be tested, or a total of nine valves. Each valve of a given size shall be set at a different pressure.

ND-7744.2 Establishment of Coefficient of Discharge

(a) Tests shall be made on each relief valve to determine its lift, opening and closing pressures, and actual capacity in terms of pounds of water per hour. A coefficient of discharge K_D shall be established for each test run as follows:

$$K_D = \frac{\text{Actual Flow}}{\text{Theoretical Flow}} = \text{Coefficient of Discharge}$$

where Actual Flow is determined quantitatively by test and Theoretical Flow is calculated by the following formula.

For test with water:

$$W_t = 2407A\sqrt{(P - P_d)w}$$

where

W_t	= Theoretical Flow, lb/hr
A	= actual minimum discharge area through the valve at developed lift, sq in.
P	= (set pressure $\times$ 1.10) plus atmospheric pressure, psia, or set pressure plus 3 psi plus atmospheric pressure, whichever is greater
P_d	= pressure at discharge from valve, psia
w	= density of water at valve inlet conditions, lb/cu ft

The average of the coefficients of discharge K_D of the tests shall be multiplied by 0.90 and the product shall be taken as the coefficient K of the design. The coefficient of the design shall not be greater than 0.876 (the product of 0.9×0.975).

(b) If any of the experimentally determined coefficients fall outside of a range of $\pm 5\%$ of the average coefficient, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average coefficient shall be determined, excluding the replaced valve test results. If any individual coefficient is now outside of the $\pm 5\%$ range, then the test shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design.

ND-7744.3 Calculation of Certified Capacity

(a) The certified capacity of all sizes and pressures of a given design for which the value of K has been established under the provisions of ND-7744.2 shall not exceed the value calculated by the theoretical formula above and multiplied by the coefficient K .

Page 311

(b) The coefficient shall not be applied to valves whose beta ratio (the ratio of valve throat and inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that individual coefficients of discharge, K_D , for valves of the extreme ends of a larger range is within $\pm 5\%$ of the average coefficient, K . For designs where lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio (L/D).

ND-7745 Laboratory Acceptance of Pressure Relieving Capacity Tests

Tests shall be conducted at a place where the testing facilities, methods, procedures, and Authorized Observer (person supervising the tests) meet the applicable requirements of ASME PTC 25-1994. The tests shall be made under the supervision of and certified by an Authorized Observer. The testing facilities, methods, procedures, and qualifications of

the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation of an ASME designee. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designee for review and acceptance.¹⁶

ND-7746 Proration of Capacity

(a) The capacity of a pressure relief valve applied to a system may be prorated to an overpressure greater than the overpressure for which the valve is certified. This overpressure shall be within the allowable limits of the system.

(b) Depending on the method used for the initial capacity certification:

(1) the prorated capacity shall be 90% of the average slope determined in ND-7742 multiplied by the prorated relieving pressure (psia), or;

(2) the prorated capacity shall be calculated using the appropriate formula from ND-7743.2 (where P is the prorated relieving pressure (psia) multiplied by the coefficient K).

ND-7750 CAPACITY CERTIFICATION OF VACUUM RELIEF VALVES

ND-7751 General Requirements

ND-7751.1 Capacity Certification.

Capacity certification procedures shall be as required in ND-7752 through ND-7755.

ND-7751.2 Test Media.

Capacity certification tests for vacuum relief valves for air and gas service shall be conducted with dry steam, air, or gas. For steam test purposes the limits of 98% minimum quality and 20°F (11°C) maximum superheat shall apply. Capacity shall be corrected to dry saturated condition from these limits.

ND-7751.3 Test Method and Pressure.

Capacity tests may be conducted by pressurizing the valve instead of using a vacuum, provided the inlet conditions of the valve (not the vessel) are known and the inlet pressure is not greater than 5 psi (35 kPa), and the direction of flow through the valve is the same on pressure as is experienced on vacuum. Tests shall be conducted at twice the set pressure or 1 psi (7 kPa), whichever is greater.

ND-7751.4 Blowdown.

Blowdown shall be recorded at the time of the test.

ND-7751.5 Drawings.

Prior to a test, the Certificate Holder shall submit drawings showing the valve construction to the Authorized Observer. The Authorized Observer shall submit the drawings and test results to the ASME designee for review and acceptance.

ND-7751.6 Design Change.

When changes are made in the design of a vacuum relief valve in such a manner as to affect the flow path, lift, or performance characteristics of the valve, new tests in accordance with this Article shall be performed.

ND-7752 Single Valve Method

(a) When a single valve at a single pressure is to be capacity tested, the capacity rating may be based on three separate and distinct tests of the single valve at the specified set pressure. The certified capacity rating of the valve shall not exceed 90% of the average capacity established by the tests. Failure of the individual test capacities to fall within $\pm 5\%$ of the average capacity shall be cause for rejection of the test. The reason for the failure shall be determined and the test repeated.

(b) Should additional valves of the same design be constructed at a later date, the results of the test on the original valve may be included as applicable to the particular test method selected.

ND-7753 Slope Method

Four valves of each combination of pipe size and orifice size shall be tested. These four valves shall be set at pressures which cover the appropriate range of pressures for which the valves are to be used or set within the range of the test facility. The slope of each

Page 312

test shall be calculated and averaged, where slope is defined as the measured capacity divided by the quantity, $F[(P)(P - P_o)]^{1/2}$

where

$$F = \sqrt{\left(\frac{k}{k-1}\right) (r^{2/k}) \left[\frac{1 - (r)^{\frac{k-1}{k}}}{1 - r} \right]}$$

P	= inlet pressure, psi
P_o	= discharge pressure, psi
k	= ratio of specific heats, c_p/c_v
r	= pressure ratio, P/P_o

If any of the experimentally determined slopes fall outside of a range of $\pm 5\%$ of the average slope, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average slope shall be determined, excluding the replaced valve test results. If any individual slope is now outside of the $\pm 5\%$ range, then the tests shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design. The certified capacity shall be 90% of the average slope multiplied by the quantity, $F[(P)(P - P_o)]^{1/2}$.

ND-7754 Coefficient of Discharge Method

A coefficient K may be established for a specific vacuum relief valve design in accordance with ND-7754.1 and ND-7754.2.

ND-7754.1 Number of Valves to Be Tested.

For each design, three valves of three different sizes, a total of nine valves, shall be tested. Each valve of a given size shall be set at a different pressure.

ND-7754.2 Establishment of Coefficient of Discharge

(a) Tests shall be made on each relief valve to determine its lift, opening and closing pressures, and actual capacity. A coefficient of discharge K_D shall be established for each run as follows:

$$K_D = \frac{\text{Actual Flow}}{\text{Theoretical Flow}} = \text{Coefficient of Discharge}$$

where Actual Flow is determined quantitatively by test and Theoretical Flow is calculated from the appropriate equation for the test fluid. The following formula may be used for other than saturated steam flow:

$$W = 735FA \left[\frac{MP (P - P_o)}{T} \right]^{1/2}$$

$$Q = 279,000FA \left[\frac{P(P - P_o)}{MT} \right]^{1/2}$$

where

or is obtained from Fig. ND-7754.2(a)-1.

A	= flow area, sq in.
M	= molecular weight
P	= inlet pressure, psi
P_o	= discharge pressure, psi
T	= temperature, deg Rankin
k	= ratio of specific heats, C_v/C_p
r	= pressure ratio, P_o/P
Q	= cu ft/hr at 14.7 psi and 60°F
W	= lb/hr

The average of the coefficients of discharge K_D of the tests required shall be multiplied by 0.90 and their product shall be the coefficient K of that design. The coefficient of the design shall not be greater than 0.876 (the product of 0.9×0.975).

(b) If any of the experimentally determined coefficients fall outside of a range of $\pm 5\%$ of the average coefficient, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average coefficient shall be determined, excluding the replaced valve test results. If any individual coefficient is now outside of the $\pm 5\%$ range, then the test shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design.

ND-7754.3 Calculation of Relieving Capacity

(a) The certified relieving capacity of all sizes and pressures of a given design, for which the value of K has been established, shall be calculated by the appropriate formula given above multiplied by the coefficient K . Values obtained from pressurized tests may be converted to equivalent vacuum from the above equation.

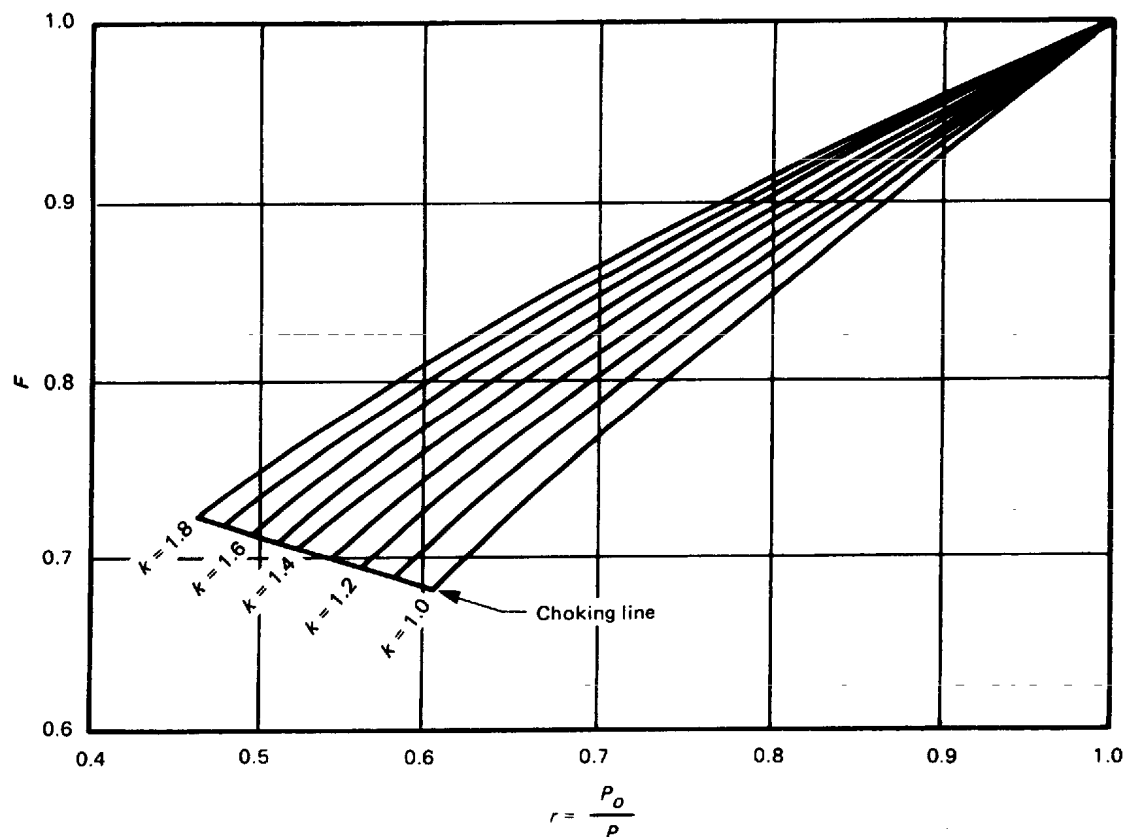


FIG. ND-7754.2(a)-1 VALUES OF F FOR NONCHOKING FLOW

FIG. ND-7754.2(a)-1 VALUES OF F FOR NONCHOKING FLOW

(b) The coefficient shall not be applied to valves whose beta ratio (the ratio of valve throat and inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that individual coefficients of discharge, K_d , for valves of the extreme ends of a larger range is within $\pm 5\%$ of the average coefficient, K . For designs where lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio (L/D).

ND-7755 Laboratory Acceptance of Relieving Capacity Tests

Tests shall be conducted at a place where the testing facilities, methods, procedures, and person supervising the tests (Authorized Observer) meet the applicable requirements of ASME PTC 25-1994. The tests shall be made under the supervision of, and certified by, an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation of an ASME designee. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designee for review and acceptance.

ND-7760 CAPACITY DETERMINATION OF RUPTURE DISK DEVICES

ND-7761 General Requirements

ND-7761.1 Capacity Determination Procedures

- (a) Capacity determination procedures without flow tests shall be as given in ND-7762.1 and ND-7763.1.
- (b) Capacity determination procedures with flow tests shall be as required in ND-7762.2.

ND-7761.2 Test Media

- (a) Capacity tests of rupture disk devices for steam service shall be conducted with dry saturated steam. For test purposes, the limits of 98% minimum quality

Page 314

and 20°F (11°C) maximum superheat shall apply. Capacity shall be corrected to the dry saturated condition from within these limits.

- (b) Capacity tests for rupture disk devices for air and gas service shall be conducted with air, gas, or dry saturated steam.

ND-7761.3 Test Pressure.

Capacity tests of rupture disk devices shall be conducted at a pressure not exceeding 110% of the burst pressure.

ND-7761.4 Drawings.

Prior to tests, the Certificate Holder shall submit drawings showing the rupture disk device construction to the Authorized Observer. The Authorized Observer shall submit the drawings and test results to the ASME designee for review and acceptance.

ND-7761.5 Design Changes

- (a) When, in a type of rupture disk device, changes occur which may affect the flow area of the rupture disk device, each such change shall be treated as a different series of disks and must be tested.
- (b) When changes are made in the design of a type of rupture disk device in such a manner as to affect area or performance characteristics of the rupture disk device, new tests must be made.

ND-7762 Capacity Determination of Rupture Disk Devices in Combination With Pressure Relief Valves

ND-7762.1 Capacity Determination Without Flow Test

- (a) The rated capacity of the combination of a pressure relief valve when installed with a rupture disk device at the inlet side of the valve shall not exceed 80% of the certified capacity of the valve. Alternatively, the capacity of such a combination shall be established in accordance with ND-7762.2.
- (b) The rated capacity of the combination of a pressure relief valve when installed with a rupture disk device at the outlet of the valve shall be the certified capacity of the valve.

ND-7762.2 Capacity of Pressure Relief Valves in Combination With a Rupture Disk Device at the Inlet.

For each combination of pressure relief valve design and rupture disk device design, the Certificate Holder or the rupture disk device manufacturer shall have the capacity of the combination determined as prescribed in (a) and (b) below.

- (a) The Certificate Holder or the rupture disk device manufacturer shall submit for tests the smallest rupture disk device size with the equivalent size of pressure relief valve that is intended to be used as a combination device. The pressure relief valve to be tested shall have the largest orifice used in the particular inlet size.
- (b) Tests shall be performed in accordance with the requirements of (1) through (5) below. The rupture disk device and

pressure relief valve combination to be tested shall be arranged to duplicate the combination assembly design.

(1) The test shall be made using the minimum burst pressure of the rupture disk device design that is to be used in combination with the pressure relief valve design. The stamped bursting pressure shall be between 90% and 100% of the stamped set pressure of the valve.

(2) The test procedure to be used shall be as follows.

(a) The pressure relief valve by itself shall be tested for capacity without the rupture disk device at a pressure 10% above the valve set pressure.

(b) The rupture disk device shall then be installed in front of the pressure relief valve and the disk burst to operate the valve. The capacity test shall be performed on the combination at 10% above the valve set pressure duplicating the test of (a) above.

(3) The tests shall be repeated with two additional rupture disks of the same nominal rating for a total of three rupture disks to be tested with the single valve. The results of the test capacity shall fall within a range of 10% of the average capacity of the three tests. Failure to meet this requirement shall be cause to require retest for determination of cause of the discrepancies.

(4) From the results of the tests, a Combination Capacity Factor shall be determined. The Combination Capacity Factor is the ratio of the average capacity which is determined by the combination tests to the capacity which is determined by the test of (a) above. The Combination Capacity Factor shall be used as a multiplier to the certified capacity of the pressure relief valve in all sizes of the design except when a different factor has been established for larger sizes and other pressures in accordance with ND-7762.3. The value of the Combination Capacity Factor shall not be greater than one. The Combination Capacity Factor shall apply only to combinations of the same design and manufacture of the pressure relief valve and the same design and manufacture of the rupture disk device as those tested.

(5) The test laboratory shall submit the test results to the ASME designee for acceptance of the Combination Capacity Factor.

ND-7762.3 Optional Testing of Rupture Disk Devices and Pressure Relief Valves

(a) If desired, a Certificate Holder or a rupture disk manufacturer may conduct tests in the same manner

Page 315

as given in ND-7762.2 using the next two larger sizes of the same design of rupture disk device and pressure relief valve to determine a Combination Capacity Factor applicable to larger sizes. If a greater Combination Capacity Factor is established and can be approved, it may be used for all larger sizes of the combination, but the Factor shall not be greater than one.

(b) If desired, additional tests may be conducted at higher pressures in accordance with ND-7762.2 to establish a maximum Combination Capacity Factor to be used at all pressures higher than the highest tested, but the Factor shall not be greater than one.

ND-7763 Capacity of Rupture Disk Devices

ND-7763.1 Calculated Capacity

(a) The calculated capacity of a rupture disk device shall not exceed a value based on the applicable theoretical formula multiplied by a value for K of 0.62. For compressible fluids, see Appendix XVIII. The theoretical formula for liquids shall be as follows:

$$W_t = 2407A\sqrt{(P - P_d)w}$$

where

W_t	= Theoretical Flow, lb/hr
A	= minimum net flow area existing after rupture disk burst, sq in.
P	= (stamped rupture pressure $\times$ 1.10) plus atmospheric pressure, flow rating pressure, psia
P_d	= pressure at discharge from rupture disk device, psi
w	= specific weight of liquid at rupture disk device inlet conditions, lb/cu ft

(b) The minimum net flow area is the calculated net area after a complete burst of the rupture disk with appropriate allowance for any structural members which may reduce the net flow area through the rupture disk device. For sizing purposes, the net flow area shall not exceed the nominal pipe size area of the rupture disk device.

ND-7763.2 Tested Capacity. (In preparation.)

ND-7764 Laboratory Acceptance of Pressure Relieving Capacity Tests

Tests shall be conducted at a place where the testing facilities, methods, procedures, and Authorized Observer (person supervising the tests) meet the applicable requirements of ASME PTC 25-1994. The tests shall be made under the supervision of, and certified by, an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation of an ASME designee. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designee for review and acceptance.

ND-7800 MARKING, STAMPING, AND DATA REPORTS

ND-7810 PRESSURE AND VACUUM RELIEF VALVES

ND-7811 Marking and Stamping

Each pressure relief valve shall be plainly marked by the Certificate Holder with the required data below in such a way that the marking will not be obliterated in service. The data shall be in characters not less than $\frac{3}{32}$ in. high. The marking shall be placed on the valve or on a nameplate securely fastened to the valve. The Code NV Symbol shall be stamped on the valve or nameplate, but the other required data may be stamped, etched, impressed, or cast. The marking shall include the following:

- (a) name, or an acceptable abbreviation, of the Certificate Holder
- (b) Certificate Holder's design or type number
- (c) size _____ (NPS, the nominal pipe size) of the valve inlet
- (d) set pressure _____ psi
- (e) certified capacity and overpressure in percent or psi in accordance with ND-7700

Pressure Relief Valves:

- lb/hr of saturated steam for valves certified on steam, or
- scfm (standard cubic feet per minute) at 60°F (16°C) and 14.7 psia of air for valves certified on air or gas, or
- gal/min of water at 70°F for valves certified on water

Vacuum Relief Valves:

- scfh (standard cubic feet per hour) at 60°F (16°C) and 14.7 psi (101 kPa)
- (f) applicable official Code Symbol Stamp, as shown in Table NCA-8100-1

In addition to the above, each pressure relief valve shall have a separate nameplate attached to the component that includes the marking requirements of NCA-8220 and ND-3593.2.

Page 316

ND-7812 Report Form for Pressure and Vacuum Relief Valves

A Data Report Form NV-1 shall be filled out and signed by the Certificate Holder and signed by the Inspector for each pressure and vacuum relief valve stamped with the Code NV Symbol.

ND-7820 RUPTURE DISK DEVICES

ND-7821 Rupture Disks

Every rupture disk shall be plainly marked by the manufacturer in such a way that the marking will not be obliterated in service. The rupture disk marking shall be placed on the flange of the rupture disk or on a metal tab permanently attached thereto.¹⁷ The marking shall include the following:

- (a) name or identifying trademark of the manufacturer
- (b) manufacturer's design or type number
- (c) lot number
- (d) size _____ in.
- (e) stamped bursting pressure _____ psi
- (f) specified disk temperature _____ °F
- (g) capacity _____ lb of saturated steam/hr or standard cu ft of air [60°F (16°C) and 14.7 psia (101 kPa)]/min
- (h) year built

ND-7822 Disk Holders (If Used)

Rupture disk holders shall be marked with the following:

- (a) name or identifying trademark of the manufacturer
- (b) manufacturer's design or type number

17 In lieu of marking all of the listed items on the flange or tab of each rupture disk, the marking may consist of a manufacturer's coding number sufficient to identify each rupture disk with a certificate or tab which includes the required information and is supplied with each lot of rupture disks.

(c) size _____ in.

(d) year built

(e) serial number

ND-7830 PRESSURE RELIEF VALVE IN COMBINATION WITH RUPTURE DISK DEVICES

ND-7831 Marking When Capacity Is Approved in Accordance With ND-7762.1

The marking shall be placed either on the valve or the rupture disk holder or on a plate or plates securely fastened to the valve or the rupture disk holder. The marking shall include a Combination Capacity Factor of 0.8.

ND-7832 Marking When Capacity Is Approved in Accordance With ND-7762.2

The following marking shall be in addition to the marking required by ND-7811 and ND-7822. The marking shall be placed on the valve or the rupture disk holder or on a plate or plates securely fastened to the valve or the rupture disk holder. The marking shall include the following:

(a) name of the Certificate Holder

(b) design or type or serial number of valve

(c) name of manufacturer of rupture disk device

(d) design or type designation of rupture disk device

(e) approved Combination Capacity Factor

ND-7840 CERTIFICATE OF AUTHORIZATION TO USE CODE SYMBOL STAMP

Each pressure and vacuum relief valve within the scope of this Article shall be constructed by a Certificate Holder possessing a Code NV Symbol Stamp and a valid Certificate of Authorization. Pressure and vacuum relief valves shall have the Code NV Symbol applied in accordance with the rules of ND-8100.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 ND-8000

ARTICLE ND-8000 NAMEPLATES, STAMPING, AND REPORTS

Page 317

ND-8100 GENERAL REQUIREMENTS

The requirements for nameplates, stamping, and reports shall be as given in NCA-8000.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 ND SI UNITS

SI UNITS

Page 319

The 1998 Edition of the Boiler and Pressure Vessel Code is based on U.S. Customary (ft-lb) units of measurement which are to be regarded as the standard. This supplement is provided as a convenience to the Code user and contains SI conversion factors for units contained in the Code.

Page 320

Page 321

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

Quantity	Unit	Symbol	Other Units or Limitations
Space and Time			
plane angle	radian	rad	degree (decimalized)
length	meter	m	
area	square meter	m ²	
volume	cubic meter	m ³	liter (L) for liquid only (use without prefix other than in milliliter, mL)
time	second	s	minute (min), hour (h), day (d), week, and year
Periodic and Related Phenomena			
frequency	hertz	Hz	revolutions per second (r/s)
rotational frequency	revolutions per second	s ⁻¹	revolutions per minute (r/m)
Mechanics			
mass	kilogram	kg	
density	kilogram per cubic meter	kg/m ³	
moment of inertia	kilogram · meter ²	kg · m ²	
force	newton	N	
moment of force (torque)	newton-meter	N · m	
pressure and stress	pascal	Pa	(pascal = newton per square meter)
energy, work	joule	J	kilowatt-hour (kW · h)
power	watt	W	
impact strength	joule	J	
section modulus	meter ³	m ³	
moment of section (second moment of area)	meter ⁴	m ⁴	
fracture toughness	Pa · $\sqrt{m}$		
Heat			
temperature — thermodynamic [Note (2)]	kelvin	K	degree Celsius (°C)
temperature — other than thermodynamic	degree Celsius	°C	kelvin (K)
linear expansion coefficient	meter per meter-kelvin	K ⁻¹	°C ⁻¹
quantity of heat	joule	J	
heat flow rate	watt	W	
thermal conductivity	watt per meter-kelvin	W/(m · K)	W/(m · °C)
thermal diffusivity	square meter per second	m ² /s	
specific heat capacity	joule per kilogram-kelvin	J/(kg · K)	J/(kg · °C)
Electricity and Magnetism			
electric current	ampere	A	
electric potential	volt	V	
current density	ampere per meter ²	A/m ²	
magnetic field strength	ampere per meter	A/m	

NOTES:

- (1) Conversion factors between SI units and U.S. customary are given in SI-1, "ASME Orientation and Guide for Use of SI (Metric) Units," and ASTM E 380.
- (2) Preferred use for temperature and temperature interval is degrees Celsius (°C), except for thermodynamic and cryogenic work where kelvins may be more suitable. For temperature interval, 1 K = 1°C exactly.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

COMMONLY USED CONVERSION FACTORS (For Others See ASTM E 380) [See Note (1)]

Quantity	To Convert From	To	Multiply by [Note (2)]	
plane angle	degree	rad	1.745 329	E-02
length	in	m	2.54*	E-02
	ft	m	3.048*	E-01
	yd	m	9.144*	E-01
area	in ²	m ²	6.451 6*	E-04
	ft ²	m ²	9.290 304*	E-02
	yd ²	m ²	8.361 274	E-01
volume	in ³	m ³	1.638 706	E-05
	ft ³	m ³	2.831 685	E-02
	US gallon	m ³	3.785 412	E-03
	Imperial gallon	m ³	4.546 09	E-03
	liter	m ³	1.0*	E-03
mass	lbm	kg	4.535 924	E-01
	ton (metric) (mass)	kg	1.000 00*	E+03
	ton (short 2000 lbm)	kg	9.071 847	E+02
force	kgf	N	9.806 65*	E+00
	lbf	N	4.448 222	E+00
bending, torque	kgf · m	N · m	9.806 65*	E+00
	lbf · in	N · m	1.129 848	E-01
	lbf · ft	N · m	1.355 818	E+00
pressure, stress	kgf/m ²	Pa	9.806 65*	E+00
	lbf/ft ²	Pa	4.788 026	E+01
	lbf/in ² (psi)	Pa	6.894 757	E+03
	kips/in ²	Pa	6.894 757	E+06
	bar	Pa	1.0*	E+05
energy, work	Btu (IT) [Note (3)]	J	1.055 056	E+03
	ft · lbf	J	1.355 818	E+00
power	hp (550 ft · lbf/s)	W	7.456 999	E+02
fracture toughness	ksi $\sqrt{\text{in}}$	Pa · $\sqrt{\text{m}}$	1.098 843	E+06
temperature	°C	K	$t_K = t_C + 273.15$	
	°F	K	$t_K = (t_F + 459.67)/1.8$	
	°F	°C	$t_C = (t_F - 32)/1.8$	
temperature interval	°C	K	1.0*	E+00
	°F	K or °C	5.555 555	E-01

NOTES:

- (1) Care should be taken when converting formulas or equations that contain constant terms or factors. The value of these terms must be understood and may also require conversion.
- (2)(a) Relationships that are exact in terms of the base units are followed by a single asterisk.
- (b) The factors are written as a number greater than 1 and less than 10 with 6 or less decimal places. The number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example: 3.523 907 E-02 is $3.523\ 907 \times 10^{-2}$ or 0.035 239 07.
- (3) International Table

COMMONLY USED CONVERSION FACTORS

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NE A98

1998 ADDENDA SUMMARY OF CHANGES

Page xxv

Changes given below are identified on the pages by a margin note, **98**, placed next to the affected area.

Page	Location	Change
4	NE-1132.2	In subpara. (e), reference to NE-4438 corrected by Errata to read NE-4430
22	NE-2212.1	Reference to NE-2226.4 corrected by Errata to read NE-2226(b)(5)
64	NE-3213.10	First sentence corrected by Errata
75	NE-3221.5	In subpara. (c), reference to NE-3221(e)(4) corrected by Errata to read NE-2221(e)(4)
78	NE-3226	Reference to NCA-2145 corrected by Errata to read NCA-2142.3
91	NE-3325.3	Subparagraph (f) corrected by Errata
93	NE-3326.2	Equation (9) corrected by Errata
101	NE-3338.2	In subpara. (d)(1), second equation corrected by Errata
147	Table NE-4622.7(b)-1	Note (3) corrected by Errata
156	NE-5221	Reference to NE-5211.1 corrected by Errata to read NE-5280
157	NE-5280	(1) First paragraph designated as subpara. (a) (2) Subparagraphs (a), (b) and (c) redesignated as (1), (2), and (3), respectively (3) New subpara. (b) added
179	NE-8100	Reference to NE-2331, footnote 7 corrected by Errata to read NE-2331, footnote 4

NOTE: Volume 42 of the Interpretations to Section III, Divisions 1 and 2, of the ASME Boiler and Pressure Vessel Code follows the last page of the Edition to Subsection NCA.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NE INTRO

INTRODUCTION

1998 ASME
BOILER &
PRESSURE VESSEL CODE
AN INTERNATIONAL CODE

III

Division 1 -
Subsection NE

Class MC
Components

RULES FOR
CONSTRUCTION
OF NUCLEAR
POWER PLANT
COMPONENTS

[ASME logo] The American Society of
Mechanical Engineers

**IMPORTANT INFORMATION
ON THE 1998 BOILER AND
PRESSURE VESSEL CODE ADDENDA
DISTRIBUTION SCHEDULE**

There is a change in the way the Addenda to the 1998 Edition of the ASME Boiler and Pressure Vessel Code are distributed. The 1998 Edition, published July 1, 1998, incorporates the 1998 Addenda revisions, additions, or deletions. There will be no separate 1998 Addenda issued in a replacement page format. Two additional Addenda to the 1998 Edition, in the form of replacement pages, will be issued on July 1, 1999 and July 1, 2000.

The Summary of Changes published with the 1998 Edition lists and describes the revisions that are part of the 1998 Addenda. These changes are identified with a margin note, **98**, denoting the affected area.

The Addenda for 1999 and 2000 will also have a Summary of Changes and identifiers printed on the replacement pages. The revisions, additions, or deletions will be incorporated directly into the affected pages. It is advisable to retain the title sheets and all replaced pages for reference.

The effective dates for Code Editions and Addenda are described in the Foreword.

ASME BOILER AND PRESSURE VESSEL CODE
AN INTERNATIONAL CODE

RULES FOR
CONSTRUCTION OF
NUCLEAR BOILERS
PLANT COMPONENTS

III

Division 1 -
Subsection NE

Class MC
Components

1998 Edition

July 1, 1998

ASME BOILER AND
PRESSURE VESSEL
COMMITTEE
SUBCOMMITTEE ON
NUCLEAR POWER

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
NEW YORK, NEW YORK

Date of Issue - July 1, 1998

(Includes all Addenda dated December 1997 and earlier)

This code or standard was developed under procedures accredited as meeting the criteria for American National Standards. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment which provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not "approve," "rate," or "endorse" any item, construction, proprietary device, or activity.

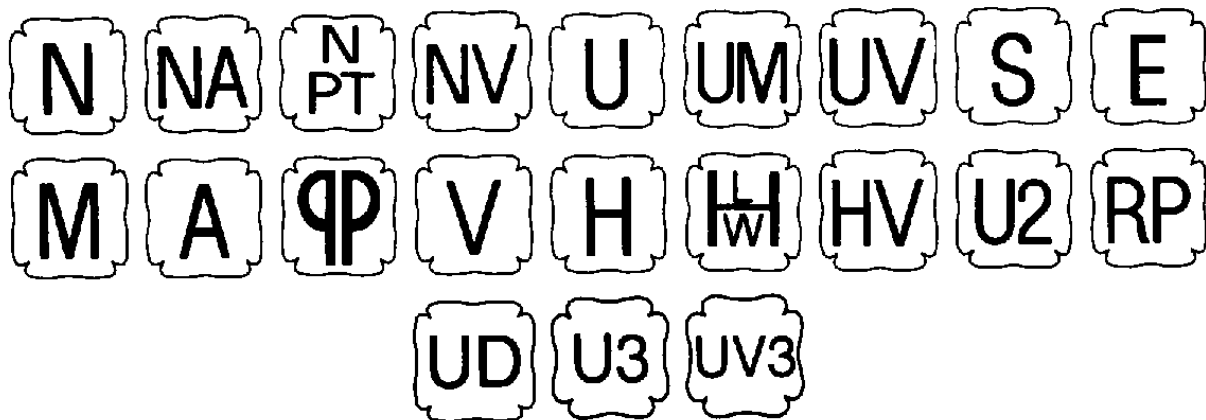
ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of any applicable Letters Patent, nor assume any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations issued in accordance with governing ASME procedures and policies which preclude the issuance of interpretations by individual volunteers.

The footnotes in this document are part of this American National Standard.

[ASME logo] ASME collective membership mark



LOGO

The above ASME symbols are registered in the U.S. Patent Office.

"ASME" is the trademark of the American Society of Mechanical Engineers.

No part of this document may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Library of Congress Catalog Card Number: 56-3934

Printed in the United States of America

Adopted by the Council of the American Society of Mechanical Engineers, 1914.

Revised 1940, 1941, 1943, 1946, 1949, 1952, 1953, 1956, 1959, 1962, 1965, 1968, 1971, 1974, 1977, 1980, 1983, 1986, 1989, 1992, 1995, 1998

The American Society of Mechanical Engineers
Three Park Avenue, New York, NY 10016-5990

Copyright © 1998 by
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
All Rights Reserved

1998

ASME BOILER AND PRESSURE VESSEL CODE

SECTIONS

I Rules for Construction of Power Boilers

II Materials

Part A - Ferrous Material Specifications

Part B - Nonferrous Material Specifications

Part C - Specifications for Welding Rods, Electrodes, and Filler Metals

Part D - Properties

III Subsection NCA - General Requirements for Division 1 and Division 2

III Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service Appendices

III Division 2 - Code for Concrete Reactor Vessels and Containments

III Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

IV Rules for Construction of Heating Boilers

V Nondestructive Examination

VI Recommended Rules for the Care and Operation of Heating Boilers

VII Recommended Guidelines for the Care of Power Boilers

VIII Rules for Construction of Pressure Vessels

 Division 1

 Division 2 - Alternative Rules

 Division 3 - Alternative Rules for Construction of High Pressure Vessels

IX Welding and Brazing Qualifications

X Fiber-Reinforced Plastic Pressure Vessels

XI Rules for Inservice Inspection of Nuclear Power Plant Components

ADDENDA

Colored-sheet Addenda, which include additions and revisions to individual Sections of the Code, are published annually and will be sent automatically to purchasers of the applicable Sections up to the publication of the 2001 Code. The 1998 Code is available only in the loose-leaf format; accordingly, the Addenda will be issued in the loose-leaf, replacement-page format.

INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code. The Interpretations for each individual Section will be published separately and will be included as part of the update service to that Section. They will be issued semiannually (July and December) up to the publication of the 2001 Code. Interpretations of Section III, Divisions 1 and 2, will be included with the update service to Subsection NCA.

CODE CASES

The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 1998 Code Cases book: (1) Boilers and Pressure Vessels and (2) Nuclear Components. Supplements will be sent automatically to the purchasers of the Code Cases books up to the publication of the 2001 Code.

Page v

FOREWORD

The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety governing the design, fabrication, and inspection during construction of boilers and pressure vessels, and to interpret these rules when questions arise regarding their intent. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property and to provide a margin for deterioration in service so as to give a reasonably long, safe period of usefulness. Advancements in design and material and the evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction¹, and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by

knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

Construction, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are responsible for the application of these programs to their design.

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practice as determined by the engineer.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Boiler and Pressure Vessel Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Mandatory Appendix covering preparation of technical inquiries). Proposed revisions to the Code resulting from inquiries will be presented to the Main Committee for appropriate action. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by ASME.

Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute and published in *Mechanical Engineering*

Page viii

to invite comments from all interested persons. After the allotted time for public review and final approval by ASME, revisions are published annually in Addenda to the Code.

Code Cases may be used in the construction of components to be stamped with the ASME Code symbol beginning with the date of their approval by ASME.

Code Editions may be used on or after the date of issue shown in the Edition. After Code revisions are approved by ASME, they may be used beginning with the date of issue shown on the Addenda. Revisions to material specifications are originated by the American Society for Testing and Materials (ASTM) and other recognized national or international organizations, and are usually adopted by ASME. However, those revisions may or may not have any effect on the suitability of material, produced to earlier editions of specifications, for use in ASME construction. ASME material specifications approved for use in each construction Code are listed in the Appendices of Section II, Parts A and B. These Appendices list, for each specification, the latest edition adopted by ASME, and earlier and later editions considered by ASME to be identical for ASME construction.

Owners of nuclear power plants are cautioned that Code Editions, Addenda, and Cases to be used in construction shall be acceptable to the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

Each state and municipality in the United States and each province in Canada that adopts or accepts one or more Sections of the Boiler and Pressure Vessel Code is invited to appoint a representative to act on the Conference Committee to the Boiler and Pressure Vessel Committee. Since the members of the Conference Committee are in active contact with the administration and enforcement of the rules, the requirements for inspection in this Code correspond with those in effect in their respective jurisdictions. The required qualifications for an Authorized Inspector under these rules may be obtained from the

administrative authority of any state, municipality, or province which has adopted these rules.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, method of fabrication, inspection, and safety devices. Permission may be granted to regulatory bodies and organizations publishing safety standards to use a complete Section of the Code by reference. If usage of a Section, such as Section IX, involves exceptions, omissions, or changes in provisions, the intent of the Code might not be attained.

Where a state or other regulatory body, in the printing of any Section of the Boiler and Pressure Vessel Code, makes additions or omissions, it is recommended that such changes be clearly indicated.

The National Board of Boiler and Pressure Vessel Inspectors is composed of chief inspectors of states and municipalities in the United States and of provinces in Canada that have adopted the Boiler and Pressure Vessel Code. This Board, since its organization in 1919, has functioned to uniformly administer and enforce the rules of the Boiler and Pressure Vessel Code. The cooperation of that organization with the Boiler and Pressure Vessel Committee has been extremely helpful.

The Code Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The Scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Code for vessels or components not considered to be within its Scope or may establish additions or deletions in that Scope. Accordingly, inquiries regarding such laws or regulations are to be directed to the issuing enforcement or regulatory body.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the ASME Boiler and Pressure Vessel Committee. ASME is to be notified should questions arise concerning improper use of an ASME Code symbol.

The specifications for materials given in Section II are identical with or similar to those of specifications published by ASTM, AWS, and other recognized national or international organizations. When reference is made in an ASME material specification to a non-ASME specification for which a companion ASME specification exists, the reference shall be interpreted as applying to the ASME material specification. Not all materials included in the material specifications in Section II have been adopted for use in this Section. Usage is limited to those materials and grades listed in at least one of the tables of Section II, Part D, Subpart 1, identified as applicable to this Section. All materials allowed by this Section and used for construction within the scope of these rules shall be furnished in accordance with material specifications

Page ix

contained in Section II or referenced in Appendices A of Section II, Parts A and B except where otherwise provided in Code Cases or in this Section of the Code. Materials covered by these specifications are acceptable for use in items covered by the Code Sections only to the degree indicated in the applicable Section. Materials for Code use should preferably be ordered, produced, and documented on this basis. Material produced to an acceptable specification with requirements different from the requirements of the corresponding specification listed in Appendix A of Part A or Part B may also be used in accordance with the above, provided the material manufacturer or vessel manufacturer certifies with evidence acceptable to the Authorized Inspector that the corresponding ASME specification requirements of specifications listed in Appendix A of Part A or Part B have been met. Material produced to an acceptable material specification is not limited as to country of origin.

When required by context in this Section, the singular shall be interpreted as the plural, and vice-versa; and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

Publication of the SI (Metric) Edition of the ASME Boiler and Pressure Vessel Code was discontinued with the 1986 Edition. Effective October 1, 1986, the SI Edition was withdrawn as an ASME Boiler and Pressure Vessel Code document.

Page xi

STATEMENT OF POLICY ON THE USE OF CODE SYMBOLS AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the

requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use Code Symbols for marking items or constructions which have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the symbols, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications which might so indicate. An organization holding a Code Symbol and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code."

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified items will carry the symbol. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

The ASME logo, which is the cloverleaf with the letters ASME within, shall not be used by any organization other than ASME.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Code Symbol Stamp described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the various Code Symbols shall not be used on any item which is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME which tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

Page xiii

PERSONNEL ASME Boiler and Pressure Vessel Committee Subcommittees, Subgroups, and Working Groups

As of December 31, 1997

MAIN COMMITTEE

D. A. Canonico, *Chair*

G. G. Karcher, *Vice Chair*

J. S. Brzuszkiewicz, *Secretary*

R. W. Barnes

F. P. Barton

D. L. Berger

M. D. Bernstein

M. N. Bressler

W. J. Carter
T. M. Cullen
J. R. Farr
R. E. Feigel
J. G. Feldstein
M. Gold
O. F. Hedden
A. J. Justin
D. F. Landers
W. M. Lundy
J. R. MacKay
T. J. Mawson
T. G. McCarty
G. C. Millman
R. A. Moen
C. C. Neely
C. J. Pieper
R. F. Reedy
B. W. Roberts
F. J. Schaaf, Jr.
A. Selz
K. K. Tam
D. E. Tanner

EXECUTIVE COMMITTEE (MAIN COMMITTEE)

G. G. Karcher, *Chair*
D. A. Canonico, *Vice Chair*
J. S. Brzuszkiewicz, *Secretary*
F. P. Barton
J. R. Farr
J. G. Feldstein
M. Gold
O. F. Hedden
A. J. Justin
J. R. MacKay
T. G. McCarty
T. P. Pastor
T. E. Quaka
R. F. Reedy
A. J. Spencer

HONORARY MEMBERS (MAIN COMMITTEE)

R. D. Bonner
R. J. Bosnak
H. M. Canavan
L. J. Chockie
J. S. Clarke
W. E. Cooper

W. D. Doty
R. C. Griffin
E. J. Hemzy
E. C. Kistner, Jr.
J. E. Lattan
J. LeCoff
F. N. Moschini
C. E. Rawlins
W. E. Somers
L. P. Zick, Jr.

HONORS AND AWARDS COMMITTEE

J. R. MacKay, *Chair*
A. J. Spencer, *Vice Chair*
F. R. Lyons, *Secretary*
F. P. Barton
W. J. Carter
J. G. Feldstein
M. Gold
F. E. Gregor
E. C. Kistner, Jr.
T. P. Pastor
R. F. Reedy

MARINE CONFERENCE GROUP

J. Tiratto, *Chair*
C. F. Banks
L. W. Douthwaite
J. L. Jones
G. F. Wright

CONFERENCE COMMITTEE

D. E. Tanner - Tennessee (*Chair*)
R. D. Reetz - North Dakota (*Vice Chair*)
A. J. Justin - National Board of Boiler and Pressure Vessel Inspectors (*Secretary*)
R. J. Aben, Jr. - Michigan
J. S. Aclaro - Los Angeles, California
E. A. Anderson - Chicago, Illinois
J. Anderson - South Dakota
R. Barkdoll - Washington
F. P. Barton - Virginia
C. Castle - Nova Scotia, Canada
R. R. Cate - Louisiana
L. Chase - Northwest Territories, Canada
R. A. Coomes - Kentucky
J. Corcoran - Connecticut
M. H. Diehl, Jr. - Maryland
D. A. Douin - Illinois

D. Eastman - Newfoundland and Labrador, Canada

G. L. Ebeyer - New Orleans, Louisiana

F. Ellis - New Hampshire

E. Everett - Georgia

P. C. Hackford - Utah

D. Hanrath - North Carolina

J. B. Harlan - Delaware

K. Hynes - Prince Edward Island, Canada

D. T. Jagger - Ohio

D. J. Jenkins - Kansas

M. Kotb - Quebec, Canada

J. P. Larson - Minnesota

K. T. Lau - Alberta, Canada

J. Lemire - California

G. A. Lundberg - Florida

W. C. Lundine - Oregon

M. A. Malek - Maine

I. W. Mault - Manitoba, Canada

H. T. McEwen - Mississippi

A. W. Meiring - Indiana

R. Mile - Ontario, Canada

T. J. Monroe - Oklahoma

Y. Nagpaul - Hawaii

J. D. Payton - Pennsylvania

D. K. Peetz - Missouri

D. C. Price - Yukon Territory, Canada

R. S. Pucek - Wisconsin

T. E. Rennie - Arizona

L. Roussinos - British Columbia, Canada

M. Shuff - West Virginia

R. Snyder - New Jersey

N. Surtees - Saskatchewan, Canada

M. J. Verhagen - Wisconsin

R. B. West - Iowa

M. J. Wheel - Vermont

K. A. White - Nevada

R. K. White - New York

T. F. Wickham - Rhode Island

C. S. Withers - Colorado

SUBCOMMITTEE ON POWER BOILERS (SC I)

J. R. MacKay, *Chair*

M. D. Bernstein, *Vice Chair*

P. D. Stumpf, *Secretary*

D. L. Berger

E. Everett

D. N. French

F. R. Gerety
J. Hainsworth
T. E. Hansen
J. S. Hunter
W. L. Lowry
T. C. McGough
P. A. Molvie
D. K. Parrish
J. T. Pillow
R. G. Presnak
B. W. Roberts
R. D. Schueler, Jr.
R. V. Wielgoszinski
R. L. Williams

Page xiv

Subgroup on Design (SC I)

M. D. Bernstein, *Chair*
R. D. Schueler, Jr., *Vice Chair*
P. A. Molvie, *Secretary*
M. A. Farrugia
J. D. Fishburn
C. F. Jeerings
K. C. Morrison
A. Nassif
N. Surtees
R. V. Wielgoszinski

Subgroup on Fabrication and Examination (SC I)

D. L. Berger, *Chair*
R. E. McLaughlin, *Secretary*
R. W. Boyce
D. N. French
J. Hainsworth
T. E. Hansen
M. H. Iken
J. M. Lyons
J. T. Pillow
M. E. Reese
R. D. Schueler, Jr.
R. F. Slack, Sr.
R. V. Wielgoszinski

Subgroup on General Requirements (SC I)

T. C. McGough, *Chair*
M. D. Bernstein, *Vice Chair*
W. L. Lowry, *Secretary*
D. L. Berger

E. Everett
F. R. Gerety
J. Hainsworth
C. F. Jeerings
J. M. Lyons
R. E. McLaughlin
D. K. Parrish
J. T. Pillow
W. E. Somers
R. L. Williams

Subgroup on Materials (SC I)

B. W. Roberts, *Chair*
C. E. Spaeder, Jr., *Chair*
J. S. Hunter, *Secretary*
T. M. Cullen
D. N. French
J. F. Henry
J. P. Libbrecht
F. Masuyama
J. M. Tanzosh

Subgroup on Piping (SC I)

T. E. Hansen, *Chair*
D. L. Berger
M. D. Bernstein
P. D. Edwards
W. L. Lowry
T. C. McGough
R. G. Presnak
E. Whittle
P. L. Ziegler

SUBCOMMITTEE ON MATERIALS (SC II)

M. Gold, *Chair*
T. M. Cullen, *Vice Chair*
F. R. Lyons, *Secretary*
A. P. Ahrendt
M. N. Bressler
A. Cohen
R. Dirscherl
W. D. Doty
W. D. Edsall
D. Gandy
M. H. Gilkey
J. J. Heger
J. F. Henry
G. C. Hsu

F. Masuyama
E. Michalopoulos
R. A. Moen
R. K. Nanstad
E. G. Nisbett
J. T. Parsons
D. W. Raho
B. W. Roberts
E. Shapiro
C. E. Spaeder, Jr.
R. W. Swindeman
J. M. Tanzosh
B. E. Thurgood
A. W. Zeuthen

Subgroup on External Pressure (SC II)

R. W. Mikitka, *Chair*
D. J. Green
D. S. Griffin
E. Michalopoulos
B. R. Morelock
D. Nadel
C. E. Spaeder, Jr.
C. H. Sturgeon

Subgroup on Ferrous Specifications (SC II)

E. G. Nisbett, *Chair*
B. M. Dingman
W. D. Edsall
T. Graham
W. N. Holliday
E. A. Jonas
D. C. Krouse
J. F. Longenecker
W. C. Mack
A. S. Melilli
J. T. Parsons
E. J. Rozic, Jr.
E. Uptis
A. W. Zeuthen
R. H. Zong

Subgroup on International Material Specifications (SC II)

J. T. Parsons, *Chair*
D. C. Agarwal
J. Cameron
R. Dirscherl
W. D. Doty
D. M. Fryer

M. Gold
M. H. Iken
W. M. Lundy
H. Masahisa
T. F. Miskell
F. Osweiller
A. P. Povilonis
R. D. Schueler, Jr.
R. R. Seeley
E. A. Steen
E. Upitis
E. O. Woolridge

subgroup on Nonferrous Alloys (SC II)

D. W. Rahoi, *Chair*
D. C. Agarwal, *Secretary*
W. R. Apblett
L. G. Coffee
A. Cohen
R. Dirscherl
M. H. Gilkey
G. C. Hsu
M. Katcher
E. Shapiro
L. E. Shoemaker
R. C. Sutherlin

Subgroup on Strength, Ferrous Alloys (SC II)

B. W. Roberts, *Chair*
J. M. Tanzosh, *Secretary*
A. P. Ahrendt
W. R. Apblett
T. M. Cullen
M. Gold
J. J. Heger
C. L. Hoffmann
A. Iseda
F. Masuyama
R. A. Moen
D. W. Rahoi
C. E. Spaeder, Jr.
R. W. Swindeman
B. E. Thurgood

Subgroup on Strength of Weldments (SC II & SC IX)

C. E. Spaeder, Jr., *Chair*
W. D. Doty
D. W. Rahoi

B. W. Roberts
C. Robino
W. J. Sperko
J. M. Tanzosh
B. E. Thurgood

Subgroup on Toughness (SC II)

J. M. Barsom
D. A. Hansen
A. Selz
R. S. Vecchio
S. Yukawa
R. Zawierucha

Page xv

SUBCOMMITTEE ON NUCLEAR POWER (SC III)

C. J. Pieper, *Chair*
R. M. Jessee, *Vice Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
Y. Asada
R. W. Barnes
J. N. Baysden
W. H. Borter
E. B. Branch
M. N. Bressler
F. C. Cherny
G. D. Cooper
R. P. Deubler
W. D. Doty
F. R. Drahos
K. Ennis
B. A. Erler
D. Hanrath
C. L. Hoffmann
K.-H. Hsu
D. F. Landers
W. C. LaRochelle
T. J. Mawson
W. N. McLean
R. A. Moen
D. B. Nickerson
R. F. Perrin
R. F. Reedy
M. W. Smith
J. D. Stevenson
R. E. Tome

K. R. Wichman

Subgroup on Containment Systems for Spent Fuel and High-Level Waste Transport Packagings (SC III)

J. D. Stevenson, *Chair*

H. H. Chung

R. R. Doggart

E. L. Farrow

K. Goldmann

R. H. Jones

W. H. Lake

R. W. Lambert

H. W. Lee

P. McConnell

R. E. Nickell

D. J. Nolan

D. T. Raske

T. Saegusa

R. H. Smith

K. B. Sorenson

P. Turula

N. Urabe

C. R. Witt

S. Yukawa

Subgroup on Design (SC III)

R. W. Barnes, *Chair*

E. B. Branch, *Vice Chair*

R. S. Hill III, *Secretary*

Y. Asada

M. N. Bressler

C. W. Bruny

J. R. Cole

G. D. Cooper

R. P. Deubler

N. W. Edwards

R. E. Gimple

D. Hanrath

R. W. Haupt

T. Iida

B. Jarman

D. F. Landers

W. N. McLean

D. B. Nickerson

E. C. Rodabaugh

J. R. Santangelo

G. C. Slagis

J. D. Stevenson

J. H. Wawrzeniak

K. R. Wichman

R. Wray

Working Group on Administration (SG-D) (SC III)

E. B. Branch, *Chair*

R. W. Barnes, *Vice Chair*

R. S. Hill III, *Secretary*

C. W. Bruny

G. D. Cooper

R. P. Deubler

J. T. Land

D. F. Landers

W. N. McLean

D. B. Nickerson

J. R. Santangelo

R. Wray

Working Group on Core Support Structures (SG-D) (SC III)

J. T. Land, *Chair*

R. H. Hansen

K. B. Larsen

J. F. Mullooly

B. L. Silverblatt

Working Group on Dynamic and Extreme Load Conditions (SG-D) (SC III)

R. Wray, *Chair*

A. E. Meligi, *Secretary*

P. L. Anderson

M. K. Au-Yang

R. D. Blevins

G. J. Bohm

D. L. Caldwell

P.-Y. Chen

A. Hadjian

M. Hartzman

W. S. LaPay

H. Lockert

P. R. Olson

R. F. Perry

J. Wallach

Working Group on Piping (SG-D) (SC III)

D. F. Landers, *Chair*

R. S. Hill III, *Vice Chair*

P. Hirschberg, *Secretary*

T. M. Adams

G. A. Antaki

J. R. Cole

A. B. Glickstein

R. W. Haupt
J. C. Hennart
R. D. Hookway
R. B. Jenkins
K. A. Manoly
J. C. Minichiello
S. E. Moore
A. N. Nguyen
D. B. Nickerson
O. O. Oyamada
R. D. Patel
E. C. Rodabaugh
J. R. Santangelo
M. S. Sills
G. C. Slagis
E. A. Wais

Working Group on Pumps (SG-D) (SC III)

D. B. Nickerson, *Chair*
H. L. Brammer
P. Burchett
R. E. Cornman, Jr.
A. A. Fraser
M. Higuchi
G. R. Jones
J. W. Leavitt
J. E. Livingston
R. A. Schussler
H. Taffarodi
G. K. Vaghasia

Working Group on Supports (SG-D) (SC III)

R. P. Deubler, *Chair*
R. M. Dulin, Jr., *Secretary*
U. S. Bandyopadhyay
F. J. Birch
M. N. Bressler
J. R. Cole
J. C. Finneran, Jr.
R. W. Haupt
J. C. Hennart
A. S. Laurenson
A. Lee
R. J. Masterson
A. E. Meligi
A. N. Nguyen
J. R. Stinson

Working Group on Valves (SG-D) (SC III)

W. N. McLean, *Chair*

E. A. Bake

R. R. Brodin

W. G. Knecht

R. Koester

J. J. McGavin

S. N. Shields

H. R. Sonderegger

J. C. Tsacoyeanes

R. G. Visalli

J. R. Zahorsky

Working Group on Vessels (SG-D) (SC III)

C. W. Bruny, *Chair*

T. K. Burr, Sr.

G. D. Cooper

G. A. Deaver

N. W. Edwards

D. Hanrath

W. J. Heilker

B. Jarman

T. M. Khan

O. Maekawa

K. A. Manoly

A. Merend

G. K. Miller

W. Z. Novak

E. Pelling

H. S. Thornton

Page xvi

Special Working Group on Environmental Effects (SG-D) (SC III)

R. S. Hill III, *Chair*

Y. Asada

W. J. Heilker

C. L. Hoffmann

R. A. Moen

W. Z. Novak

S. Yukawa

Special Working Group on Seismic Piping Rules (SG-D) (SC III)

E. B. Branch, *Chair*

T. M. Adams

G. A. Antaki

R. D. Hookway

J. C. Minichiello

M. S. Sills

E. A. Wais

Subgroup on General Requirements (SC III & SC 3C)

W. C. LaRochelle, *Chair*

K. Ennis, *Secretary*

A. Appleton

J. R. Barbee

J. N. Baysden

L. M. Beason

B. H. Berg

R. E. Kelley

G. S. Korin

A. S. Laurenson

C. Lizotte

M. J. Meyer

M. R. Minick

L. C. Oakes

R. F. Perrin

U. Potapovs

B. B. Scott

D. E. Tanner

D. V. Walshe

Subgroup on Materials, Fabrication, and Examination (SC III)

C. L. Hoffmann, *Chair*

G. P. Milley, *Secretary*

C. W. Allison

D. Doyle

F. R. Drahos

G. M. Foster

G. B. Georgiev

J. E. Harris

R. W. Jackson

R. M. Jessee

C. C. Kim

R. A. Moen

C. J. Pieper

R. R. Seeley

N. M. Simpson

R. C. Soin

W. J. Sperko

K. B. Stuckey

S. Yukawa

Subgroup on Pressure Relief (SC III)

F. C. Cherny, *Chair*

S. F. Harrison, Jr.

E. M. Petrosky

M. W. Smith

M. W. Smith
A. L. Szeglin
B. S. York
J. R. Zahorsky

Special Working Group on Editing and Review (SC III)

R. F. Reedy, *Chair*
W. H. Borter
M. N. Bressler
R. P. Deubler
B. A. Erler
W. C. LaRochelle
M. W. Smith
J. D. Stevenson
E. O. Woolridge

JOINT ACI-ASME COMMITTEE ON CONCRETE COMPONENTS FOR NUCLEAR SERVICE (SC 3C)

B. A. Erler, *Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
R. M. Attar
A. C. Eberhardt
J. Gutierrez
D. J. Haavik
M. F. Hessheimer
T. E. Johnson
G. R. Murphy
S. F. Putman
B. B. Scott
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Design (SC 3C)

D. G. Adams
A. C. Eberhardt
T. E. Johnson
S. F. Putman
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Materials, Construction, and Examination (SC 3C)

D. J. Haavik, *Chair*
J. F. Artuso
R. M. Attar
B. A. Erler
J. Gutierrez

SUBCOMMITTEE ON HEATING BOILERS (SC IV)

F. P. Barton, *Chair*
P. A. Molvie, *Vice Chair*
B. P. Feder, *Secretary*
R. B. Duggan
W. L. Haag, Jr.
W. M. Hiddleston
J. D. Hoh
K. M. McTague
R. I. Mullican
E. A. Nordstrom
J. L. Seigle
D. E. Tanner
S. V. Voorhees
R. H. Weigel
R. V. Wielgoszinski
J. I. Woodworth
T. L. Bedeaux, Alternate

Subgroup on Care and Operation of Heating Boilers (SC IV)

J. I. Woodworth, *Chair*
B. P. Feder, *Secretary*
K. J. Hoey
J. D. Hoh
F. M. Lucas
K. M. McTague
P. A. Molvie
R. I. Mullican
R. H. Weigel
T. F. Wickham
T. L. Bedeaux, Alternate

Subgroup on Cast Iron Boilers (SC IV)

K. M. McTague, *Chair*
R. B. Duggan
R. H. Weigel
T. F. Wickham
J. I. Woodworth
T. L. Bedeaux, Alternate

Subgroup on Water Heaters (SC IV)

W. L. Haag, Jr., *Chair*
T. D. Gantt
W. M. Hiddleston
F. M. Lucas
K. M. McTague
R. I. Mullican
D. Smith
D. E. Tanner

M. A. Taylor

Subgroup on Welded Boilers (SC IV)

P. A. Molvie, *Chair*

T. L. Bedeaux

D. H. Mapes

E. A. Nordstrom

J. L. Seigle

R. F. Slack, Sr.

R. P. Sullivan

D. E. Tanner

R. V. Wielgoszinski

SUBCOMMITTEE ON NONDESTRUCTIVE EXAMINATION (SC V)

T. G. McCarty, *Chair*

J. E. Batey, *Vice Chair*

F. S. Fitzgerald, *Secretary*

A. S. Birks

B. H. Clark, Jr.

W. T. Clayton

R. A. Coomes

N. Y. Faransso

H. C. Graber

O. F. Hedden

G. W. Hembree

F. B. Kovacs

J. F. Manning

W. C. McGaughey

R. D. McGuire

Page xvii

Subgroup on General Requirements/Personnel Qualifications and Inquiries (SC V)

R. D. McGuire, *Chair*

J. E. Batey

W. T. Clayton

N. Y. Faransso

H. C. Graber

G. W. Hembree

J. R. MacKay

J. P. Swezy

Subgroup on Surface Examination Methods (SC V)

H. C. Graber, *Chair*

S. J. Akrin

T. Alexander

A. S. Birks

B. H. Clark

R. A. Coomes

G. W. Hembree

Subgroup on Volumetric Methods (SC V)

J. E. Batey, *Chair*

S. J. Akrin

W. T. Clayton

N. Y. Faransso

H. C. Graber

G. W. Hembree

B. Kellerhall

E. K. Kietzman

F. B. Kovacs

R. W. Kruzic

J. F. Manning

W. C. McGaughey

J. R. Mitchell

Working Group on Acoustic Emissions (SG-VM) (SC V)

B. H. Clark, Jr.

P. M. Horrigan

J. F. Manning

J. R. Mitchell

Working Group on Radiography (SG-VM) (SC V)

G. W. Hembree, *Chair*

S. J. Akrin

T. Alexander

J. E. Batey

N. Y. Faransso

H. C. Graber

F. B. Kovacs

Working Group on Ultrasonics (SG-VM) (SC V)

W. T. Clayton, *Chair*

O. F. Hedden

B. Kellerhall

E. K. Kietzman

J. F. Manning

W. C. McGaughey

R. Paillaman

F. J. Sattler

M. L. Shakinovsky

SUBCOMMITTEE ON PRESSURE VESSELS (SC VIII)

T. P. Pastor, *Chair*

K. Mokhtarian, *Vice Chair*

A. J. Roby, *Secretary*

A. P. Ahrendt

V. Bogosian

S. M. Caldwell

W. J. Carter

S. C. Cyr
R. Dirscherl
R. M. Elliott
J. R. Farr
R. E. Feigel
J. G. Feldstein
G. L. Hollinger
M. J. Houle
W. S. Jacobs
G. G. Karcher
G. B. Komora
K. T. Lau
R. W. Mikitka
U. R. Miller
C. C. Neely
K. J. Schneider
A. Selz
J. R. Sims, Jr.
A. J. Spencer
E. A. Steen
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Design (SC VIII)

U. R. Miller, *Chair*
R. E. Knoblock, *Secretary*
M. R. Bauman
M. R. Breach
S. M. Caldwell
N. W. Edwards
J. R. Farr
J. A. Hayward
G. L. Hollinger
W. S. Jacobs
G. G. Karcher
G. B. Komora
R. W. Mikitka
K. Mokhtarian
T. P. Pastor
M. D. Rana
A. Selz
S. C. Shah
J. W. Stokes
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Fabrication and Inspection (SC VIII)

E. A. Steen, *Chair*
K. Mokhtarian, *Vice Chair*
W. J. Bees
R. W. Boyce
S. C. Cyr
R. E. Feigel
H. E. Gordon
M. J. Houle
W. S. Jacobs
R. A. Johnson
A. S. Lester III
F. C. Ouyang
M. J. Rice
W. P. Webb

Subgroup on General Requirements (SC VIII)

R. M. Elliott, *Chair*
A. P. Ahrendt
V. Bogosian
W. J. Carter
W. P. Crow
J. P. Glaspie
C. R. Good
D. B. Kadakia
J. C. Keenan
W. E. Laveck, Jr.
A. S. Mann
C. C. Neely
A. S. Olivares
K. J. Schneider
A. J. Spencer

Subgroup on Materials (SC VIII)

R. Dirscherl, *Chair*
D. C. Agarwal
A. P. Ahrendt
J. Cameron
W. D. Doty
W. D. Edsall
M. Katcher
W. M. Lundy
E. E. Morgenegg
E. G. Nisbett
J. T. Parsons
D. W. Raho
K. K. Tam
B. K. Thakur

Special Working Group on Heat Transfer Equipment (SC VIII)

G. B. Komora, *Chair*
R. P. Zoldak, *Secretary*
C. F. Andreone
D. E. Bolt
S. M. Caldwell
T. K. Haldas
M. J. Holtz
W. G. Jandrasits
R. Mahadeen
U. R. Miller
F. Osweiller
J. E. Soehrens
A. I. Soler
W. A. Treff
S. Yokell

Page xviii

Special Working Group on High-Pressure Vessels (SC VIII)

J. R. Sims, Jr., *Chair*
P. A. Reddington, *Secretary*
L. P. Antalffy
J. E. Baxter
R. C. Biel
T. B. Boyd
D. J. Burns
P. N. Chaku
E. L. Danfelt
R. E. Feigel
D. M. Fryer
J. L. Heck, Jr.
A. H. Honza
V. T. Hwang
M. M. James
P. Jansson
J. A. Kapp
D. P. Kendall
A. K. Khare
S. C. Mordre
G. J. Mraz
E. H. Perez
L. M. Picqueur
E. D. Roll
W. L. Stewart
J. F. Sullivan
F. W. Tatar

Special Working Group on Toughness (SC VIII)

W. S. Jacobs, *Chair*

J. Cameron

W. D. Doty

D. A. Hansen

G. G. Karcher

G. B. Komora

K. Mokhtarian

J. L. Mooney

C. C. Neely

M. D. Rana

J. W. Stokes

SUBCOMMITTEE ON WELDING (SC IX)

J. G. Feldstein, *Chair*

W. J. Sperko, *Vice Chair*

J. Labrador, *Secretary*

R. Barkdoll

D. A. Bowers

M. L. Carpenter

W. D. Doty

P. D. Flenner

M. J. Houle

R. A. Johnson

W. M. Lundy

R. D. McGuire

J. J. Meyer

A. H. Miller

B. R. Newmark

P. P. Norris

S. D. Reynolds, Jr.

W. K. Scattergood

G. W. Spohn III

M. J. Stanko

J. M. Tanzosh

R. R. Young

Subgroup on Brazing (SC IX)

M. J. Houle, *Chair*

A. S. Artayet

M. L. Carpenter

C. F. Jeerings

A. H. Miller

C. Robino

Subgroup on General Requirements (SC IX)

B. R. Newmark, *Chair*

R. Barkdoll

P. R. Evans

P. C. Filean
R. M. Jessee
D. W. Mann
A. S. Olivares
C. E. Wainwright
R. A. Weiss
K. R. Willens

Subgroup on Materials (SC IX)

M. L. Carpenter, *Chair*
L. P. Connor
P. D. Flenner
R. M. Jessee
A. H. Miller
H. A. Sadler
C. E. Sainz
C. E. Spaeder, Jr.
W. J. Sperko
M. J. Stanko
R. R. Young

Subgroup on Performance Qualification (SC IX)

J. J. Meyer, *Chair*
V. A. Bell
D. A. Bowers
L. P. Connor
R. A. Coomes
P. D. Flenner
G. Herrmann
M. J. Houle
W. M. Lundy
R. D. McGuire
S. R. Nordman
P. P. Norris
W. K. Scattergood
G. W. Spohn III

Subgroup on Procedure Qualification (SC IX)

J. J. Meyer, *Chair*
R. K. Brown, Jr.
R. A. Johnson
A. H. Miller
P. P. Norris
A. S. Olivares
F. C. Ouyang
S. D. Reynolds, Jr.
M. J. Rice
W. K. Scattergood

W. J. Sperko
T. C. Wiesner

SUBCOMMITTEE ON FIBER-REINFORCED PLASTIC PRESSURE VESSELS (SC X)

P. J. Conlisk, *Chair*
D. Eisberg, *Vice Chair*
A. J. Roby, *Secretary*
K. M. Agrawal
F. L. Brown
J. L. Bustillos
T. W. Cowley
T. J. Fowler
S. V. Hoa
L. E. Hunt
J. C. Murphy
A. L. Newberry
D. J. Painter
J. A. Rolston
B. F. Shelley
P. R. Wilt

SUBCOMMITTEE ON NUCLEAR INSERVICE INSPECTION (SC XI)

O. F. Hedden, *Chair*
T. J. Mawson, *Vice Chair*
G. L. Fechter, *Secretary*
C. W. Allison
W. H. Bamford, Jr.
R. L. Beverly
J. M. Bloom
R. W. Boyce
C. D. Cowfer
D. D. Davis
R. L. Dyle
T. N. Epps III
R. E. Gimple
F. E. Gregor
L. B. Gross
K. Iida
C. A. Ireland
R. D. Kerr
D. F. Landers
T. F. Lentz
J. T. Lindberg
G. C. Millman
C. R. Osman
P. C. Riccardella
L. Sage
F. J. Schaaf, Jr.

J. E. Staffiera
R. P. Sullivan
R. W. Swayne
R. J. Tamminga
J. C. Tobin
R. A. Yonekawa

Honorary Members (SC XI)

S. H. Bush
L. J. Chockie
J. P. Houstrup
L. R. Katz
R. R. MacCary

Page xviv

Subgroup on Evaluation Standards (SC XI)

W. H. Bamford, Jr., *Chair*
M. Kupinski, *Secretary*
J. M. Bloom
R. C. Cipolla
R. M. Gamble
T. J. Griesbach
P. J. Hijek
K. Iida
Y. Imamura
J. G. Merkle
S. Ranganath
P. C. Riccardella
D. A. Scarth
W. L. Server
C. A. Tomes
W. A. Van Der Sluys
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa

Working Group on Flaw Evaluation (SG-ES) (SC XI)

R. C. Cipolla, *Chair*
W. H. Bamford, Jr.
M. Basol
J. M. Bloom
E. Friedman
T. J. Griesbach
F. D. Hayes
D. N. Hopkins
K. Iida
Y. Imamura

M. Kupinski
H. S. Mehta
J. G. Merkle
J. S. Panesar
R. K. Qashu
S. Ranganath
D. A. Scarth
T. S. Schurman
W. L. Server
F. A. Simonen
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Working Group on Operating Plant Criteria (SG-ES) (SC XI)

T. J. Griesbach, *Chair*
W. H. Bamford, Jr.
H. Behnke
B. A. Bishop
W. F. Brady
E. Friedman
S. R. Gosselin
E. M. Hackett
P. J. Hijeck
S. D. Leshnoff
P. Manbeck
J. S. Panesar
W. E. Pennell
J. H. Phillips
S. Ranganath
S. T. Rosinski
W. L. Server
E. A. Siegel
F. A. Simonen
T. D. Spry
K. K. Yoon
S. Yukawa

Working Group on Pipe Flaw Evaluation (SG-ES) (SC XI)

D. A. Scarth, *Chair*
G. M. Wilkowski, *Secretary*
W. H. Bamford, Jr.
J. M. Bloom
R. C. Cipolla
N. G. Cofie

S. K. Daftuar
G. H. De Boo
E. Friedman
D. N. Hopkins
K. Iida
H. S. Mehta
J. G. Merkle
J. S. Panesar
D. Quinones
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Subgroup on Liquid-Metal-Cooled Systems (SC XI)

C. G. McCargar, *Chair*
W. L. Chase
S. Hattori
R. Hundal
W. Kwant
J. C. Tobin

Working Group on Liquid-Metal Reactor Covers (SG-LMCS) (SC XI)

W. L. Chase, *Chair*
S. Hattori
R. Hundal
W. Kwant

Subgroup on Nondestructive Examination (SC XI)

R. L. Beverly, *Chair*
N. R. Bentley, *Secretary*
D. C. Adamonis
F. L. Becker
F. T. Carr
C. B. Cheezem
W. T. Clayton
C. D. Cowfer
F. J. Dodd
T. N. Epps III
D. O. Henry
M. R. Hum
S. N. Liu
R. D. McGuire
M. C. Modes
C. R. Osman
F. J. Schaaf, Jr.
J. C. Spanner, Jr.
C. J. Wirtz

Working Group on Personnel Qualification and Surface Visual and Eddy Current Examination (SG-NDE) (SC XI)

C. J. Wirtz, *Secretary*

B. L. Curtis

N. Economos

H. B. Garland

D. O. Henry

H. E. Houserman

J. J. McArdle III

R. D. McGuire

S. A. Redner

M. F. Sherwin

A. L. Smith

D. Spake

J. C. Spanner, Sr.

J. C. Spanner, Jr.

T. V. Tran

Working Group on Pressure Testing (SG-NDE) (SC XI)

G. P. Alexander

T. M. Anselmi

T. B. Basso

J. Boughman

T. R. Bugelholll

R. J. Cimoch

C. E. Jensen

W. N. Keisler

D. Lamond

F. J. Schaaf, Jr.

D. Terao

Working Group on Procedure Qualification and Volumetric Examination (SG-NDE) (SC XI)

C. D. Cowfer, *Chair*

C. E. Larsen, *Secretary*

D. C. Adamonis

F. L. Becker

N. R. Bentley

B. Bevins

F. T. Carr

C. B. Cheezem

W. T. Clayton

S. R. Doctor

F. J. Dodd

T. N. Epps III

B. Kellerhall

G. A. Lofthus

J. K. McClanahan

M. C. Modes

M. Saporito
T. T. Taylor
S. M. Walker

Subgroup on Repairs, Replacements, and Modifications (SC XI)

R. E. Gimple, *Chair*
W. C. Holston, *Secretary*
R. W. Boyce
M. N. Bressler
S. B. Brown
C. E. Hartz
R. A. Hermann
C. A. Ireland
R. D. Kerr
D. F. Landers
R. S. Lewis
T. J. Mawson
M. S. McDonald
R. R. Stevenson
R. P. Sullivan
R. W. Swayne
R. E. Tome
D. E. Waskey
R. A. Yonekawa

Page xx

Working Group on Design Reconciliation (SG-RR&M) (SC XI)

W. C. Holston, *Chair*
J. T. Conner, *Secretary*
R. W. Boyce
S. B. Brown
J. E. Charnley
T. E. Hiss
E. V. Imbro
D. N. Irvine, Jr.
D. F. Landers
R. W. Swayne
F. Tehranchi
H. J. Thailer
R. E. Tome

Working Group on Responsibilities and Program Requirements (SG-RR&M) (SC XI)

R. A. Yonekawa, *Chair*
R. R. Stevenson, *Secretary*
S. K. Fisher
G. M. Foster
C. E. Hartz
R. S. Lewis

M. S. McDonald
U. Potapovs
S. M. Swilley
A. J. Walcutt
J. Ghergurovich, *Alternate*

Working Group on Welding and Special Repair Processes (SG-RR&M) (SC XI)

D. E. Waskey, *Chair*
R. E. Cantrell, *Secretary*
D. A. Delsignore
A. L. Finney
P. D. Fisher
A. J. Giannuzzi
R. A. Hermann
R. P. Indap
R. D. Kerr
B. R. Newton
P. P. Norris
J. E. O'Sullivan
J. H. Sodergren
K. R. Willens

Subgroup on Water-Cooled Systems (SC XI)

T. F. Lentz, *Chair*
K. Christian, *Secretary*
C. W. Allison
W. J. Briggs
T. R. Bugelholl
D. D. Davis
A. F. Deardorff
R. L. Dyle
L. B. Gross
T. C. Hinkle
S. D. Kulat
M. P. Lintz
J. E. Staffiera
C. W. Tahnk
R. J. Tamminga
D. Terao
S. M. Walker
R. A. West

Working Group on Concrete Containment (SG-WCS) (SC XI)

W. J. Briggs, *Chair*
B. Talmadge, *Secretary*
H. G. Ashar
K. K. N. Chao
M. J. Ferlisi
H. T. Hill

R. D. Hough
C. N. Krishnaswamy
D. Naus
S. C. Petitgout
C. G. Ranganath

Working Group on Implementation of Risk-Based Examination (SG-WCS) (SC XI)

T. J. Mawson, *Chair*
A. McNeill III, *Secretary*
J. Agold
S. A. Ali
B. A. Bishop
J. W. Connor
A. F. Deardorff
H. Q. Do
R. Fougrousse
S. R. Gosselin
J. T. Lindberg
I. Mach
R. K. Mattu
P. J. O'Regan
J. H. Phillips
F. A. Simonen
T. V. Vo
R. A. West

Working Group on Inspection of Systems and Components (SG-WCS) (SC XI)

R. L. Dyle, *Chair*
G. C. Park, *Secretary*
G. L. Belew
T. W. Brombach
R. Fougrousse
T. C. Hinkle
M. R. Hum
S. D. Kulat
J. T. Lindberg
M. P. Lintz
T. K. McLellan
C. Pendleton
C. M. Ross
C. W. Tahnk
K. B. Thomas
E. Throckmorton
R. A. West
J. Whitiman

Working Group on Metal Containment (SG-WCS) (SC XI)

J. E. Staffiera, *Chair*

W. E. Norris, *Secretary*
W. J. Briggs
K. K. N. Chao
M. J. Ferlisi
R. W. Hammelmann
M. P. Lintz
S. C. Petitgout
C. G. Ranganath
G. W. Robin
R. T. Zak

Special Working Group on Low-Temperature Heavy Water

C. D. Cowfer, *Chair*
J. M. Morrison, *Secretary*
B. Awadalla
K. F. Schmidt
P. R. Vormelker
S. H. Zaidi

Working Group on General Requirements (SC XI)

A. T. Roberts III, *Chair*
R. G. Edl, *Secretary*
D. A. Graham
L. B. Gross
C. A. Ireland
D. A. Jackson
R. K. Mattu
L. Sage
R. J. Scott
J. C. Shropshire
R. J. Tamminga

Special Working Group on Editing and Review (SC XI)

R. W. Swayne, *Chair*
R. L. Beverly
L. B. Gross
M. P. Lintz
J. E. Staffiera
C. J. Wirtz

Special Working Group on Plant Life Extension (SC XI)

F. E. Gregor, *Chair*
L. B. Gross, *Secretary*
D. D. Davis
D. A. Graham
D. L. Harrison
M. P. Lintz
P. Manbeck
H. W. Massie, Jr.

D. W. Peltola
D. A. Piccione
C. M. Regan
V. N. Shah
R. J. Tamminga

SUBCOMMITTEE ON TRANSPORT TANKS (SC XII)

A. Selz, *Chair*
P. D. Stumpf, *Secretary*
A. N. Antoniou
S. C. Cyr
K. Ennis
M. Hennemand
C. H. Hochman
G. G. Karcher
P. P. Laluc
G. McRae
M. R. Minick
T. P. Pastor
M. D. Rana
C. M. Serratella
G. R. Stoeckinger
N. Surtees
J. P. Swezy
A. P. Varghese
S. V. Voorhees
W. L. White

Page xxi

Subgroup on Design and Materials (SC XII)

M. D. Rana, *Chair*
D. A. Canonico
W. D. Doty
G. G. Karcher
P. P. Laluc
T. P. Pastor
T. A. Rogers
C. M. Serratella
A. P. Varghese
E. Whittle

Subgroup on Fabrication and Inspection (SC XII)

S. V. Voorhees, *Chair*
D. A. Canonico
M. L. Coats
M. Hennemand
D. J. Kreft
G. McRae

M. R. Minick
N. Surtees
J. P. Swezy

Subgroup on General Requirements (SC XII)

C. H. Hochman, *Chair*
T. Alexander
A. N. Antoniou
D. Carter
K. Ennis
M. A. Garrett
J. C. Keenan
F. A. Licari
G. R. Stoeckinger
W. L. White

SUBCOMMITTEE ON BOILER AND PRESSURE VESSEL ACCREDITATION (SC-BPVA)

A. J. Spencer, *Chair*
A. J. Justin, *Vice Chair*
K. I. Baron, *Secretary*
M. B. Doherty
D. A. Douin
P. D. Edwards
R. M. Elliott
C. E. Ford
J. J. Greene
R. C. Howard
B. B. MacDonald
M. L. Sisk
B. C. Turczynski
R. V. Wielgoszinski
R. L. Williams
V. A. Bell, Alternate
V. Bogosian, Alternate
M. A. De Vries, Alternate
J. R. Farr, Alternate
R. G. Friend, Alternate
W. C. LaRochelle, Alternate
A. S. Lester III, Alternate
K. M. McTague, Alternate
G. P. Milley, Alternate
R. E. Muise, Alternate
P. G. Scheckermann, Alternate
N. Surtees, Alternate

SUBCOMMITTEE ON NUCLEAR ACCREDITATION (SC-NA)

T. E. Quaka, *Chair*
R. R. Stevenson, *Vice Chair*

S. Griffin, *Secretary*
C. W. Allison
M. N. Bressler
G. Deily
F. R. Drahos
J. E. Harris
M. Kotb
W. C. LaRochelle
U. Potapovs
H. B. Prasse
A. J. Spencer
G. M. Tolson
L. M. Beason, Alternate
R. W. Boyce, Alternate
S. Dasgupta, Alternate
P. D. Edwards, Alternate
J. P. Ellenberger, Alternate
R. E. Feigel, Alternate
D. Hanrath, Alternate
K. A. Huber, Alternate
A. J. Justin, Alternate
N. C. Kist, Alternate
A. A. Lotfi, Alternate
R. P. McIntyre, Alternate
O. E. Trapp, Staff Representative

SUBCOMMITTEE ON DESIGN (SC-D)

W. J. Carter, *Chair*
F. S. Fitzgerald, *Secretary*
R. W. Barnes
C. Becht IV
O. F. Hedden
R. W. Mikitka
K. Mokhtarian
W. J. O'Donnell
R. D. Schueler, Jr.
M. P. Schwartz
A. Selz

Subgroup on Design Analysis (SC-D)

T. P. Pastor, *Secretary*
P. J. Conlisk
A. G. Eggers
J. L. Hechmer
G. L. Hollinger
D. P. Jones
A. Kalnins
W. J. Koves

T. H. Liu
O. Maekawa
A. Merend
T. V. Narayanan
E. L. Thomas, Jr.

Subgroup on Elevated Temperature Design (SC-D)

C. Becht IV, *Chair*
J. M. Corum, *Secretary*
C. R. Brinkman
R. D. Campbell
D. S. Griffin
R. I. Jetter
C. Lawton
W. J. O'Donnell
D. A. Osage
C. C. Schultz, Jr.
L. K. Severud
D. F. Shaw
A. L. Snow
B. E. Thurgood

Subgroup on Fatigue Strength (SC-D)

C. R. Brinkman
P. R. Donavin
J. A. Hayward
J. L. Hechmer
D. P. Jones
G. Kharshafdjian
C. Lawton
A. Merend
H. H. Ziada

Subgroup on Openings (SC-D)

M. P. Schwartz, *Chair*
R. W. Mikitka, *Secretary*
M. R. Breach
V. T. Hwang
S. C. Lou
R. B. Luney
J. P. Madden
K. C. Morrison
D. R. Palmer
M. D. Rana
E. C. Rodabaugh

Special Working Group on Bolted Flanged Joints (SC-D)

R. W. Mikitka, *Chair*
G. D. Bibel

G. D. Bibel
G. Kharshafdjian
D. L. Kurle
E. Michalopoulos
S. N. Pagay
J. R. Payne
R. W. Schneider
R. D. Schueler, Jr.
A. Selz

SUBCOMMITTEE ON SAFETY VALVE REQUIREMENTS(SC-SVR)

E. C. Kistner, Jr., *Chair*
M. D. Bernstein, *Vice Chair*
U. D'Urso, *Secretary*
J. F. Ball
J. A. Cox
R. D. Danzy
R. J. Doelling
D. A. Douin
R. G. Friend
H. I. Gregg
S. F. Harrison, Jr.
C. F. Laitner
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson
D. J. Scallan
C. M. Schroepfer
A. J. Spencer
J. C. Standfast
E. A. Steen
L. L. Thompson
J. A. West
T. J. Ferrigan, *Alternate*

Page xxii

Subgroup on Design (SC-SVR)

R. G. Friend, *Chair*
J. Cahoon, Jr.
R. D. Danzy
D. B. DeMichael
R. J. Doelling
H. I. Gregg
S. R. Irvin
C. F. Laitner
P. R. Sievert
A. J. Spencer

E. A. Steen
T. R. Tarbay
J. A. West

Subgroup on General Requirements (SC-SVR)

M. D. Bernstein, *Chair*
J. F. Ball
V. M. Deluca
D. A. Douin
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson
J. C. Standfast
L. L. Thompson

Subgroup on Testing (SC-SVR)

S. F. Harrison, Jr., *Chair*
S. Cammeresi
J. A. Cox
W. F. Hart
D. M. Papa
D. J. Scallan
C. M. Schroepfer
D. E. Snyder

Page xxiii

ORGANIZATION OF SECTION III

1. GENERAL

Section III consists of Division 1, Division 2, and Division 3. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter "N" for Division 1, by the letter "C" for Division 2, and by the letter "W" for Division 3. The following eleven books make up the three Divisions.

Subsection NCA - General Requirements for Division 1 and Division 2

Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

Division 2 - Code for Concrete Reactor Vessels and Containments

Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

The Division 2 book includes Subsection CC - Concrete Containments and Division 2 Appendices.

The Division 3 book includes Subsections WA and WB for General Requirements and Class TP (Type B) Containment, respectively.

2. SUBSECTIONS

Subsections are divided into Articles, Subarticles, paragraphs, and, where necessary, subparagraphs and subsubparagraphs.

3. ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections followed by Arabic numbers, such as NB-1000. Where possible, Articles dealing with the same topics are given the same number in each Subsection in accordance with the following general scheme:

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination
6000	Testing
7000	Overpressure Protection
8000	Nameplates, Stamping, and Reports

The numbering of Articles and the material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the rules have been prepared with some gaps in the numbering.

4. SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

5. SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as NB-2130, and generally have no text. When a number such as NB-1110 is followed by text, it is considered a paragraph.

6. PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

7. SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as NB-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

8. SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

9. REFERENCES

References used within Section III generally fall into one of the following four categories.

A. References to Other Portions of Section III

When a reference is made to another Article, Subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to NB-3000 includes all material in Article NB-3000; reference to NB-3200 includes all material in Subarticle NB-3200; reference to NB-3230 includes all paragraphs NB-3231 through NB-3236.

B. References to Other Sections

Other Sections referred to in Section III are:

Section II, Materials. When a requirement for a material, or for the examination or testing of a material, is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II. These references begin with the letter "S."

Section V, Nondestructive Examination. Section V references begin with the letter "T" and relate to the nondestructive examination of material or welds.

Section IX, Welding and Brazing Qualifications. Section IX references begin with the letter "Q" and relate to welding and brazing requirements.

Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components. When a reference is made to inservice inspection, the rules of Section XI shall apply.

C. Reference to Specifications and Standards Other Than Published in Code Sections

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials. At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E71-64 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

2 The American National Standards Institute (ANSI) was formerly known as the American Standard Association. Standards approved by the Association were designated by the prefix "ASA" followed by the number of the standard and the year of publication. More recently, the American Standards Institute was known as the United States of America Standard Institute. Standards were designated by the prefix "USAS" followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the numbers of the standard have remained unchanged.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by the American Society of Mechanical Engineers and approved by the American National Standards Institute². When a product is to conform to such a standard, for example ANSI B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NB-3132-1, for example ANSI B16.5-1977. Standards published by the American Society of Mechanical Engineers are available from ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-6, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, 127 Park Street, N.E., Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NB-3132-1, for example MSS SP-6-1963.

(4) Specifications for welding and brazing materials are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33135. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix "SF," for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-620 and API-2000. When documents so designated are referred to in Section III,

they are standards published by the American Petroleum Institute.

D. References to Appendices

Two types of Appendices are used in Section III and are designated Mandatory and Nonmandatory.

(1) Mandatory Appendices contain requirements which must be followed in construction; such references are designated by a Roman numeral followed by Arabic numerals. References to II-1100 or XI-3212, for example, relate to the Mandatory Appendices.

(2) Nonmandatory Appendices provide information or guidance for the use of Section III; such references are designated by a capital letter followed by Arabic numerals. A reference to D-1100, for example, relates to a Nonmandatory Appendix.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NE-1000

ARTICLE NE-1000 INTRODUCTION

Page 1

NE-1100 SCOPE AND GENERAL REQUIREMENTS

NE-1110 ASPECTS OF CONSTRUCTION COVERED BY THESE RULES

Subsection NE establishes rules for material, design, fabrication, examination, inspection, testing, and preparation of reports for metal containment vessels.

NE-1120 RULES FOR CLASS MC CONTAINMENT VESSELS

(a) Class MC containment vessels shall be constructed in accordance with the rules of this Subsection, except as provided in NCA-2134(c). Only containment vessels and their appurtenances shall be classified as Class MC. Piping, pumps, and valves which are part of the containment system (NE-1130) or which penetrate or are attached to the containment vessel shall be classified as Class 1 or Class 2 by the Design Specification and meet the requirements of the applicable Subsection. Figure NE-1120-1 shows some typical penetrations with different Class designations.

(b) Subsection NE does not contain rules to cover all details of construction of Class MC containment vessels. The Certificate Holder shall provide details of construction which will be consistent with those provided by the rules of this Subsection. These details of construction shall be subject to the approval of the Owner or his designee, and acceptance by the Inspector.

NE-1130 BOUNDARIES OF JURISDICTION

The containment system includes (a) through (c) as follows:

(a) the containment vessel;

(b) all penetration assemblies or appurtenances attached to the containment vessel;

(c) all piping, pumps, and valves attached to the containment vessel, or to penetration assemblies out to and including any valves required to isolate the system and provide a pressure boundary for the containment function. Classification of such items shall be given in the Design Specifications (NCA-3250 and NE-1120).

NE-1131 Boundaries of the Containment Vessel

The Design Specification shall define the boundary of a containment vessel to which piping or another component is attached. Figure NE-1132-1 shows typical jurisdictional boundaries. The boundary shall not be closer to the containment vessel than:

- (a) the first circumferential joint in welded connections (the connecting weld shall be considered part of the piping);
- (b) the face of the first flange in bolted connections (the bolts shall be considered part of the piping);
- (c) the first threaded joint in screwed connections.

NE-1132 Boundary Between Containment Vessel and Attachments

NE-1132.1 Attachments

- (a) An attachment is an element, in contact with or connected to the inside or outside of the pressure retaining portion of a containment vessel, which may have either a pressure retaining or nonpressure-retaining function and either a structural or nonstructural function.
- (b) Attachments with a pressure retaining function include items such as stiffeners and vessel opening reinforcement.
- (c) Attachments with a nonpressure-retaining function include items such as thermal sleeves, turning vanes, and containment vessel support load path items such as vessel saddles, support and shear lugs, brackets, and skirts.
- (d) Attachments with a structural function (structural attachments) perform a pressure retaining function or are in the containment vessel support load path.

Page 4

- (e) Attachments with a nonstructural function (nonstructural attachments) do not perform a pressure retaining function, nor are they in the containment vessel support load path. Nonstructural attachments include items such as nameplates, insulation supports, and locating and lifting lugs.

[98]

NE-1132.2 Jurisdictional Boundary.

The jurisdictional boundary between the containment vessel and an attachment defined in the Design Specification shall not be any closer to the pressure retaining portion of the vessel than as defined in (a) through (g) below. Figures NE-1132.2-1, NE-1132.2-2, and NE-1132.2-3 are provided as an aid in defining the boundary and construction requirements of this Subsection.

- (a) Attachments cast or forged with the containment vessel and weld buildup on the vessel surface shall be considered part of the containment vessel.
- (b) Attachments, welds, and fasteners having a pressure retaining function shall be considered part of the containment vessel.
- (c) Except as provided in (d) and (e) below, the boundary between the containment vessel and an attachment not having a pressure retaining function shall be at the surface of the vessel.
- (d) The first connecting weld of a nonpressure-retaining structural attachment to the containment vessel shall be considered part of the vessel unless the weld is more than $2t$ from the pressure retaining portion of the vessel, where t is the nominal thickness of the pressure retaining material. Beyond $2t$ from the pressure retaining portion of the vessel, the first weld shall be considered part of the attachment.
- (e) The first connecting weld of a welded nonstructural attachment to the containment vessel shall be considered part of the attachment. At or within $2t$ from the pressure retaining portion of the component the first connecting weld shall conform to NE-4430.
- (f) Mechanical fasteners used to connect a nonpressure-retaining attachment to the containment vessel shall be considered part of the attachment.
- (g) The boundary may be located further from the pressure retaining portion of the containment vessel than as defined in (a) through (f) above when specified in the Design Specification.

[98]

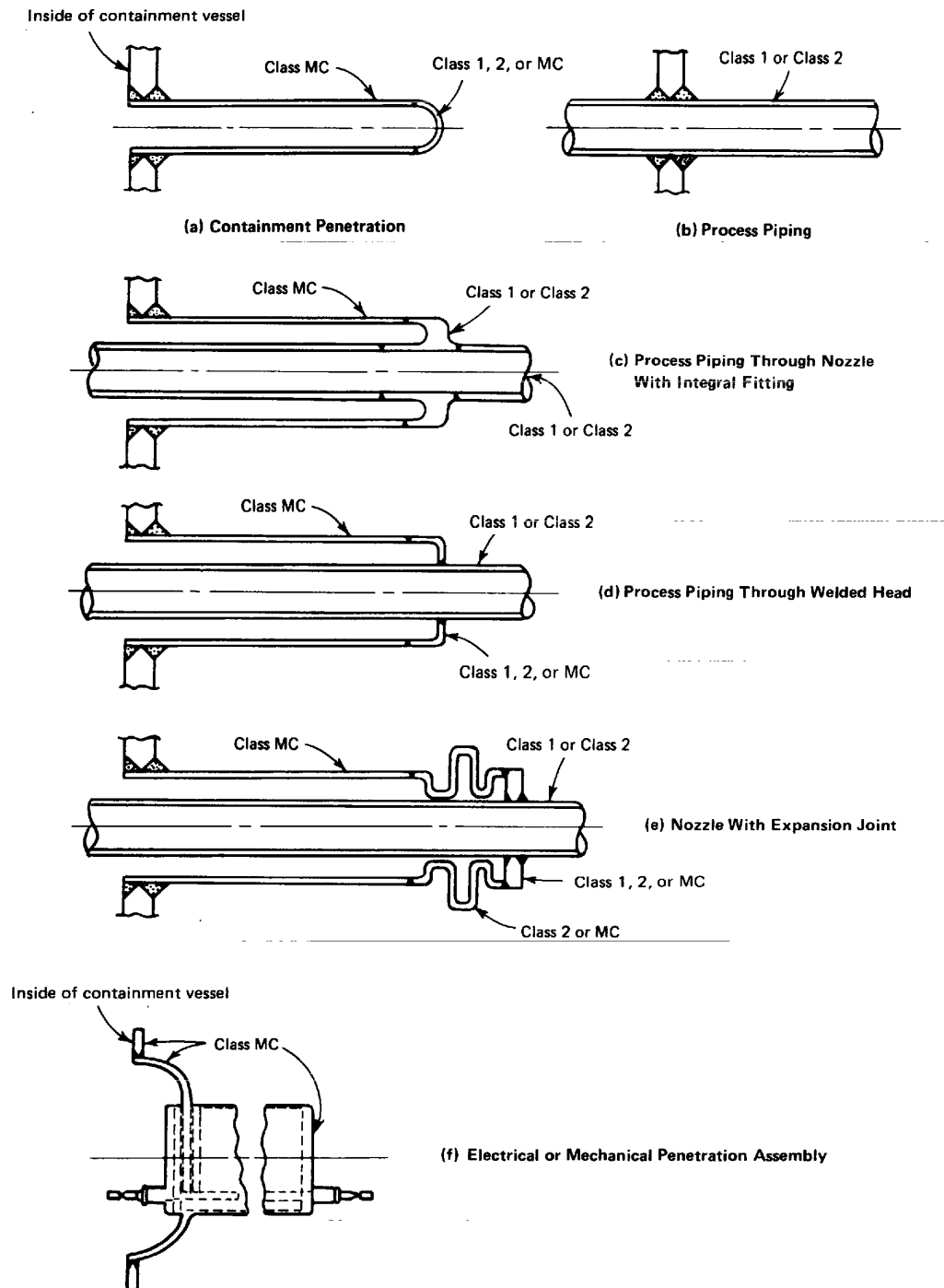


FIG. NE-1120-1 TYPICAL CONTAINMENT PENETRATIONS

FIG. NE-1120-1 TYPICAL CONTAINMENT PENETRATIONS

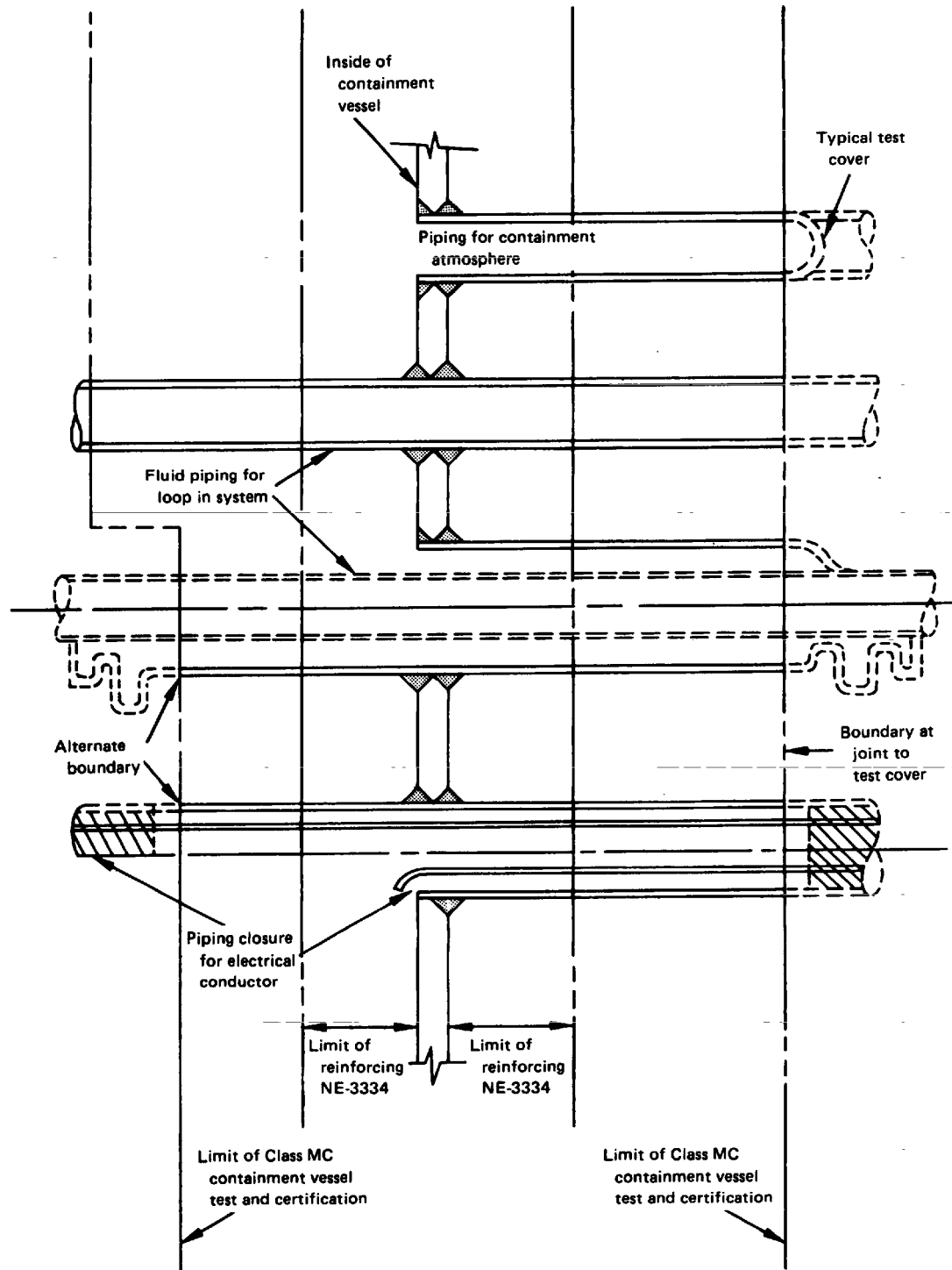
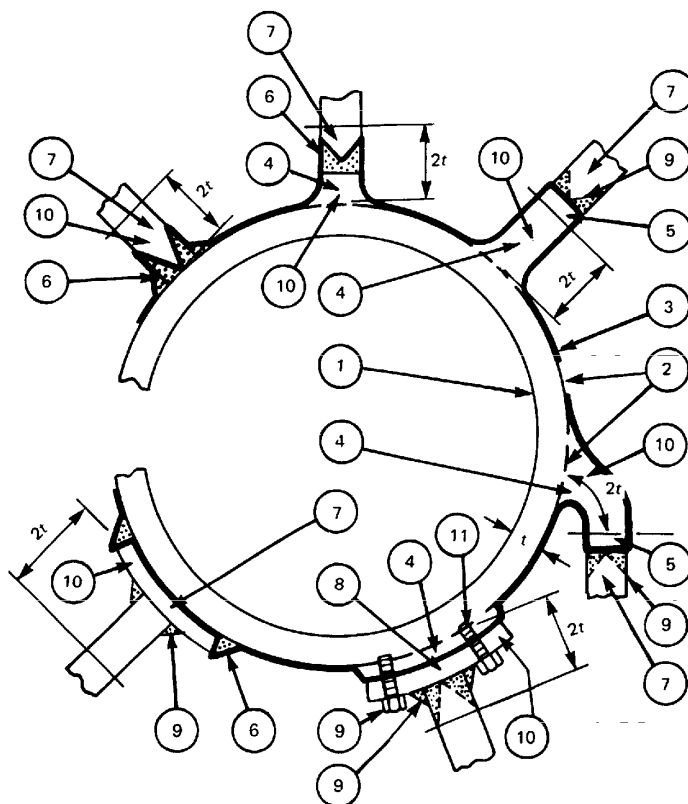


FIG. NE-1132-1 SOME TYPICAL JURISDICTIONAL BOUNDARIES FOR WELDED CONNECTIONS CLASS MC CONTAINMENT VESSELS

FIG. NE-1132-1 SOME TYPICAL JURISDICTIONAL BOUNDARIES FOR WELDED CONNECTIONS CLASS MC CONTAINMENT VESSELS



- ① Containment vessel shall conform to Subsection NE.
- ② Pressure retaining portion of the containment vessel.
- ③ Jurisdictional boundary (heavy line).
- ④ Cast or forged attachment or weld buildup shall conform to Subsection NE.
- ⑤ Beyond $2t$ from the pressure retaining portion of the containment vessel, the design rules of NF-3000 may be used as a substitute for the design rules of NE-3000.
- ⑥ At or within $2t$ from the pressure retaining portion of the containment vessel, the first connecting weld shall conform to Subsection NE.
- ⑦ Beyond $2t$ from the pressure retaining portion of the containment vessel or beyond the first connecting weld, the attachment shall conform to Subsection NF [Note (1)].
- ⑧ Bearing, clamped, or fastened attachment shall conform to Subsection NF [Note (1)].
- ⑨ Attachment connection shall conform to Subsection NF [Note (1)].
- ⑩ At or within $2t$ from the pressure retaining portion of the containment vessel, the interaction effects of the attachment shall be considered in accordance with NE-3135.
- ⑪ Drilled holes shall conform to Subsection NE.

GENERAL NOTE:

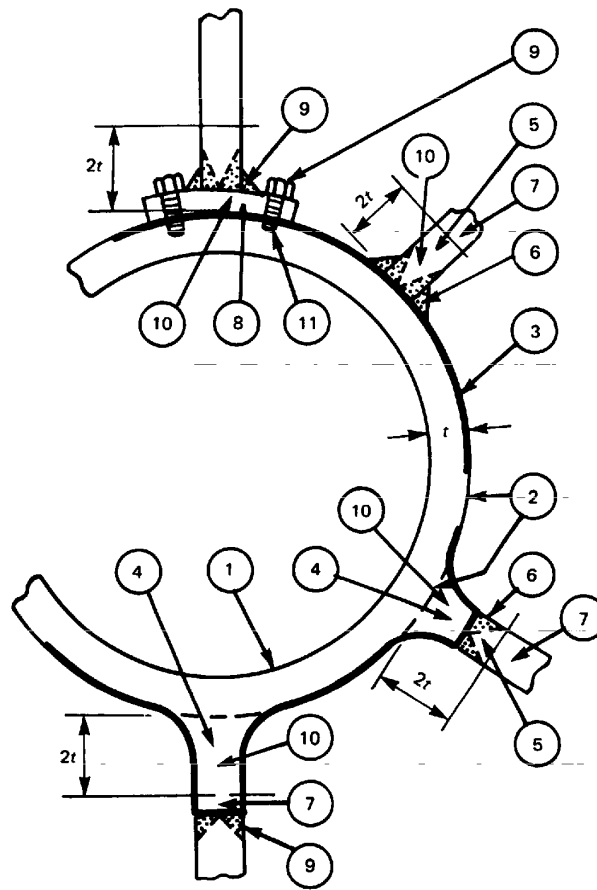
These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

NOTE:

- (1) If the attachment is an intervening element [NF-1110(c)], material, design, and connections, as appropriate, are outside Code jurisdiction.

FIG. NE-1132.2-1 ATTACHMENTS IN THE CONTAINMENT VESSEL SUPPORT LOAD PATH WHICH DO NOT PERFORM A PRESSURE RETAINING FUNCTION

FIG. NE-1132.2-1 ATTACHMENTS IN THE CONTAINMENT VESSEL SUPPORT LOAD PATH WHICH DO NOT PERFORM A PRESSURE RETAINING FUNCTION



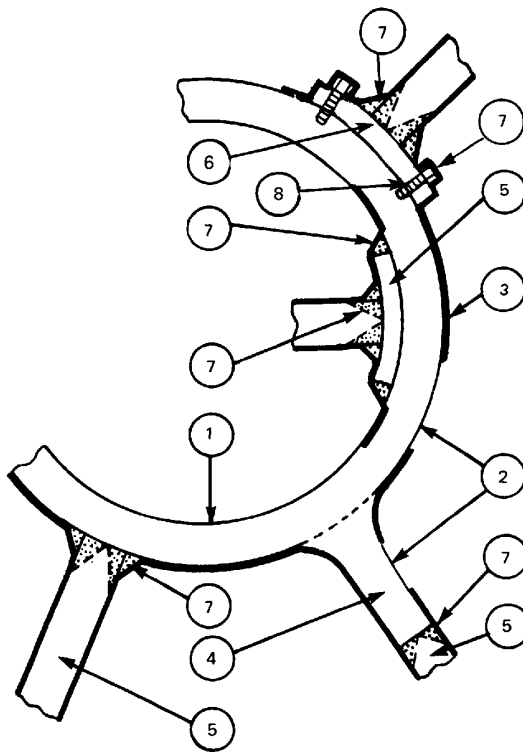
- ① Containment vessel shall conform to Subsection NE.
- ② Pressure retaining portion of the containment vessel.
- ③ Jurisdictional boundary (heavy line).
- ④ Cast or forged attachment or weld buildup shall conform to Subsection NE.
- ⑤ At or within $2t$ from the pressure retaining portion of the containment vessel, the material of the first welded nonstructural attachment shall conform to NE-2190; design is outside Code jurisdiction.
- ⑥ At or within $2t$ from the pressure retaining portion of the containment vessel, the first connecting weld shall conform to NE-4430.
- ⑦ Beyond $2t$ from the pressure retaining portion of the containment vessel, the nonstructural attachment is outside Code jurisdiction.
- ⑧ Bearing, clamped, or fastened nonstructural attachment is outside Code jurisdiction.
- ⑨ Nonstructural attachment connection is outside Code jurisdiction.
- ⑩ At or within $2t$ from the pressure retaining portion of the containment vessel, the interaction effects of the nonstructural attachment shall be considered in accordance with NE-3135.
- ⑪ Drilled holes shall conform to Subsection NE.

GENERAL NOTE:

These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

FIG. NE-1132.2-2 ATTACHMENTS WHICH DO NOT PERFORM A PRESSURE RETAINING FUNCTION AND ARE NOT IN THE CONTAINMENT VESSEL SUPPORT LOAD PATH (NONSTRUCTURAL ATTACHMENTS)

FIG. NE-1132.2-2 ATTACHMENTS WHICH DO NOT PERFORM A PRESSURE RETAINING FUNCTION AND ARE NOT IN THE CONTAINMENT VESSEL SUPPORT LOAD PATH (NONSTRUCTURAL ATTACHMENTS)



- ① Containment vessel shall conform to Subsection NE.
- ② Pressure retaining portion of the containment vessel.
- ③ Jurisdictional boundary (heavy line).
- ④ Cast or forged attachment or weld buildup shall conform to Subsection NE.
- ⑤ Welded attachment shall conform to Subsection NE.
- ⑥ Bearing, clamped, or fastened attachment shall conform to Subsection NE.
- ⑦ Attachment connection shall conform to Subsection NE.
- ⑧ Drilled holes shall conform to Subsection NE.

GENERAL NOTE:

These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

**FIG. NE-1132.2-3 ATTACHMENTS WHICH PERFORM A
PRESSURE RETAINING FUNCTION**

FIG. NE-1132.2-3 ATTACHMENTS WHICH PERFORM A PRESSURE RETAINING FUNCTION

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NE-2000

ARTICLE NE-2000 MATERIAL

NE-2100 GENERAL REQUIREMENTS FOR MATERIAL

NE-2110 SCOPE OF PRINCIPAL TERMS EMPLOYED

(a) The term *material* as used in this Subsection is defined in NCA-1220. The term *Material Organization* is defined in NCA-9000.

(b) The term *pressure retaining material* as used in this Subsection applies to items such as vessel shells, heads, and nozzles; pipes, tubes, and fittings; and bolting which joins pressure retaining items.

(c) The requirements of this Article make reference to the term *thickness*. For the purpose intended, the following definitions of nominal thickness apply:

(1) *plate* - the thickness is the dimension of the short transverse direction

(2) *forgings* - the thickness is the dimension defined as follows:

(a) *hollow forgings* - the nominal thickness is measured between the inside and outside surfaces (radial thickness)

(b) *disk forgings* (axial length less than the outside diameter) - the nominal thickness is the axial length

(c) *flat ring forgings* (axial length less than the radial thickness) - for axial length > 2 in. (51 mm), the axial length is the nominal thickness. For axial length > 2 in. (51 mm), the radial thickness is the nominal thickness.

(d) *rectangular solid forgings* - the least rectangular dimension is the nominal thickness

(3) *castings*

(a) Thickness *t* for fracture toughness testing is defined as the nominal pipe wall thickness of the connecting piping.

(b) Thickness *t* for heat treatment purposes is defined as the thickness of the pressure retaining wall of the casting, excluding flanges and sections designated by the designer as nonpressure retaining.

NE-2120 PRESSURE RETAINING MATERIAL

NE-2121 Permitted Material Specifications

(a) Pressure retaining material shall conform to the requirements of one of the specifications for materials given in Table NE-2121(a)-1 and Table NE-2121(a)-2 and to all of the requirements of this Article which apply to the product form in which the material is used. Attachments which perform a pressure retaining function shall be pressure retaining material.

(b) The requirements of this Article do not apply to material for items not associated with the pressure retaining function of a component, such as shafts, stems, trim, spray nozzles, bearings, bushings, springs, and wear plates, nor to seals, packing, gaskets, valve seats, and ceramic insulating material and special alloys used as seal material in electrical penetration assemblies.

(c) Pressure retaining material of ferritic steel whose thickness exceeds $\frac{1}{4}$ in. (6 mm) for containment vessels shall be normalized or quenched and tempered, fully killed, and melted to a fine grain melting practice, whenever the material is not impact tested (NE-2311).

(d) Welding and brazing materials used in manufacture of items shall comply with an SFA Specification in Section II, Part C, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article. The requirements of this Article do not apply to materials used as backing rings or backing strips in welded joints.

(e) The requirements of this Article do not apply to hard surfacing or corrosion resistant weld metal overlay which is 10% or less of the thickness of the base material (NE-3122).

NE-2122 Special Requirements Conflicting With Permitted Material Specifications

**TABLE NE-2121(a)-1
MATERIAL SPECIFICATIONS AND GRADES PERMITTED FOR CLASS MC CONSTRUCTION**

Carbon Steel	Pipe, Tube, Fitting (continued)
Plate	SA-358 Grade 304L Class 1, 304LN Class 1, 304 Class 1, 304H Class 1
SA-36	SA-376 Grade TP304LN, TP304, TP304H
SA-299	SA-403 Class WP304L, WP304LW, WP304, WP304H, WP304W, WP304HW, WP304LN, WP304LNW
SA-516 Grade 55, 60, 65, 70	SA-430 Grade FP304, FP304H
SA-537 Class 1, 2	SA-452 Grade TP304H
SA-737 Grade B, C	SA-813 Grade TP304L, TP304LN, TP304, TP304H, TP304N
SA-738 Grade A, C	SA-814 Grade TP304L, TP304LN, TP304, TP304H
Forging	
SA-105	
SA-181 Class 60, 70	
SA-266 Class 1, 2	
SA-350 Grade LF1, LF2	
SA-508 Class 1	
SA-541 Class 1	
Casing	High Alloy Type 316 Stainless Steels
SA-216 Grade WCA, WCB, WCC	Plate
SA-352 Grade LCB	SA-240 Type 316L, 316, 316H 316LN
SA-487 Grade 16 Class A	Forging
Bar	SA-281 Grade F316L, F316LN, F316, F316H
SA-36	SA-336 Class F316LN, F316, F316H
SA-695 Grade 35 Type B, Grade 40 Type B	Casting
SA-696 Grade B, C	SA-351 Grade CF3M, CD8M
Pipe, Tube, Fitting	Bar
SA-106 Grade A, B, C	SA-479 Type 316L, 316, 316LN
SA-178 Grade C	Pipe, Tube, Fitting
SA-210 Grade A-1	SA-213 Grade TP316L, TP316, TP316H, TP316LN
SA-234 Grade WPB, WPCW, WPCW	SA-249 Grade TP316L, TP316, TP316H, TP316LN
SA-333 Grade 1, 6	SA-312 Grade TP316L, TP316, TP316H, TP316LN
SA-334 Grade 1, 6	SA-358 Grade 316L Class 1, 316 Class 1, 316H Class 1, 316LN Class 1
SA-420 Grade WPL6, WPL6W	SA-376 Grade TP316LN, TP316, TP316H
SA-671 Grade CC60, CC65, CC70, CD70, CD80, CE55, CE60, CK75	SA-403 Class WP316L, WP316LW, WP316LN, WP316LNW, WP316, WP316W, WP316H, WP316HW
SA-691 Grade CMS75, CMSH70, CMSH80	SA-430 Grade FP316, FP316H
Shape	SA-452 Grade TP316H
SA-36	SA-813 Grade TP316L, TP316, TP316H, TP316LN
Precipitation Hardened Steels	SA-814 Grade TP316L, TP316, TP316H, TP316LN, TP316N
Plate	
SA-693 Grade 630	High Alloy Type 309, 310 Stainless Steels
Bar	Casting
SA-564 Grade 630	SA-351 Grade CH8, CK20, CH20
Forging	
SA-705 Grade 630	
High Alloy Type 304 Stainless Steels	High Alloy Type 321 Steels
Plate	Plate
SA-240 Type 304, 304L, 304H, 304LN	SA-240 Type 321
Forging	Forging
SA-182 Grade F304, F304L, F304H, F304LN	SA-182 Grade F321, F321H
SA-336 Class F304, F304LN, F304H	SA-336 Class F321, F321H
Casting	Bar
SA-351 Grade CF3, CF8, CF3A, CF8A	SA-479 Grade 321
Bar	Pipe, Tube, Fitting
SA-479 Type 304L, 304LN, 304	SA-213 Grade TP321, TP321H
Pipe, Tube, Fitting	SA-249 Grade TP321, TP321H
SA-213 Grade TP304L, TP304LN, TP304, TP304H	SA-312 Grade TP321, TP321H
SA-249 Grade TP304L, TP304LN, TP304, TP304H	SA-376 Grade TP321, TP321H
SA-312 Grade TP304L, TP304LN, TP304, TP304H	SA-403 Class WP321, WP321H, WP321W, WP321HW
	SA-430 Grade FP321, FP321H
	SA-813 Grade TP321, TP321H
	SA-814 Grade TP321, TP321H

**TABLE NE-2121(a)-1 (CONT'D)
MATERIAL SPECIFICATIONS AND GRADES PERMITTED FOR CLASS MC CONSTRUCTION**

High Alloy Type 347, 348 Stainless Steels	Pipe, Tube, Fitting
Plate	SA-249 Grade TPXM-19
SA-240 Type 347, 348	SA-312 Grade TPXM-19
Forging	SA-358 Grade XM-19
SA-182 Grade F347, F347H, F348, F348H	SA-403 Class WPXM-19, WPXM-19W
SA-336 Class F347, F347H	SA-813 Grade TPXM-19
Casting	SA-814 Grade TPXM-19
SA-351 Grade CF8C	
Bar	
SA-479 Grade 347, 348	High Nickel Alloys
Pipe, Tube, Fitting	Plate
SA-213 Grade TP347, TP347H, TP348, TP348H	SB-168 Grade N06600
SA-249 Grade TP347, TP347H, TP348, TP348H	SB-409 Grade 800, 800H
SA-312 Grade TP347, TP347H, TP348, TP348H	SB-443 Grade N06625
SA-376 Grade TP347, TP347H, TP348	Bar
SA-403 Class WP347, WP347H, WP347W, WP347HW, WP348, WP348H, WP348W, WP348HW	SB-166 Grade N06600
SA-430 Grade FP347, FP347H	SB-408 Grade 800, 800H
SA-452 Grade TP347H	Pipe, Tube, Fitting
SA-813 Grade TP347, TP347H, TP348H	SB-163 Grade N06600, 800, 800H
SA-814 Grade TP347, TP347H, TP348, TP348H	SB-167 Grade N06600
	SB-407 Grade 800, 800H
Type XM-19 Stainless Steels	Nickel-Copper Alloys
Plate	Plate
SA-240 Type XM-19	SB-127 Grade 400
Forging	Bar
SA-182 Grade FXM-19	SB-164 Grade 400, 405
Bar	Pipe, Tube, Fitting
SA-479 Type XM-19	SB-163 Grade 400
	SB-165 Grade 400

TABLE NE-2121-(a)-1 (CONT'D) MATERIAL SPECIFICATIONS AND GRADES PERMITTED FOR CLASS MC CONSTRUCTION

wherever these special requirements conflict with the material specification requirements [NCA-3856]. Where the special requirements include an examination, test, or treatment which is also required by the material specification, the examination, test, or treatment need be performed only once. Required nondestructive examinations shall be performed as specified for each product form in NE-2500. Any examination, repair, test, or treatment may be performed by the Material Organization or Certificate Holder as provided in NE-4121.1. Any hydrostatic or pneumatic pressure test required by a material specification need not be performed, provided the material is identified as not having been pressure tested and it is subsequently pressure tested, except where the location of the material in the vessel or the installation would prevent performing any nondestructive examination required by the material specification to be performed subsequent to the hydro static or pneumatic test.

TABLE NE-2121(a)-2 PERMITTED BOLTING MATERIAL SPECIFICATIONS

Low Alloy Steels

SA-193 Grade B7, B16

SA-320 Grade L43

High Alloy Steels

SA-193 Grade B6 Class 410

SA-193 Grade B8, B8C, B8T, B8M

SA-437 Grade B4B, B4C

SA-453 Grade 651, 610

TABLE NE-2121(a)-2 PERMITTED BOLTING MATERIAL SPECIFICATIONS

NE-2124 Material Size Ranges and Tolerances

(a) Material outside the limits of size or thickness given in any specification in Section II may be used if the material is in compliance with the other requirements of the specification and no size limitation is given in this Subsection. In those specifications in which chemical composition or mechanical properties are indicated to vary with size or thickness, any material outside the specification range shall be required to

Page 20

conform to the composition and mechanical properties shown for the nearest specified range [NCA-3856].

(b) Plate material shall be ordered not thinner than the design thickness. Vessels, except for piping, made of plate furnished with an under tolerance of not more than the lesser value of 0.01 in. (0.3 mm) or 6% of the ordered thickness may be used at the full design pressure for the thickness ordered. If the specification to which the plate is ordered allows a greater under tolerance, the ordered thickness of the material shall be sufficiently greater than the design thickness so that the thickness of the material furnished is not more than the lesser of 0.01 in. (0.3 mm) or 6% under the design thickness.

(c) If pipe or tube is ordered by its nominal wall thickness, the manufacturing under tolerance on wall thickness shall be taken into account. The manufacturing under tolerances are given in the several pipe and tube specifications listed in Table NE-2121(a)-1. After the minimum wall thickness is determined, it shall be increased by an amount sufficient to provide for the manufacturing under tolerance allowed in the pipe or tube specification.

NE-2125 Materials in Combination¹

A vessel may be designed and constructed of any combination of materials permitted in NE-2000 provided the applicable rules are followed and the requirements of Section IX for welding dissimilar metals are met.

¹ Because of the different thermal coefficients of expansion of dissimilar material, caution should be exercised in design and construction under the provisions of this paragraph in order to avoid

NE-2126 Condition of Material for Intended Service

Specific chemical compositions, heat treatment procedures, fabrication requirements, and supplementary tests may be required to ensure that the component will be in its most favorable condition for the intended service. This is particularly true for components subject to severe corrosion. These rules do not indicate the selection of material suitable for the intended service or the amount of corrosion allowance to be provided. It is recommended that Owners assure themselves, by appropriate tests or other means, that the material selected and its heat treatment during fabrication will be suitable for the intended service with respect both to corrosion resistance and to retention of satisfactory mechanical properties during the desired service life.

NE-2127 Clad Plate

(a) Clad plate used in constructions in which the design calculations are based on the total thickness, including cladding, shall conform to one of the following specifications:

- (1) SA-263 Corrosion-Resisting Chromium Steel Clad Plate, Sheet, and Strip;
- (2) SA-264 Stainless Chromium-Nickel Steel Clad Plate, Sheet, and Strip;
- (3) SA-265 Nickel and Nickel-Base Alloy Clad Steel Plate.

(b) Clad plate used in constructions in which the design calculations are based on the clad plate thickness, exclusive of the thickness of the cladding material, may consist of any base plate material satisfying the requirements of NE-2121 and any metallic cladding material of weldable quality that in the judgment of the Owner is suitable for the intended service.

(c) Integrally clad steel plate in which any part of the cladding is included in the design calculations, as permitted in NE-3122.4(b), shall show a minimum shear strength of 20.0 ksi when tested in the manner described in the plate specification. One shear test shall be made on each such clad plate as rolled and the results shall be reported by the mill.

(d) When any part of the cladding thickness is specified as an allowance for corrosion, such added thickness shall be removed before mill tension tests are made. When corrosion of the cladding is not expected, no part of the cladding material need be removed before testing, even though excess thickness seems to have been provided or is available as corrosion allowance.

NE-2128 Bolting Material

(a) Material for nuts shall conform to SA-194 or to the requirements for nuts in the specification for the bolting material which is to be used.

(b) Nuts shall be threaded to Class 2B or finer tolerances according to ANSI B1.1. Materials for nuts and washers shall be selected as follows.

- (1) Carbon steel nuts and carbon steel washers may be used with carbon steel bolts or studs.
- (2) Carbon or alloy steel nuts and carbon or alloy steel washers of approximately the same hardness as the nuts may be used with alloy steel bolts or studs for metal temperatures not exceeding 900°F (482°C).
- (3) Alloy steel nuts shall be used with alloy steel studs or bolts for metal temperatures exceeding 900°F

Page 21

(482°C). Washers, if used, shall be of alloy steel with equivalent chemistry and hardness to the nut material.

(c) Nuts shall be semifinished, chamfered, and trimmed. For use with flanges conforming to the standards listed in NE-3362, nuts shall conform at least to the dimensions given in ANSI B18.2 for Heavy Series Nuts. For use with connections designed in accordance with the rules in Appendix XI, nuts may be of the ANSI Standard Heavy Series or they may be of other dimensions, provided their strength is equal to that of the bolting, giving due consideration to bolt hole clearance, bearing area, thread form and class off it, thread shear, and radial thrust from threads.

NE-2130 CERTIFICATION OF MATERIAL

All material used in the construction of Class MC containment vessels shall be certified as required in NCA-3862 and NCA-3861. Certified Material Test Reports are required for pressure retaining material except as provided by NCA-3861. A Certificate of Compliance may be provided in lieu of Certified Material Test Reports for all other material. Copies of all Certified Material Test Reports and Certificates of Compliance applicable to material used in a vessel shall be furnished with the material.

NE-2140 WELDING MATERIAL

For the requirements governing the material to be used for welding, see NE-2400.

NE-2150 MATERIAL IDENTIFICATION

The identification of pressure retaining material shall meet the requirements of NCA-3856. Material for small items shall be controlled during manufacture of the vessel so that they are identifiable as acceptable material at all times. Welding and brazing material shall be controlled during the repair of material and the manufacture of vessels so that they are identifiable as acceptable until the material is actually consumed in the process(NE-4122).

NE-2160 DETERIORATION OF MATERIAL IN SERVICE

Consideration of deterioration of material caused by service is generally outside the scope of this Subsection. It is the responsibility of the Owner to select material suitable for the conditions stated in the Design Specifications (NCA-3250), with specific attention being given to the effects of service conditions upon the properties of the material.

NE-2170 HEAT TREATMENT TO ENHANCE IMPACT PROPERTIES

Carbon steels, low alloy steels, and high alloy chromium (Series 4XX) steels may be heat treated by quenching and tempering to enhance their impact properties. Postweld heat treatment of the material at a temperature of not less than 1100°F (593°C) may be considered to be the tempering phase of the heat treatment. The requirements of NE-2220 shall be met.

NE-2180 PROCEDURES FOR HEAT TREATMENT OF MATERIAL

When heat treating temperature or time is required by the material specification and the rules of this Subsection, the heat treating shall be performed in temperature-surveyed and -calibrated furnaces or the heat treating shall be controlled by measurement of material temperature by thermocouples in contact with the material or attached to blocks in contact with the material, or by calibrated pyrometers instruments. Heat treating shall be performed under furnace loading conditions such that the heat treatment is in accordance with the material specification and the rules of this Subsection.

NE-2190 NONPRESSURE-RETAINING MATERIAL

(a) Material in the containment vessel support load path and not performing a pressure retaining function (see NE-1130) welded to pressure retaining material shall meet the requirements of NF-2000.

(b) Material not performing a pressure retaining function and not in the containment vessel support load path (nonstructural attachments) welded at or within $2t$ of the pressure retaining portion of the vessel need not comply with NE-2000 or NF-2000 provided the requirements of NE-4430 are met.

(c) Structural steel rolled shapes, which are permitted by this Subsection to be furnished with a Certificate of Compliance, may be repaired by welding using the welders, documentation, and examination requirements specified in SA-6.

Page 22

NE-2200 MATERIAL TEST COUPONS AND SPECIMENS FOR FERRITIC STEEL MATERIAL

NE-2210 HEAT TREATMENT REQUIREMENTS

NE-2211 Test Coupon Heat Treatment for Ferritic Material²

Where ferritic steel material is subjected to heat treatment during fabrication or installation of a containment vessel, the material used for the tensile and impact test specimens shall be heat treated in the same manner as the containment vessel, except that test coupons and specimens for P-No. 1 material with a nominal thickness of 2 in. (51 mm) or less are not required to be so heat treated. The Certificate Holder shall provide the Material Organization with the temperature and heating and cooling rate to be used. In the case of postweld heat treatment, the total time at temperature or temperatures for the test material shall be at least 80% of the total time at temperature or temperatures during actual postweld heat treatment of the material, and the total time at temperature or temperatures for the test material, coupon, or specimen may be performed in a single cycle.

NE-2212 Test Coupon Heat Treatment for Quenched and Tempered Material

[98]

NE-2212.1 Cooling Rates.

Where ferritic steel material is subjected to quenching from the austenitizing temperature, the test coupons representing those materials shall be cooled at a rate similar to and no faster than the main body of the material, except in the case of certain forgings and castings [NE-2223.3 and NE-2226(b)(5)]. This rule shall apply for coupons taken directly from the material as well as for separate test coupons representing the material, and one of the general procedures described in NE-2212.2 or one of the specific procedures described in NE-2220 shall be used for each product form.

[98]

2 Any Postweld heat treatment which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

NE-2212.2 General Procedures.

One of the general procedures in (a), (b), and (c) below may be applied to quenched and tempered material or test coupons representing the material, provided the specimens are taken relative to the surface of the product in accordance with NE-2220. Further specific details of the methods to be used shall be the obligation of the Material Organization and the Certificate Holder.

(a) Any procedure may be used which can be demonstrated to produce a cooling rate in the test material that matches the cooling rate of the main body of the product at the region midway between midthickness and the surface ($1/4t$) and no nearer any heat treated edge than a distance equal to the nominal thickness t being quenched within 25°F (14°C) and 20 sec at all temperatures after cooling begins from the austenitizing temperature.

(b) If cooling rate data for the material and cooling rate control devices for the test specimens are available, the test specimens may be heat treated in the device to represent the material, provided that the provisions of (a) above are met.

(c) When any of the specific procedures described in NE-2220 are used, faster cooling rates at the edges may be compensated for by:

- (1) taking the test specimens at least t from a quenched edge, where t equals the material thickness;
- (2) attaching a steel pad at least t wide by a partial penetration weld (which completely seals the buffered surface) to the edge where specimens are to be removed; or
- (3) using thermal barriers or insulation at the edge where specimens are to be removed.

It shall be demonstrated (and this information shall be included in the Certified Material Test Report) that the cooling rates are equivalent to (a) or (b) above.

NE-2220 PROCEDURE FOR OBTAINING TEST COUPONS AND SPECIMENS FOR QUENCHED AND TEMPERED MATERIAL

NE-2221 General Requirements

The procedure for obtaining test specimens for quenched and tempered material is related to the product form. Coupon and specimen location shall be as required by the material specification, except as stated in the following paragraphs of this Subarticle. References to dimensions signify nominal values.

NE-2222 Plates

NE-2222.1 Orientation and Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from a rolled surface and with the midlength of the specimen at least t from

Page 23

any heat treated edge, where t is the nominal thickness of the material.

NE-2222.2 Requirements for Separate Test Coupons.

Where a separate test coupon is used to represent the component material, it shall be of sufficient size to ensure that the cooling rate of the region from which the test coupons are removed represents the cooling rate of the material at least $\frac{1}{4}t$ deep and t from any edge of the product. Unless cooling rates applicable to the bulk pieces or product are simulated in accordance with NE-2212.2, the dimensions of the coupon shall be not less than $3t \times 3t \times t$, where t is the nominal material thickness.

NE-2223 Forgings

NE-2223.1 Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from any surface and with the midlength of the specimens at least t from any second surface, where t is the maximum heat treated thickness. A thermal buffer as described in NE-2212.2(c) may be used to achieve these conditions, unless cooling rates applicable to the bulk forgings are simulated as other wise provided in NE-2212.2.

NE-2223.2 Very Thick and Complex Forgings.

Test coupons for forgings which are both very thick and complex, such as contour nozzles, thick tubesheets, flanges, nozzles, and other complex forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment, may be removed from prolongations or other stock provided on the product. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service. The coupons shall be taken so that specimens shall have their longitudinal axes at a distance below the nearest heat treated surface, equivalent to at least the greatest distance that the indicated high tensile stress surface will be from the nearest surface during heat treatment, and with the midlength of the specimens a minimum of twice this distance from a second heat treated surface. In any case, the longitudinal axes of the specimens shall not be nearer than $\frac{3}{4}$ in. (19 mm) to any heat treated surface and the midlength of the specimens shall be at least $1\frac{1}{2}$ in. (38 mm) from any heat treated surface.

NE-2223.3 Coupons From Separately Produced Test Forgings.

Test coupons representing forgings from one heat and one heat treatment lot may be taken from a separately forged piece under the conditions given in (a) through (e) below.

(a) The separate test forging shall be of the same heat of material and shall be subjected to substantially the same reduction and working as the production forging it represents.

(b) The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forging.

(c) The separate test forging shall be of the same nominal thickness as the production forging.

(d) Test coupons for simple forgings shall be taken so that specimens shall have their longitudinal axes at the region

midway between midthickness and the surface and with the midlength of the specimens no nearer any heat treated edge than a distance equal to the forging thickness, except when the thickness-length ratio of the production forging does not permit, in which case a production forging shall be used as the test forging and the midlength of the specimens shall be at the midlength of the test forging.

(e) Test coupons for complex forgings shall be taken in accordance with NE-2223.2.

NE-2223.4 Test Specimens for Forgings.

When test specimens for forgings are to be taken under the applicable specification, the Inspector shall have the option of witnessing the selection, placing an identifying stamp on them, and witnessing the testing of these specimens.

NE-2224 Location of Coupons

(a) *Bars.* Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside or rolled surface, and with the midlength of the specimens at least t from a heat treated end where t is either the bar diameter or thickness.

(b) *Bolting Material.* For bolting material, the coupons shall be taken in conformance with the applicable material specification and with the midlength of the specimen at least one diameter or thickness from a heat treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

NE-2225 Tubular Products and Fittings

NE-2225.1 Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal

Page 24

axes at least $\frac{1}{4}t$ from the inside or outside surface and with the midlength of the specimens at least t from a heat treated end where t is the nominal wall thickness of the tubular product.

NE-2225.2 Separately Produced Coupons Representing Fittings.

Separately produced test coupons representing fittings may be used. When separately produced coupons are used, the requirements of NE-2223.3 shall be met.

NE-2226 Tensile Test Specimen Location (for Quenched and Tempered Ferritic Steel Castings)

NOTE: Users of this requirement should note that the hardenability of some grades may limit the usable section size.

(a) This section applies only to quenched and tempered ferritic steel castings with a thickness t exceeding 2 in. (51 mm), where t is the thickness of the pressure retaining wall of the casting, excluding flanges and sections designated by the designer as nonpressure retaining. The order, inquiry, and drawing shall designate what the thickness t is for the casting.

(b) One of the following shall apply.

(1) The longitudinal centering of the thickness of the tension test specimen shall be taken at least $\frac{1}{4}t$ from the t dimension surface. For cylindrical castings, the longitudinal center line of the specimens shall be taken at least $\frac{1}{4}t$ from the outside or inside surface and the gage length at least t from the as-heat-treated end.

(2) Where separately cast test coupons are used, their dimensions shall be not less than $3t \times 3t \times t$ and each specimen cut from it shall meet the requirements of (b). The test coupon shall be of the same heat of steel and shall receive substantially the same casting practices as the production casting it represents. (Centrifugal castings may be represented by statically cast coupons.) The test coupon shall be heat treated under the same conditions as the production casting(s). The t dimension of the test coupon shall be the same maximum thickness t as defined in (a) above. Where separate test blocks require reheat treatment, thermal buffers in accordance with (b) may be used.

(3) Where specimens are to be removed from the body of the casting, a steel, thermal buffer pad $1t \times 1t \times$ at least $3t$ shall be joined to the casting surface by a partial penetration weld completely sealing the buffered surface prior to the heat treatment process. The test specimens shall be removed from the casting in a location adjacent to the center third of the buffer pad. They shall be located at a minimum distance of $\frac{1}{2}$ in. from the buffered surface and $\frac{1}{4}$ from the other heat treated surfaces.

(4) Where specimens are to be removed from the body of the casting, thermal insulation or other thermal barriers shall be used during the heat treatment process adjacent to the casting edge where specimens are to be removed. It shall be demonstrated that the cooling rate of the test specimen is no faster than that of specimens taken by the method described in (b)(1) above. This information shall be included in the test reports.

(5) Where castings are cast or machined to essentially the finished product configuration prior to heat treatment, the test specimens shall be removed from a casting prolongation or other stock on the product at a location below the nearest heat treated surface indicated on the order. The specimens shall be located with their longitudinal axes a distance below the nearest heat treated surface equivalent to at least the greatest distance that the indicated high tensile stress surface will be from the nearest heat treated surface and with their midlength a minimum of twice this distance from a second heat treated surface. In any case, the longitudinal axes of the test specimens shall be no nearer than $\frac{1}{4}$ in. (6 mm) to a heat treated surface and the midlength shall be at least $1\frac{1}{2}$ in. (38 mm) from a second heat treated surface. The component manufacturer shall specify the surfaces of the finished product subjected to high tensile stress in service.

NE-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL

NE-2310 MATERIAL TO BE IMPACT TESTED

NE-2311 Material for Which Impact Testing Is Required

(a) Pressure retaining material shall be impact tested in accordance with the requirements of NE-2330, except that impact testing of materials described in (1) through (9) below is not a requirement of this Subsection, provided the requirements of NE-2121(c) are met.

(1) material with a nominal section thickness of $\frac{5}{8}$ in. (16 mm) or less where the thickness shall be taken as defined in (a) through (d) below:

(a) for vessels, use the nominal thickness of the shell or head, as applicable;

(b) for nozzles or parts welded to vessels, use the lesser of the vessel shell thickness to which the

Page 25

item is welded or the maximum radial thickness of the item exclusive of integral shell butt welding projections;

**TABLE NE-2311(a)-1
EXEMPTIONS FROM IMPACT TESTING UNDER
NE-2311(a)(8)**

Material [Note (1)]	Material Condition [Note (2)]	T_{NDT} , [Notes (3), (4)] °F
SA-537 Class 1	N	-30
SA-516 Grade 70	Q&T	-10
SA-516 Grade 70	N	0
SA-508 Class 1	Q&T	+10
SA-299 [Note (5)]	N	+20
SA-216 Grades WCB, WCC	Q&T	+30

NOTES:

- (1) These materials are exempt from toughness testing when LST — T_{NDT} is satisfied in accordance with the rules established in Appendix R.
- (2) Material Condition letters refer to:
N — Normalize
Q&T — Quench and Temper
- (3) These values for T_{NDT} were established from data on heavy section steel (thickness greater than 2½ in.). Values for sections less than 2½ in. thick are held constant until additional data are obtained.
- (4) T_{NDT} — temperature at or above nil-ductility transition temperature NDT (ASTM E 208-91); T_{NDT} is 10°F below the temperature at which at least two specimens show no-break performance.
- (5) Materials made to a fine grain melting practice.

TABLE NE-2311(a)-1 EXEMPTIONS FROM IMPACT TESTING UNDER NE-2311(a)(8)

(c) for flat heads, tubesheets, or flanges, use the maximum shell thickness associated with the butt welding hub;

(d) for integral fittings used to attach process piping to the containment vessel (Fig. NE-1120-1), use the larger nominal thickness of the pipe connections;

- (2) bolting, including studs, nuts, and bolts with a nominal size of 1 in. (25 mm) or less;
- (3) bars with a nominal cross-sectional area which does not exceed 1 sq in. (645 mm²);
- (4) all thicknesses of material for pipe, tube, and fittings with a nominal pipe size 6 in. diameter (DN 150) and smaller;
- (5) material for fittings with pipe connections of $\frac{5}{8}$ in. (16 mm) nominal wall thickness and less;
- (6) austenitic stainless steels;
- (7) nonferrous materials;

³ T_{NDT} - temperature at or above the nil-ductility transition temperature NDT (ASTM E 208-91) T_{NDT} is 10°F below the temperature at which at least two specimens show no-break performance.

(8) materials listed in Table NE-2311(a)-1 for which the listed value of T_{NDT} ³ is lower than the Lowest Service Metal Temperature⁴ (LST) by an amount established by the rules in Appendix R. This exemption does not exempt either the weld metal (NE-2430) or the welding procedure qualification (NE-4335) from impact testing.

(9) materials for components for which the Lowest Service Temperature exceeds 150°F (66°C);

(b) The Design Specification shall state the Lowest Service Temperature for the component.

(c) Drop weight tests are not required for the martensitic high alloy chromium (Series 4XX) steels and precipitation-hardening steels listed in Section II, Part D, subpart 1, Table 1A. The other requirements of NE-2331 and NE-2332 apply for these steels. For nominal wall thicknesses greater than $2\frac{1}{2}$ in. (57 mm), the required C_v values shall be 40 mils (1.00 mm) lateral expansion.

NE-2320 IMPACT TEST PROCEDURES

NE-2321 Types of Tests

NE-2321.1 Drop Weight Tests.

The drop weight test, when required, shall be performed in accordance with ASTM E 208-91. Specimen types P-1, P-2, or P-3 may be used. When drop weight tests are performed to meet the requirements of NE-2300, the test temperature and the results shall be reported on the Certified Material Test Report.

NE-2321.2 Charpy V-Notch Tests.

The Charpy V-notch tests (C_v), when required, shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Fig. 11, Type A. A test shall consist of a set of three full-size 10 mm × 10 mm specimens. The lateral expansion and absorbed energy, as applicable, and the test temperature, as well as the orientation and location of all tests performed to meet the requirements of NE-2330 shall be reported in the Certified Material Test Report.

⁴ The Lowest Service Metal Temperature shall be the lowest temperature which the metal may experience in service while the plants is in operation and shall be established by appropriate calculations based on atmospheric ambient conditions, the insulation or enclosure provided, and the minimum temperature which will be maintained inside the vessel during the plant operation.

NE-2322 Test Specimens

NE-2322.1 Location of Test Specimens.

Impact test specimens shall be removed from a depth within the material that is at least as far from the material surface as that specified for tensile test specimens in the material

Page 26

specification. For bolting, the C_v impact test specimens shall be taken with the longitudinal axis of the specimen located at least one-half radius or 1 in. (25 mm) below the surface plus the machining allowance per side, whichever is less. The fracture plane of the specimen shall be at least one diameter or thickness from the heat treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the

quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

NE-2322.2 Orientation of Test Specimens

(a) Specimens for C_v impact tests for quenched and tempered material shall be oriented in accordance with the requirements of NE-2220 and for other material in accordance with the requirements given in SA-370.

(b) Specimens for drop weight tests may have their axes oriented in any direction.

NE-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS

NE-2331 Pressure Retaining Material Test Methods and Temperature

(a) Pressure retaining material shall be impact tested in accordance with one of the test methods indicated below.

(1) Charpy V-notch testing at or below the Lowest Service Metal Temperature.⁴⁵

(2) Drop weight testing to show that the Lowest Service Metal Temperature⁴ ($LST - T_{NDT}$) is satisfied in accordance with the rules established in Appendix R.

5 The requirements for impact testing of the heat affected zone (NE-4335.2) may result in reduced impact test temperatures for the base material.

6 The Lowest Overpressure Test Metal Temperature shall be the lowest temperature which the metal may experience during the overpressure test. It shall be established by appropriate calculations based on atmospheric conditions, the insulation or enclosure provided, and the temperature which will be maintained inside the vessel during the test.

(b) In addition, when the Design Specification requires a vessel hydrostatic or pneumatic test temperature which is lower than the Lowest Service Metal Temperature,⁴ the impact testing for pressure retaining material shall be performed in accordance with (a) above, at or below the lowest specified vessel test temperature. As an alternative, a Lowest Overpressure Test Metal Temperature⁶ shall be specified. In this case, Charpy

V-notch testing, in addition to the tests required by (a) above, shall be performed as specified in NE-2321.2 at a temperature 30°F (17°C) or more below the Lowest Overpressure Test Metal Temperature in accordance with NE-2333.

**TABLE NE-2332.1-1
REQUIRED C_v LATERAL EXPANSION VALUES
FOR PRESSURE RETAINING MATERIAL
OTHER THAN BOLTING**

Nominal Wall Thickness, in.	Lateral Expansion, mils [Notes (1) and (2)]	
	Average of 3	Lowest 1 of 3
$\frac{5}{8}$ in. or less [Note (3)]	...	...
Over $\frac{5}{8}$ in. to 1 in., incl.	20	15
Over 1 in. to $1\frac{1}{2}$ in., incl.	25	20
Over $1\frac{1}{2}$ in. to $2\frac{1}{2}$ in., incl.	35	30
Over $2\frac{1}{2}$ in. [Note (4)]	45	40

NOTES:

- (1) Where weld metal tests of NE-2400 are made to these requirements, the impact lateral expansion shall conform to the requirements of either of the base materials being joined.
- (2) Where two base materials having different required lateral expansion values are joined, the weld metal lateral expansion requirements of NE-4330 shall conform to the requirements of either of the base materials.
- (3) No test required.
- (4) For use with NE-2332.2(b).

TABLE NE-2332.1-1 REQUIRED C_v LATERAL EXPANSION VALUES FOR PRESSURE RETAINING MATERIAL
OTHER THAN BOLTING

(c) The use of the material below the temperature established by the methods of (a) or (b) above may be justified by methods equivalent to those contained in Appendix G.

NE-2332 Specific Test Methods and Acceptance Standards for Pressure Retaining Material for Tests Based on Lowest Service Metal Temperatures

NE-2332.1 Pressure Retaining Material Other Than Bolting With 2½ in. (64 mm) Maximum Thickness.

Except as limited in NE-4335, apply one of the methods of NE-2331(a) to test: the base material; the base material, the heat affected zone, and the weld metal for the weld procedure qualification tests of NE-4335; and the weld metal for NE-2431.

The impact test results shall meet one of the acceptance standards applicable to the specified test method.

(a) *Charpy V-Notch Testing for Lateral Expansion Values.* The test results of the three specimens, collectively and singly, shall meet the respective requirements of Table NE-2332.1-1.

Page 27

**TABLE NE-2332.1-2
REQUIRED C_v ENERGY VALUES¹ FOR PRESSURE RETAINING MATERIAL OTHER THAN BOLTING**

Nominal Wall Thickness, in.	Energy, ft-lb for Base Materials [Note (2)] of Specified Minimum Yield Strength, ksi					
	55 ksi or Below		Over 55 ksi to 75 ksi, Incl.		Over 75 ksi to 105 ksi, Incl.	
	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3
⅝ in. or less [Note (3)]	...	...	...	...	...	...
Over ⅝ in. to 1 in., incl.	20	15	25	20	30	25
Over 1 in. to 1½ in., incl.	25	20	30	25	35	30
Over 1½ in. to 2½ in., incl.	35	30	40	35	45	40
Over 2½ in. [Note (4)]	45	40	50	45	55	50

NOTES:

- (1) Where weld metal tests of NE-2400 are made to these requirements, the impact energy shall conform to the requirements of either of the base materials being joined.
- (2) Where two base materials having different required energy values are joined, the weld metal impact energy requirements of the procedure qualification tests of NE-4330 shall conform to the requirements of either of the base materials.
- (3) No test required.
- (4) For use with NE-2332.2(b).

TABLE NE-2332.1-2 REQUIRED C_v ENERGY VALUES¹ FOR PRESSURE RETAINING MATERIAL OTHER THAN BOLTING

(b) *Charpy V-Notch Testing for Absorbed Energy Values.* The test results of the three specimens, collectively and singly, shall meet the respective requirements of Table NE-2332.1-2.

(c) *Drop Weight Testing.* An acceptance test shall consist of at least two no-break specimens as described in ASTM E 208-91.

NE-2332.2 Pressure Retaining Material Other Than Bolting With Thickness Exceeding 2½ in. (64 mm)

(a) The base material and the weld procedure qualification weld metal tests of NE-4335 shall be tested by the drop weight method as specified in NE-2321.1 and NE-2331(a)(2).

(b) Except as limited in NE-4335, apply one of the methods of NE-2331(a) to test the base material and the heat affected zone of the weld procedure qualification tests for NE-4335 and the weld metal for NE-2431.

(c) The acceptance standards shall be as given in NE-2332.1(a), NE-2332.1(b), or NE-2332.1(c), as applicable.

NE-2332.3 Bolting Material.

The drop weight test is not applicable to bolting materials. For bolting material, including nuts, studs, and bolts, a Charpy V-notch test shall be performed. Optionally, the test may be performed at the Lowest Service Metal Temperature, or at a temperature 30°F (17°C) or more below the Lowest Service Metal Temperature.

(a) When tested at the Lowest Service Metal Temperature, lateral expansion and absorbed energy values shall be determined, and all three specimens shall meet the requirements of Table NE-2332.3(a)-1.

**TABLE NE-2332.3(a)-1
REQUIRED C_v VALUES FOR
BOLTING MATERIAL TESTED IN ACCORDANCE
WITH NE-2332.3(a)**

Nominal Diameter, in.	Lateral Expansion, mils	Absorbed Energy, ft-lb
1 or less	No test required	No test required
Over 1 through 4	25	No requirements
Over 4	25	45

TABLE NE-2332.3(a)-1 REQUIRED C_v VALUES FOR BOLTING MATERIAL TESTED IN ACCORDANCE WITH NE-2332.2(a)

(b) When tested at 30°F (17°C) or more below the Lowest Service Metal Temperature, lateral expansion and absorbed energy values shall be determined, and all three specimens shall meet the requirements of Table NE-2332.3(b)-1.

NE-2333 Specific Test Methods and Acceptance Standards for Pressure Retaining Material for Tests Based on Lowest Overpressure Test Metal Temperature

NE-2333.1 Pressure Retaining Material Other Than Bolting.

Apply the method of NE-2331(a)(1) to test: the base material; the base material, the heat affected zone, and the weld metal for the weld procedure

**TABLE NE-2332.3(b)-1
REQUIRED C_v VALUES FOR BOLTING MATERIAL
TESTED IN ACCORDANCE WITH
NE-2332.3(b) AND NE-2333.2**

Nominal Diameter, in.	Lateral Expansion, mils	Absorbed Energy, ft-lb
1 or less	No test required	No test required
Over 1 through 4	15	30
Over 4	20	35

TABLE NE-2332.3(b)-1 REQUIRED C_v VALUES FOR BOLTING MATERIAL TESTED IN ACCORDANCE WITH NE-2332.3(b) AND NE-2333.2

qualification tests of NE-4335; and the weld metal for NE-2431.

**TABLE NE-2333.1-1
REQUIRED C_v ENERGY VALUES FOR PRESSURE
RETAINING MATERIAL OTHER THAN BOLTING
FOR THE OVERPRESSURE TEST**

Energy, ft-lb, for Base Materials [Notes (1) and (2)] of Specified Minimum Tensile Strength, ksi				
Nominal Wall Thickness, in.	60 ksi or Below		Over 60 ksi	
	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3
$\frac{5}{8}$ in. or less [Note (3)]	...	...	...	...
Over $\frac{5}{8}$ in.	15	10	20	15

NOTES:

- (1) Where weld metal tests of NE-2400 are made to these requirements, the impact energy shall conform to the requirements of either of the base materials being joined.
- (2) Where two base materials having different required energy values are joined, the weld metal impact energy requirements of the procedure qualification tests of NE-4330 shall conform to the requirements of either of the base materials.
- (3) No test required.

TABLE NE-2333.1-1 REQUIRED C_v ENERGY VALUES FOR PRESSURE RETAINING MATERIAL OTHER THAN BOLTING FOR THE OVERPRESSURE TEST

The impact test results of the three specimens, collectively and singly, shall meet the respective requirements of Table NE-2333.1-1.

NE-2333.2 Bolting Material.

For bolting material, including nuts, studs, and bolts, a Charpy V-notch test shall be performed. The test shall be

performed at or below the Lowest Service Metal Temperature, and all three specimens shall meet the requirements of Table NE-2332.3(a)-1.

NE-2340 NUMBER OF IMPACT TESTS REQUIRED

NE-2341 Plates

One test shall be made from each plate as heat treated. Where plates are furnished in the nonheat-treated condition and qualified by heat treated test specimens, one test shall be made for each plate as-rolled. The term as-rolled refers to the plate rolled from a slab or directly from an ingot, not to its heat treated condition.

NE-2342 Forgings and Castings

(a) Where the weight of an individual forging or casting is less than 1000 lb (454 kg), one test shall be made to represent each heat in each heat treatment lot.

(b) When heat treatment is performed in a continuous type furnace with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a heat treatment charge shall be considered as the lesser of a continuous run not exceeding 8 hr duration or a total weight, so treated, not exceeding 2000 lb (907 kg).

(c) One test shall be made for each forging or casting of 1000 lb to 10,000 lb (454 kg to 4540 kg) in weight.

(d) As an alternative to (c), a separate test forging or casting may be used to represent forgings or castings of different sizes in one heat and heat treat lot, provided the test piece is a representation of the greatest thickness in the heat treat lot. In addition, test forgings shall have been subjected to substantially the same reduction and working as the forgings represented.

(e) Forgings or castings larger than 10,000 lb (4540 kg) shall have two tests per part for Charpy V notch, and one test for drop weights. The location of drop weight or C_v impact test specimens shall be selected so that an equal number of specimens is obtained from positions in the forging or casting 180 deg apart.

(f) As an alternative to (e) for static castings, a separately cast test coupon [NE-2226(b)(2)] may be used; one test shall be made for Charpy V-notch and one test for drop weight.

NE-2343 Bars

One test shall be made for each lot of bars with a cross-sectional area greater than 1 sq in. (645 mm²) in each lot, where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed 6000 lb (2720 kg).

Page 29

NE-2344 Tubular Products and Fittings

On products which are seamless or welded without filler metal, one test shall be made from each lot. On products which are welded with filler metal, one additional test with the specimens taken from the weld area shall also be made on each lot. A lot shall be defined as stated in the applicable material specification, but in no case shall a lot consist of products from more than one heat of material and of more than one diameter, with the nominal thickness of any product included not exceeding that to be impact tested by more than $\frac{1}{4}$ in. (6 mm); such a lot shall be in a single heat treatment load or in the same continuous run in a continuous furnace controlled within a 50°F (28°C) range and equipped with recording pyrometers.

NE-2345 Bolting Material

One test shall be made for each lot of material where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed in weight the following:

$1\frac{3}{4}$ in. diameter and less	1,500 lb
Over $1\frac{3}{4}$ in. to $2\frac{1}{2}$ in. diameter	3,000 lb

Over 5 in. diameter

6,000 lb

10,000 lb

NE-2350 RETESTS

NE-2351 Retests for Material Other Than Bolting

(a) For Charpy V-notch tests required by NE-2330, one retest at the same temperature may be conducted, provided:

(1) the average value of the test results meets the average of three requirements specified in Table NE-2332.1-1, Table NE-2332.1-2, or Table NE-2333.1-1, as applicable;

(2) not more than one specimen per test is below the lowest one of three requirements specified in Table NE-2332.1-1, Table NE-2332.1-2, or Table NE-2333.1-1, as applicable;

(3) the specimen not meeting the requirements is not lower than 5 ft-lb (6.8 J) or 5 mils (0.13 mm) below the lowest one of three requirements specified in Table NE-2332.1-1, Table NE-2332.1-2, or Table NE-2333.1-1, as applicable.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall be equal to or greater than the average of three requirements specified in Table NE-2332.1-1, Table NE-2332.1-2, or Table NE-2333.1-1, as applicable.

NE-2352 Retests for Bolting Material

(a) For Charpy V-notch tests required by NE-2330, one retest at the same temperature may be conducted, provided:

(1) not more than one specimen per test is below the acceptance requirements;

(2) the specimen not meeting the acceptance requirements is not lower than 5 ft-lb (6.8 J) or 5 mils (0.13 mm) below the acceptance requirements.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall meet the specified acceptance requirements.

NE-2360 CALIBRATION OF INSTRUMENTS AND EQUIPMENT

Calibration of temperature instruments and C_v impact test machines used in impact testing shall be performed at the frequency specified in (a) and (b) below.

(a) Temperature instruments used to control test temperature of specimens shall be calibrated and the results recorded to meet the requirements of NCA-3868 at least once in each 3 month interval.

(b) C_v impact test machines shall be calibrated and the results recorded to meet the requirements of NCA-3868. The calibrations shall be performed at least once per year using methods outlined in ASTM E 23-72 and employing standard specimens obtained from the National Institute of Standards and Technology.

NE-2400 WELDING MATERIAL

NE-2410 GENERAL REQUIREMENTS

(a) All welding material used in the construction and repair of components or material, except welding material used for hard surfacing, shall conform to the requirements of the welding material specification or to the requirements for other welding material as permitted in Section IX. In addition, welding material shall conform to the requirements stated in this Subarticle and to the rules covering identification in NE-2150.

(b) The Certificate Holder shall provide the organization performing the testing with the information listed below, as applicable:

(1) welding process;

- (3) other identification if no SFA Specification applies;
- (4) minimum tensile strength [NE-2431.1(e)] in the as-welded or heat treated condition, or both [NE-2431.1(c)];
- (5) drop weight test for material as-welded or heat treated, or both (NE-2332);
- (6) Charpy V-notch test for material as-welded, or heat treated, or both (NE-2331); the test temperature and the lateral expansion or the absorbed energy shall be provided;
- (7) the preheat and interpass temperature to be used during welding of the test coupon [NE-2431.1(c)];
- (8) postweld heat treatment time, temperature range, and maximum cooling rate, if the production weld will be heat treated [NE-2431.1(c)];
- (9) elements for which chemical analysis is required per the SFA Specification or WPS, and NE-2432;
- (10) minimum delta ferrite (NE-2433).

NE-2420 REQUIRED TESTS

The required tests shall be conducted for each lot of covered, flux-cored, or fabricated electrodes; for each heat of bare electrodes, rod, or wire for use with the OFW, GMAW, GTAW, PAW, and EGW (electro-gas welding) processes (Section IX, QW-492); for each heat of consumable inserts; for each combination of heat of bare electrodes and lot of submerged arc flux; for each combination of lot of fabricated electrodes and lot of submerged arc flux; for each combination of heat of bare electrodes or lot of fabricated electrodes and dry blend of supplementary powdered filler metal and lot of submerged arc flux; or for each combination of heat of bare electrodes and lot of electroslog flux. Tests performed on welding material in the qualification of weld procedures will satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used, provided the tests required by NE-4000 and this Subarticle are made and the results conform to the requirements of this Article. The definitions in (a) through (h) below apply.

(a) A *dry batch of covering mixture* is defined as the quantity of dry covering ingredients mixed at one time in one mixing vessel; a dry batch may be used singly or may be subsequently subdivided into quantities to which the liquid binders may be added to produce a number of wet mixes [(c) below].

(b) A *dry blend* is defined as one or more dry batches mixed in a mixing vessel and combined proportionately to produce a uniformity of mixed ingredients equal to that obtained by mixing the same total amount of dry ingredients at one time in one mixing vessel.

(c) A *wet mix* is defined as the combination of a dry batch or dry blend [(a) and (b) above, respectively] and liquid binder ingredients at one time in one mixing vessel.

(d) A *lot of covered, flux-cored, or fabricated electrodes* is defined as the quantity of electrodes produced from the same combination of heat of metal and dry batch, dry blend, or chemically controlled mixes of flux or core materials. Alternatively, a lot of covered, flux-cored, or fabricated electrodes may be considered one type and size of electrode, produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45,360 kg), from chemically controlled tube, wire, or strip, and a dry batch, a dry blend, or chemically controlled mixes of flux, provided each container of welding materials is coded for identification and trace able to the production period, the shift, line, and the analysis range of both the mix and the rod, tube, or strip used to make the electrode.

(1) *Chemically controlled tube, wire, or strip* is defined as consumable tube, wire, or strip material supplied on coils with a maximum of one splice per coil that has been chemically analyzed to assure that the material conforms to the electrode manufacturer's chemical control limits for the specific type of electrode. Both ends of each coil shall be chemically analyzed, except that those coils which are splice-free need only be analyzed on one end of the coil.

(2) *Chemically controlled mixes of flux* are defined as flux material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the electrode manufacturer's standard for each chemical element for that type of electrode. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending.

(e) A *heat of bare electrode, rod, wire, or consumable insert* is defined as the material produced from the same melt of metal.

(f) Alternatively, for carbon and low alloy steel bare electrode, rod, wire, or consumable inserts for use with SAW, OFW, GMAW, GTAW, PAW, and EGW processes, a heat may be defined as either the material produced from the same melt of metal or the material produced from one type and size of wire when produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45,360 kg), from chemically controlled wire, subject to requirements of (1), (2), and (3) below.

(1) For the chemical control of the product of the rod mill, coils shall be limited to a maximum of one splice prior to processing the wire. Chemical analysis

Page 31

shall be made from a sample taken from both ends of each coil of mill coiled rod furnished by mills permitting spliced coil practice of one splice maximum per coil. A chemical analysis need be taken from only one end of rod coils furnished by mills prohibiting spliced coil practice.

(2) Carbon, manganese, silicon, and other intentionally added elements shall be determined to identify the material to ensure that it conforms to the SFA or user's material specification.

(3) Each container of wire shall be coded for identification and traceability to the lot, production period, shift, line, and analysis of rod used to make the wire.

(g) A *lot of submerged arc or electroslag flux* is defined as the quantity of flux produced from the same combination of raw materials under one production schedule.

(h) A *dry blend of supplementary powdered filler metal* is defined as one or more mixes of material produced in a continuous period, not to exceed 24 hr and not to exceed 20,000 lb (9070 kg) from chemically controlled mixes of powdered filler metal, provided each container of powdered metal is coded for identification and traceable to the production period, the shift, and the mixing vessel. A *chemically controlled mix of powdered filler metal* is defined as powdered filler metal material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the powdered filler metal manufacturer's standard, for each chemical element, for that type of powdered filler metal. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending. The chemical analysis range of the supplemental powdered filler shall be the same as that of the welding electrode, and the ratio of powder to electrode used to make the test coupon shall be the maximum permitted for production welding.

NE-2430 WELD METAL TESTS

NE-2431 Mechanical Properties Test

Tensile and impact tests shall be made, in accordance with this paragraph, of welding material which is used to join P-Nos. 1, 3, 4, 5, 6, 7, 9, and 11 base materials in any combination, with the exceptions listed in (a) through (d) below:

(a) austenitic stainless steel and nonferrous welding material used to join the listed P-Numbers;

(b) consumable inserts (backing filler material);

(c) welding material used for GTAW root deposits with a maximum of two layers;

(d) welding material to be used for the welding of base materials exempted from impact testing by NE-2311(a)(1) through (a)(7) and NE-2311(a)(9) shall likewise be exempted from the impact testing required by this paragraph.

NE-2431.1 General Test Requirements.

The welding test coupon shall be made in accordance with (a) through (f) below, using each process with which the weld material will be used in production welding.

(a) Test coupons shall be of sufficient size and thickness such that the test specimens required herein can be removed.

(b) The weld metal to be tested for all processes except electroslag welding shall be deposited in such a manner as to

eliminate substantially the influence of the base material on the results of the tests. Weld metal to be used with the electroslag process shall be deposited in such a manner as to conform to one of the applicable Welding Procedure Specifications (WPS) for production welding, Section IX, QW-201.1. The base material shall conform with the requirements of Section IX, QW-403.1 or Section IX, QW-403.4, as applicable.

7 Any postweld held treatment time which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at a temperature specified to be applied to the test specimens

(c) The welding of the test coupon shall be performed within the range of preheat and interpass temperatures which will be used in production welding. Coupons shall be tested in the as-welded condition, or they shall be tested in the applicable postweld heat treated condition when the production welds are to be postweld heat treated. The postweld heat treatment holding time⁷ shall be at least 80% of the maximum time to be applied to the weld metal in production application. The total time for postweld heat treatment of the test coupon may be applied in one heating cycle. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the component. In addition, weld coupons for weld metal to be used with the electroslag process that are tested in the as-welded condition, or following a postweld heat treatment within the holding temperature ranges of Table NE-4622.1-1 or Table NE-4622.4(c)-1, shall have a thickness within the range of 0.5 to 1.1 times the thickness of the welds to be made in production. Electroslag weld coupons to be tested following a postweld heat treatment which will include heating the coupon to a temperature above the "Holding Temperature Range" of Table NE-4622.1-1 for the type

Page 32

of material being tested shall have a thickness within the range of 0.9 to 1.1 times the thickness of the welds to be made in production.

(d) Regardless of the welding process or welding material being tested, the tensile specimens, and the C_v impact specimens where required, shall be located and prepared in accordance with the requirements of SFA-5.1, Specification for Mild Steel Covered Electrodes. Drop weight impact test specimens, where required, shall be oriented so that the longitudinal axis is transverse to the weld with the notch in the weld face or in a plane parallel to the weld face. For impact specimen preparation and testing the applicable parts of NE-2321.1 and NE-2321.2 shall apply. The longitudinal axis of the specimen shall be at a minimum depth of $1/4t$ from a surface, where t is the thickness of the test weld.

(e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the base material specification. Where base materials of different specifications are to be welded, the tensile strength requirements shall conform to the specified minimum tensile strength requirements of either of the base material specifications.

(f) Impact specimens of the weld metal shall be tested where impact tests are required for either of the base materials of the production weld. The weld metal shall conform to the requirements of NE-2332.1, NE-2332.2, or NE-2332.3, as applicable.

NE-2431.2 Standard Test Requirements.

In lieu of the use of the General Test Requirements specified in NE-2431.1, tensile and impact tests may be made in accordance with this subparagraph where they are required for mild and low alloy steel covered electrodes. The material combinations which require weld material testing, as listed in NE-2431, shall apply for this Standard Test Requirements option. The limitations and testing under this Standard Test option shall be in accordance with (a) through (f) below.

(a) Testing to the requirements of this subparagraph shall be limited to electrode classifications included in Specification SFA-5.1 or SFA-5.5.

(b) The test assembly required by SFA-5.1 or SFA-5.5, as applicable, shall be used for test coupon preparation, except that it shall be increased in size to obtain the number of C_v specimens or the drop weight test specimens required by NE-2331, where applicable.

(c) The welding of the test coupon shall conform to the requirements of the SFA Specification for the classification of electrode being tested. Coupons shall be tested in the as-welded condition and also in the postweld heat treated condition. The postweld heat

treatment temperatures shall be in accordance with Table NE-4622.1-1 for the applicable P-Number equivalent. The

time at postweld heat treatment temperature shall be 8 hr (this qualifies postweld heat treatments of 10 hr or less). Where the postweld heat treatment of the production weld exceeds 10 hr, or the PWHT temperature is other than that required above, the general test of NE-2431.1 shall be used.

**TABLE NE-2432.1-1
SAMPLING OF WELDING MATERIALS FOR
CHEMICAL ANALYSIS**

	GTAW/PAW	GMAW	All Other Processes
A-No. 8 filler metal	Filler metal or weld deposit	Weld deposit	Weld deposit
All other filler metal	Filler metal or weld deposit	Filler metal or weld deposit	Weld deposit

TABLE NE-2432.1-1 SAMPLING OF WELDING MATERIALS FOR CHEMICAL ANALYSIS

(d) The tensile and C_v specimens shall be located and prepared in accordance with the requirements of SFA-5.1 or SFA-5.5, as applicable. Drop weight impact test specimens, where required, shall be located and oriented as specified in NE-2431.1(d).

(e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirement of the SFA Specification for the applicable electrode classification.

(f) The requirements of NE-2431.1(f) shall be applicable to the impact testing of this option.

NE-2432 Chemical Analysis Test

Chemical analysis of filler metal or weld deposits shall be made in accordance with NE-2420 and as required by the following subparagraphs.

NE-2432.1 Test Method.

The chemical analysis test shall be performed in accordance with this subparagraph and Table NE-2432.1-1, and the results shall conform to NE-2432.2.

(a) A-No. 8 welding material to be used with GTAW and PAW processes and any other welding material to be used with any GTAW, PAW, or GMAW process shall have chemical analysis performed either on the filler metal or on a weld deposit made with the filler metal in accordance with (c) or (d) below.

(b) A-No. 8 welding material to be used with other than the GTAW and PAW processes and other welding material to be used with other than the GTAW, PAW, or GMAW process shall have chemical analysis performed

on a weld deposit of the material or combination of materials being certified in accordance with (c) or (d) below. The removal of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c) below. As an alternative, the deposit shall be made in accordance with (d) below for material that will be used for corrosion resistant overlay cladding. Where the Welding Procedure Specification or the welding material specification specifies percentage composition limits for analysis, it shall state that the specified limits apply for either the filler metal analysis or the undiluted weld deposit analysis or for *in situ* cladding deposit analysis in conformance with the above required certification testing.

(c) The preparation of samples for chemical analysis of undiluted weld deposits shall comply with the method given in the applicable SFA Specification. Where a weld deposit method is not provided by the SFA Specification, the sample shall be removed from a weld pad, groove, or other test weld⁸ made using the welding process that will be followed when the welding material or combination of welding materials being certified is consumed. The weld for A-No. 8 material to be used with the GMAW or EGW process shall be made using the shielding gas composition specified in the Welding Procedure Specification that will be followed when the material is consumed. The test sample for ESW shall be removed from the weld metal of the mechanical properties test coupon. Where a chemical analysis is required for a welding material which does not have a mechanical properties test requirement, a chemical analysis test coupon shall be prepared as required by NE-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of NE-2431.1(c) do not apply.

(d) The alternate method provided in (b) above for the preparation of samples for chemical analysis of welding material to be used for corrosion resistant overlay cladding shall require a test weld made in accordance with the essential variables of the Welding Procedure Specification that will be followed when the welding material is consumed. The test weld shall be made in conformance with the requirements of Section IX, QW-214.1. The removal of chemical analysis samples shall conform with Section IX, QW-214.3, for the minimum thickness for which the Welding Procedure Specification is qualified.

⁸ The methods given in the appendix of SFA 5.9, specification for Corrosion-Resisting Chromium-Nickel Steel Welding Rods and Bare Electrodes, shall be used to establish a welding and sampling method for the pad, groove, or other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution.

TABLE NE-2432.2-1 WELDING MATERIAL CHEMICAL ANALYSIS

Cr-Ni stainless materials	C, Cr, Mo, Ni, Mn, Si, Cb
------------------------------	---------------------------

TABLE NE-2432.2-1 WELDING MATERIAL CHEMICAL ANALYSIS

NE-2432.2 Requirements for Chemical Analysis.

The chemical elements to be determined, the composition requirements of the weld metal, and the recording of results of the chemical analysis shall be in accordance with (a), (b), and (c) below.

(a) Welding material of ferrous alloy A-No. 8 (Section IX, QW-442) shall be analyzed for the elements listed in Table NE-2432.2-1, and for any other elements specified either in the welding material specification referenced by the

Welding Procedure Specification or in the Welding Procedure Specification.

(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition limits. Where the Welding Procedure Specification contains a modification of the composition limits of SFA or other referenced welding material specifications, or provides limits for additional elements, these composition limits of the Welding Procedure Specification shall apply for acceptability.

(c) The results of the chemical analysis shall be reported in accordance with NCA-3867. Elements listed in Table NE-2432.2-1 but not specified in the welding material specification or Welding Procedure Specification shall be reported for information only.

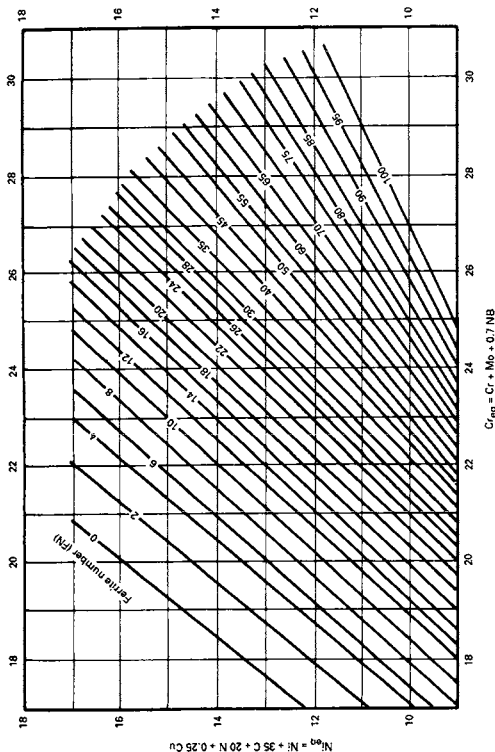
NE-2433 Delta Ferrite Determination

A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, QW-442); backing filler metal (consumable inserts); bare electrode, rod, or wire filler metal; or weld metal, except that delta ferrite determinations are not required for SFA-5.4 Type 16-8-2, or A-No. 8 weld filler metal to be used for weld metal cladding.

NE-2433.1 Method.

Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of chemical analysis of NE-2432 in conjunction with Fig. NE-2433.1-1.

(a) Calibration of magnetic instruments shall conform to AWS-A4.2-91.



GENERAL NOTES:
(a) The actual nitrogen content is preferred. If this is not available, the following applicable nitrogen value shall be used:
(1) GMAW welds: 0.06%, except that when self-shielding flux cored electrodes are used: 0.12%.
(2) Welds made using consumable inserts: 0.06%.
(b) This diagram is derived from the WRC 1982 Diagram, except that the solidification mode lines have been removed for ease of use.

FIG. NE-2433.1-1 WELD METAL DELTA FERRITE CONTENT

FIG. NE-2433.1-1 WELD METAL DELTA FERRITE CONTENT

(b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with NE-2432.1(c).

(c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number (FN).

NE-2433.2 Acceptance Standards.

The minimum acceptable delta ferrite shall be 5FN. The results of the delta ferrite determination shall be included in the Certified Material Test Report of NE-2130 or NE-4120.

NE-2440 STORAGE AND HANDLING OF WELDING MATERIAL

Suitable storage and handling of electrodes, flux, and other welding materials shall be maintained. Precautions shall be taken to minimize absorption of moisture by fluxes and cored, fabricated, and coated electrodes.

NE-2500 EXAMINATION AND REPAIR OF PRESSURE RETAINING MATERIAL

NE-2510 PRESSURE RETAINING MATERIAL

Pressure retaining material shall be examined and repaired in accordance with the material specification and as otherwise required by this Subarticle.

NE-2530 EXAMINATION AND REPAIR OF PLATE

NE-2531 Required Examination

Plates shall be examined in accordance with the requirements of the material specification.

NE-2537 Time of Examination

Acceptance examinations shall be performed at the time of manufacture as required in (a), (b), and (c) below.

(a) Examinations required by the material specification shall be performed at the time of manufacture as specified in the material specification.

(b) Radiographic examination of repair welds, when required, may be performed prior to any required postweld heat treatment.

(c) Magnetic particle or liquid penetrant examination of repair welds shall be performed after any required postweld heat treatment, except for P-No. 1 material which may be examined before or after any required postweld heat treatment.

NE-2538 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining provided the requirements of (a) and (b) below are met:

(a) the depression, after defect elimination, is blended uniformly into the surrounding surface;

(b) when the elimination of the defect reduces the thickness of the section below the minimum required by NE-3000, the material shall be repaired in accordance with NE-2539.

NE-2539 Repair by Welding

The Material Organization may repair by welding materials from which defects have been removed, provided the depth of the repair cavity does not exceed one-third of the nominal thickness and the requirements of the following subparagraphs are met. Prior approval of the Certificate Holder shall be obtained.

NE-2539.1 Defect Removal.

The defect shall be removed or reduced to an imperfection of acceptable limit by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair (NE-4211.1).

NE-2539.2 Qualification of Welding Procedures and Welders.

The welding procedure and welders or welding operators shall be qualified in accordance with NE-4000 and Section IX.

NE-2539.3 Blending of Repaired Areas.

After repair, the surface shall be blended uniformly into the surrounding surface.

NE-2539.4 Examination of Repair Welds.

Each repair weld shall be examined by the magnetic particle method (NE-2545) or by the liquid penetrant method (NE-2546). In addition, when the depth of the repair cavity exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness, the repair weld shall be radiographed in accordance with and to the applicable acceptance standards of NE-5000. The penetrometer shall be based upon the section thickness of the repaired area.

NE-2539.5 Heat Treatment After Repairs.

The product shall be heat treated after repair in accordance with the requirements of NE-4620.

NE-2539.6 Material Report Describing Defects and Repair.

Each defect repair that is required to be radiographed

Page 36

shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart which shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and a report of the results of the examinations, including radiographic film.

NE-2540 EXAMINATION AND REPAIR OF FORGINGS AND BARS

NE-2541 Required Examinations

Forgings and bars shall be examined in accordance with the requirements of the material specification, except when magnetic particle or liquid penetrant examination is specifically required by the rules of this Subsection, in which case the examination shall conform to the requirements of NE-2545 or NE-2546 as applicable.

NE-2545 Magnetic Particle Examination

NE-2545.1 Examination Procedure.

The procedure for magnetic particle examination shall be in accordance with the methods of Section V, Article 7.

NE-2545.2 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication in excess of the NE-2545.3 acceptance standards which is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the

length equal to or less than three times the width. Indications resulting from nonmetallic inclusions are not considered relevant indications.

NE-2545.3 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for material less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for material 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 sq in. (3871 mm²) of area whose major dimension is no more than 6 in. (152 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

NE-2546 Liquid Penetrant Examinations

NE-2546.1 Examination Procedure.

The procedure for liquid penetrant examination shall be in accordance with the methods of Section V, Article 6.

NE-2546.2 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities such as may occur from machining marks or surface conditions may produce similar indications which are not relevant.

(b) Any indication in excess of the NE-2546.3 acceptance standards which is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NE-2546.3 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for material less than $\frac{5}{8}$ in. (16 mm)

thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for material 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 sq in. (3871 mm²) of area whose major dimension is no more than 6 in.

(152 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

NE-2547 Time of Examination

The requirements for time of examination shall be the same as stated in NE-2537.

NE-2548 Elimination of Surface Defects

Elimination of surface defects shall be made in accordance with NE-2538.

NE-2549 Repair by Welding

The requirements for repair by welding shall be the same as stated in NE-2539, except that the depth of repair that is permitted is not limited.

NE-2550 EXAMINATION AND REPAIR OF SEAMLESS AND WELDED (WITHOUT FILLER METAL) TUBULAR PRODUCTS AND FITTINGS

NE-2551 Required Examination

(a) Wrought seamless tubular products and fittings shall comply with the requirements of NE-2557, NE-2558, and NE-2559 in addition to the basic material specification.

(b) Welded (without filler metal) tubular products and fittings shall comply with the requirements of NE-2557, NE-2558, and NE-2559; in addition, the welds shall be examined by one of the following methods:

- (1) ultrasonic examination in accordance with NE-2552;
- (2) eddy current examination in accordance with NE-2554;
- (3) radiographic examination in accordance with NE-2553.

NE-2552 Ultrasonic Examination⁹

NE-2552.1 Examination Procedure for Welds in Pipe and Tubing

(a) *Circumferential Direction 6 frac;34 in. (171 mm) O.D. and Smaller.* The welds in pipe and tubing shall be examined in two circumferential directions. The procedure for ultrasonic examination of pipe and tubing in the circumferential directions shall be in accordance with ASTM E 213-79, Standard Method for Ultrasonic Examination of Pipe and Tubing for Longitudinal Discontinuities, and the requirements of this paragraph. The procedure shall provide a sensitivity which will consistently detect defects that produce indications equal to or greater than the indications produced by standard defects included in the reference specimens specified in NE-2552.3.

(b) *Pipe and Tubing Larger Than 6 frac;34 in. (171 mm) O.D.* The welds in pipe and tubing shall be examined in two circumferential directions. The procedure for ultrasonic examination of pipe and tubing larger than 6³/₄ in. (171 mm) O.D. shall be in accordance with the requirements of SA-388 for angle beam scanning in the circumferential direction or with the requirements of ASTM E 213-79. The reference standard shall be in accordance with NE-2552.3.

(c) *Acceptance Standards.* Products with defects that produce indications in excess of the indications produced by the standard defects in the reference specimen are unacceptable unless the defects are eliminated or repaired in accordance with NE-2558 or NE-2559.

NE-2552.2 Examination Procedure for Welds in Fittings

(a) *Procedure.* The procedure for ultrasonic examination of welds in fittings shall be in accordance with the requirements of recommended practice SA-388 for angle beam examination in two circumferential directions.

(b) *Acceptance Standard.* Fittings shall be unacceptable if angle beam examination results show one or more reflectors which produce indications exceeding in amplitude the indications from the calibrated notch.

NE-2552.3 Reference Specimens

9 The volumetric examination required by this paragraph need only be conducted from one surface.

(a) The reference specimen shall be of the same nominal diameter and thickness and of the same nominal composition and heat treated condition as the product

Page 38

which is being examined. For circumferential scanning, the standard defects shall be axial notches or grooves on the outside and inside surfaces of the reference specimen and shall have a length of approximately 1 in. (25 mm) or less, a width not to exceed $\frac{1}{16}$ in. (1.6 mm) for a square notch or U-notch, a width proportional to the depth for a V-notch, and a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the nominal wall thickness.

(b) The reference specimen shall be long enough to simulate the handling of the product being examined through the examination equipment. When more than one standard defect is placed in a reference specimen, the defects shall be located so that indications from each defect are separate and distinct without mutual interference or amplification. All upset metal and burrs adjacent to the reference notches shall be removed.

NE-2552.4 Checking and Calibration of Equipment.

The proper functioning of the examination equipment shall be checked and the equipment shall be calibrated by the use of the reference specimens, as a minimum:

- (a) at the beginning of each production run of a given size and thickness of a given material;
- (b) after each 4 hr or less during the production run;
- (c) at the end of the production run;
- (d) at any time that malfunctioning is suspected.

If, during any check, it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid equipment calibration shall be reexamined.

NE-2553 Radiographic Examination

(a) *General.* When radiographic examination is performed as an alternative for ultrasonic examination of the entire volume of the material, it shall apply to the entire volume of the pipe, tube, or fitting material. Acceptance standards specified for welds shall apply to the entire volume of material examined.

(b) *Examination Procedure.* The radiographic examination shall be performed in accordance with Article 2 of Section V, as modified by NE-5111.

(c) *Acceptance Standard.* Welds that are shown by radiography to have any of the following types of discontinuities are unacceptable:

- (1) any type of crack or zone of incomplete fusion or penetration;
- (2) any other elongated indication which has a length greater than:
 - (a) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive
 - (b) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19 mm) to $1\frac{1}{4}$ in. (32 mm), inclusive
 - (c) $\frac{3}{4}$ in. (19 mm) for t over $1\frac{1}{4}$ in. (32 mm) where t is the thickness of the thinner portion of the weld;
- (3) any group of aligned indications having an aggregate length greater than t in a length of $12t$, unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication;
- (4) rounded indications in excess of that shown as acceptable in Appendix VI.

NE-2554 Eddy Current Examination

This examination method is restricted to materials with uniform magnetic properties and of sizes for which meaningful results can be obtained.

NE-2554.1 Examination Procedure.

The procedure for eddy current examination shall provide a sensitivity that will consistently detect defects by comparison with the standard defects included in the reference specimen specified in NE-2552.3. Products with defects that produce indications in excess of the reference standards are unacceptable unless the defects are eliminated or repaired in accordance with NE-2556 or NE-2557 as applicable.

NE-2554.2 Reference Specimens.

The reference specimen shall be of the same nominal diameter and thickness and of the same nominal composition and heat treated condition as the product that is being examined. The standard shall contain tangential or circumferential notches on the outside surface plus a $\frac{1}{16}$ in. (1.6 mm) diameter hole drilled through the wall. These shall be used to establish the rejection level for the product to be tested. The reference notches shall have a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the wall thickness. The width of the notch shall not exceed $\frac{1}{16}$ in. (1.6 mm). The length shall be approximately 1 in. or less. The size of reference specimens shall be as specified in NE-2552.3.

NE-2554.3 Checking and Calibration of Equipment.

The checking and calibration of examination equipment shall be the same as in NE-2552.4.

NE-2557 Time of Examination

(a) Products that are quenched and tempered shall be examined, as required, after the quenching and tempering heat treatment.

(b) Products that are not quenched and tempered shall receive the required examinations as follows.

Page 39

(1) Ultrasonic or eddy current examination, when required, shall be performed after final heat treatment, except postweld heat treatment.

(2) Radiographic examination, when required, may be performed prior to any required postweld heat treatment.

(3) Magnetic particle or liquid penetrant examination of welds, including repair welds, shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment for P-No. 1 (Section IX of the Code) materials of 2 in. (51 mm) and less nominal thickness.

(4) Forgings and rolled bars which are to be bored and/or turned to form tubular parts or fittings shall be examined after boring and/or turning, except for threading. Fittings shall be examined after final forming.

(5) When surface examination is required all external surfaces and all accessible internal surfaces shall be examined, except for bolt holes and threads.

NE-2558 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (c) below are met:

(a) the depression, after defect elimination, is blended uniformly into the surrounding surface;

(b) after defect elimination, the area is examined by the method which originally disclosed the defect to assure that the defect has been removed or reduced to an imperfection of acceptable size;

(c) if the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of NE-3000, the product shall be repaired in accordance with NE-2559.

NE-2559 Repair by Welding

Repair of defects shall be in accordance with NE-2539.

NE-2560 EXAMINATION AND REPAIR OF TUBULAR PRODUCTS AND FITTINGS WELDED WITH FILLER METAL

NE-2561 Required Examination

(a) Welded (with filler metal) tubular products, such as pipe made in accordance with SA-358, SA-409, SA-671, SA-672, and SA-691 and fittings made in accordance with the WPW grades of SA-234, SA-403, and SA-420 which are made by welding with filler metal, shall be treated as material; however, inspection by an Inspector and stamping with an NPT symbol shall be in accordance with Section III requirements. In addition to the NPT symbol, a numeral 2 shall be stamped below and outside the official Code Symbol.

(b) In addition to the requirements of the material specification and of this Article, all welds shall be examined 100% by radiography in accordance with the basic material specification. When radiographic examination is not specified in the basic material specification, the welds shall be examined in accordance with NE-2563.

(c) Tubular products and fittings which have been radiographed shall be marked to indicate that radiography has been performed. The radiographic film and a radiographic report showing film locations shall be provided with the Certified Material Test Report.

(d) The Authorized Inspector shall certify by signing the Partial Data Report Form NM-1 in accordance with NCA-5290.

NE-2563 Radiographic Examination

The radiographic examination shall be performed in accordance with the requirements of NE-2553.

NE-2567 Time of Examination

The time of examination shall be in accordance with the requirements of NE-2557.

NE-2568 Elimination of Surface Defects

Unacceptable surface defects shall be removed in accordance with the requirements of NE-2558.

NE-2569 Repair by Welding

When permitted by the basic material specification, base material defects shall be repair welded in accordance with the requirements of NE-2559. Repair welding of weld seam defects shall be in accordance with NE-4450.

NE-2570 EXAMINATION AND REPAIR OF STATICALLY AND CENTRIFUGALLY CAST PRODUCTS

In addition to the requirements of the material specifications and of this Article, statically and centrifugally

Page 40

cast products shall comply with the following subparagraphs.

**TABLE NE-2571-1
REQUIRED EXAMINATIONS**

Nominal Pipe Size	Item	Applicable Special Requirements for Class MC Castings
...	...	Cast material shall be examined by either the radiographic or the ultrasonic method, or a combination of the two methods. Castings or sections of castings which have coarse grains or configurations which do not yield meaningful results by ultrasonic examination shall be examined by the radiographic method.

TABLE NE-2571-1 REQUIRED EXAMINATIONS

NE-2571 Required Examination

Cast products shall be examined by the radiographic method, except cast ferritic steels, which shall be examined by either the radiographic or the ultrasonic method, or a combination of both methods as required for the product form by Table NE-2571-1.

NE-2572 Time of Nondestructive Examination

NE-2572.1 Acceptance Examinations.

Acceptance examinations shall be performed at the time of manufacture as stipulated in the following and Table NE-2571-1.

(a) *Ultrasonic Examination.* Ultrasonic examination, if required, shall be performed at the same stage of manufacture as required for radiography.

(b) *Radiographic Examination.* Radiography may be performed prior to heat treatment and may be performed prior to or after finish machining at the following limiting thicknesses.

(1) For finished thicknesses under $2\frac{1}{2}$ in. (64 mm), castings shall be radiographed within 20% of the finished thickness when Type 2 radiographic film is used or within $\frac{1}{2}$ in. (13 mm) of the finished thickness when Type 1 radiographic film is used. The penetrometer and the acceptance reference radiographs shall be based on the finished thickness.

(2) For finished thicknesses from $2\frac{1}{2}$ in. (64 mm) up to 6 in. (152 mm), castings shall be radiographed within 20% of the finished thickness. The penetrometer and the acceptance reference radiographs shall be based on the finished thickness.

(3) For finished thicknesses over 6 in. (152 mm), castings shall be radiographed with $\frac{1}{2}$ in. (13 mm) or 15% of the finished thickness, whichever is greater. The penetrometer and the acceptance reference radiographs shall be based on the finished thickness.

(c) Radiography of castings for pumps and valves may be performed in as-cast or rough machined thickness exceeding the limits of (b)(1), (b)(2), or (b)(3) above, subject to the following conditions.

(1) When the thickness of the as-cast or rough machined section exceeds 2 in. (51 mm), acceptance shall be based on reference radiographs for the next lesser thickness; e.g., if the section being radiographed exceeds $4\frac{1}{2}$ in. (114 mm), use reference radiographs of ASTM E 186-75 (reapproved 1979). The penetrometer shall be based on the thickness of the section being radiographed.

(2) When the thickness of the as-cast or rough machined section is 2 in. (51 mm) or less, the reference radiographs of ASTM E 446-78 shall be used and the penetrometer shall be based on the final section thickness.

(3) Weld ends for a minimum distance of t or $\frac{1}{2}$ in. (13 mm), whichever is less (where t is the design section thickness of the weld), from the final welding end shall be radiographed at a thickness within the limits given in (b)(1), (b)(2), or (b)(3) above as applicable. As an alternative, the weld ends may be radiographed in the as-cast or rough machined thickness in accordance with (a) and (b) above, and the penetrameter shall be based on the final section thickness.

(d) *Magnetic Particle or Liquid Penetrant Examination.* Magnetic particle or liquid penetrant examination shall be performed after the final heat treatment required by the material specification. Repair weld areas shall be examined after postweld heat treatment when a postweld heat treatment is performed, except that repair welds in P-No. 1 (see Section IX of the Code) material 2 in. (51 mm) nominal thickness and less may be examined prior to postweld heat treatment. For cast products with machined surfaces, all finished machine surfaces, except threaded surfaces and small deep holes, shall also be examined by the magnetic particle or the liquid penetrant method.

Page 41

NE-2573 Provisions for Repair of Base Material by Welding

The Material Organization may repair, by welding, products from which defects have been removed, provided the requirements of this Article are met.

NE-2573.1 Defect Removal.

The defects shall be removed or reduced to an imperfection of acceptable size by suitable mechanical or thermal cutting or gouging methods, and the cavity prepared for repair. When thermal cutting is performed, consideration shall be given to preheating the material.

NE-2573.2 Repair by Welding.

The Material Organization may repair castings by welding after removing the material containing unacceptable defects. The depth of the repair is not limited. A cored hole or access hole may be closed by the Material Organization by welding in accordance with the requirements of this paragraph provided the hole is closed by filler metal only. If the hole is closed by welding in a metal insert, the welding shall be performed by a holder of a Certificate of Authorization in accordance with the requirements of the Code.

NE-2573.3 Qualification of Welding Procedures and Welders.

Each manufacturer is responsible for the welding done by his organization and shall establish the procedures and conduct the tests required by NE-4000 and by Section IX of the Code in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures. He is also responsible for the welding performed by his subcontractors and shall assure himself that the subcontractors conduct the tests required by NE-4000 and by Section IX of the Code in order to qualify their welding procedures and the performance of their welders and welding operators.

NE-2573.4 Blending of Repaired Areas.

After repair, the surface shall be blended uniformly into the surrounding surface.

NE-2573.5 Examination of Repair Welds

(a) Each repair weld shall be examined by the magnetic particle method in accordance with the requirements of NE-2577 or by the liquid penetrant method in accordance with the requirements of NE-2576. In addition, when radiography is specified in the order for the original casting, repair cavities, the depth of which exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the nominal wall thickness, shall be radiographed after repair, except that weld slag, including elongated slag, shall be considered as inclusions under Category B of the applicable reference radiographs. The total area of all inclusions, including slag inclusions, shall not exceed the limits of the applicable severity level of Category B of the reference radiographs. The penetrameter and the acceptance standards for radiographic examination of repair welds shall be based on the actual section thickness at the repair area.

(b) Examination of repair welds in P-No. 1 and P-No. 8 material is not required for pumps and valves with inlet piping

connections NPS 2 (DN 50) and less.

NE-2573.6 Heat Treatment After Repairs.

The material shall be heat treated after repair in accordance with the heat treatment requirements of NE-4620, except that the heating and cooling rate limitations of NE-4623 do not apply.

NE-2573.7 Elimination of Surface Defects.

Surface defects shall be removed by grinding or machining provided the requirements of (a) through (c) below are met:

(a) the depression, after defect elimination, is blended uniformly into the surrounding surface;

(b) after defect elimination, the area is reexamined by the magnetic particle method in accordance with NE-2577 or the liquid penetrant method in accordance with NE-2576 to assure that the defect has been removed or reduced to an imperfection of acceptable size;

(c) if the elimination of the defect reduces the section thickness below the minimum required by the specification or drawing, the casting shall be repaired in accordance with NE-2539.

NE-2573.8 Material Report Describing Defects and Repairs.

Each defect repair exceeding in depth the lesser of $\frac{3}{4}$ in. (19 mm) or 10% of the nominal wall thickness shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart that shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographic film, when radiography is specified in the order for the original casting.

NE-2574 Ultrasonic Examination of Ferritic Steel Castings

Ultrasonic examination shall be performed in accordance with T-541.4 of Article 5 of Section V. Each manufacturer shall certify that the procedure is in accordance with the requirements of NE-2574 and shall make the procedure available for approval upon request.

Page 42

NE-2574.1 Acceptance Standards

(a) The Quality Levels of SA-609 as shown in Section V shall apply for the casting thicknesses indicated:

(1) Quality Level 1 for thicknesses up to 2 in. (51 mm);

(2) Quality Level 3 for thicknesses 2 in. to 4 in. (51 mm to 102 mm);

(3) Quality Level 4 for thicknesses greater than 4 in. (102 mm).

(b) In addition to the Quality Level requirements stated in (a) above, the requirements in (1) through (5) below shall apply for both straight beam and angle beam examination.

(1) Areas giving indications exceeding the Amplitude Reference Line with any dimension longer than those specified in the following tabulation are unacceptable:

UT Quality Level	Longest Dimension of Area^{10, 11, 12}
1	1.5 in.
2	2.0 in.
3	2.5 in.
4	3.0 in.

(2) Quality Level 1 shall apply for the volume of castings within 1 in. (25 mm) of the surface regardless of the overall thickness.

(3) Discontinuities indicated to have a change in depth equal to or greater than one-half the wall thickness or 1 in. (25 mm) (whichever is less) are unacceptable.

(4) Two or more imperfections producing indications in the same plane with amplitudes exceeding the Amplitude Reference Line and separated by a distance less than the longest dimension of the larger of the adjacent indications are unacceptable if they cannot be encompassed within an area less than that of the Quality Level specified in (b)(1) above.

(5) Two or more imperfections producing indications greater than permitted for Quality Level 1 for castings less than 2 in. in thickness, greater than permitted for Quality Level 2 for thicknesses 2 in.

10 The areas for the Ultrasonic Quality Levels in SA-609 refer to the surface area on the casting over which a continuous indication exceeding the transfer corrected distance amplitude curve is maintained.

11 Area are to be measured from dimensions of the movement of the search unit, using the center of the search unit as the reference point.

12 In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases, other criteria which incorporate a consideration of beam angles or beam spread must be used for realistic evaluation of the discontinuity.

(51 mm) through 4 in. (102 mm), and greater than permitted for Quality Level 3 for thicknesses greater than 4 in. (102 mm), separated by a distance less than the longest dimension of the larger of the adjacent indications, are unacceptable if they cannot be encompassed in an area less than that of the Quality Level requirements stated in (a) above.

NE-2575 Radiographic Examination

NE-2575.1 Examination.

Cast pressure retaining materials shall be examined by the radiographic method when specified in the order for the original castings, except that cast ferritic steels may be examined by either the radiographic or the ultrasonic method, or a combination of both methods. Castings or sections of castings that have coarse grains or configurations that do not yield meaningful examination results by the ultrasonic method shall be examined by the radiographic method.

NE-2575.2 Extent.

Radiographic examination shall be performed on pressure retaining castings such as vessel heads and flanges, valve bodies, bonnets and disks, pump casings and covers, and piping and fittings. The extent of radiographic coverage shall be of the maximum feasible volume and, when the shape of the casting precludes complete coverage, the coverage shall be at least as exemplified in the typical sketches as shown in Fig. NE-2575.2-1.

NE-2575.3 Examination Procedure.

The radio graphic examination shall be performed in accordance with Article 2 of Section V, with the following modifications.

(a) *Film Selection.* Only Types 1, 2, and 3 are permitted.

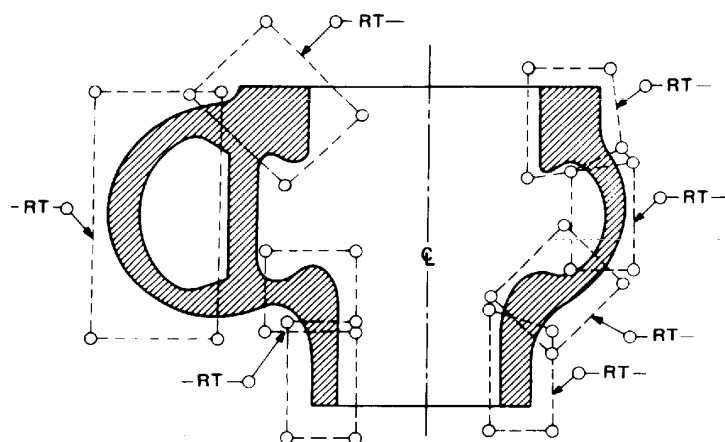
(b) *Radiographic Density.* The transmitted film density through the radiographic image of the body of the appropriate penetrometer and the area of interest shall be 1.3 minimum for single film viewing. For composite viewing of multiple film exposures, each film of the composite set shall have a minimum density of 1.0. The maximum density shall be 4.0 for either single or composite viewing. A tolerance of 0.05 in density is allowed for variations between densitometer readings.

(c) The requirements of T-274 and T-285 of Article 2 of Section V need not be met.

(d) *Image Quality Indicator (IQI) Design.* Penetrators shall be manufactured and identified in accordance with the requirements or alternates allowed in SE-142 and Appendices.

(e) *Image Quality Indicator (IQI) Selection.* The radiographic quality level shall be 2-4T for section

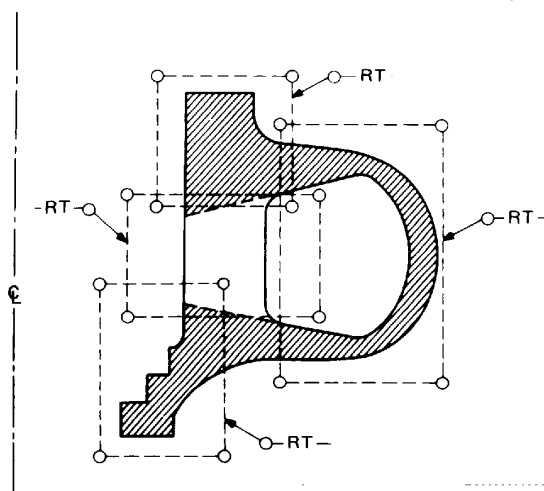
thicknesses up to and including $\frac{3}{4}$ in. (19 mm) and 2-2T for section thicknesses greater than $\frac{3}{4}$ in. (19 mm). Radiographic quality is defined in Note 2 of SE-94, Pages 44-44



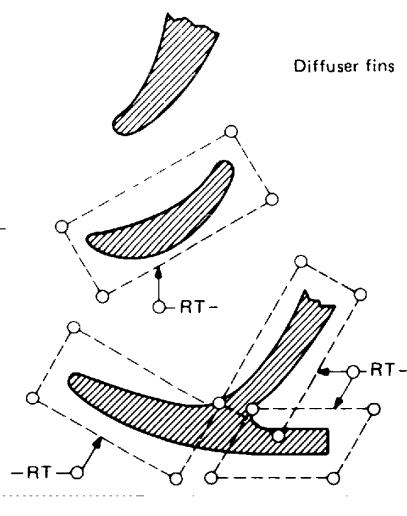
(a) Typical Volute-Type Pump Case

GENERAL NOTES:

- Radiographic examination areas shall be indicated by a circle at each change of direction. The examination symbol for radiography shall be indicated as RT.
- For nondestructive examination areas of revolution, the area shall be indicated by the examine-all-around symbol: - RT - ⌀
- The sketches are typical and are to be used as a guide for minimum required coverage. Even though a sketch may be titled, "pump" or "valve," the coverage shown by the configurations may be applied interchangeably.



(b) Typical Diffuser-Type Pump Case



(c) Typical Diffuser-Type Pump Case Detail

FIG. NE-2575.2-1 TYPICAL PRESSURE RETAINING PARTS OF PUMPS AND VALVES

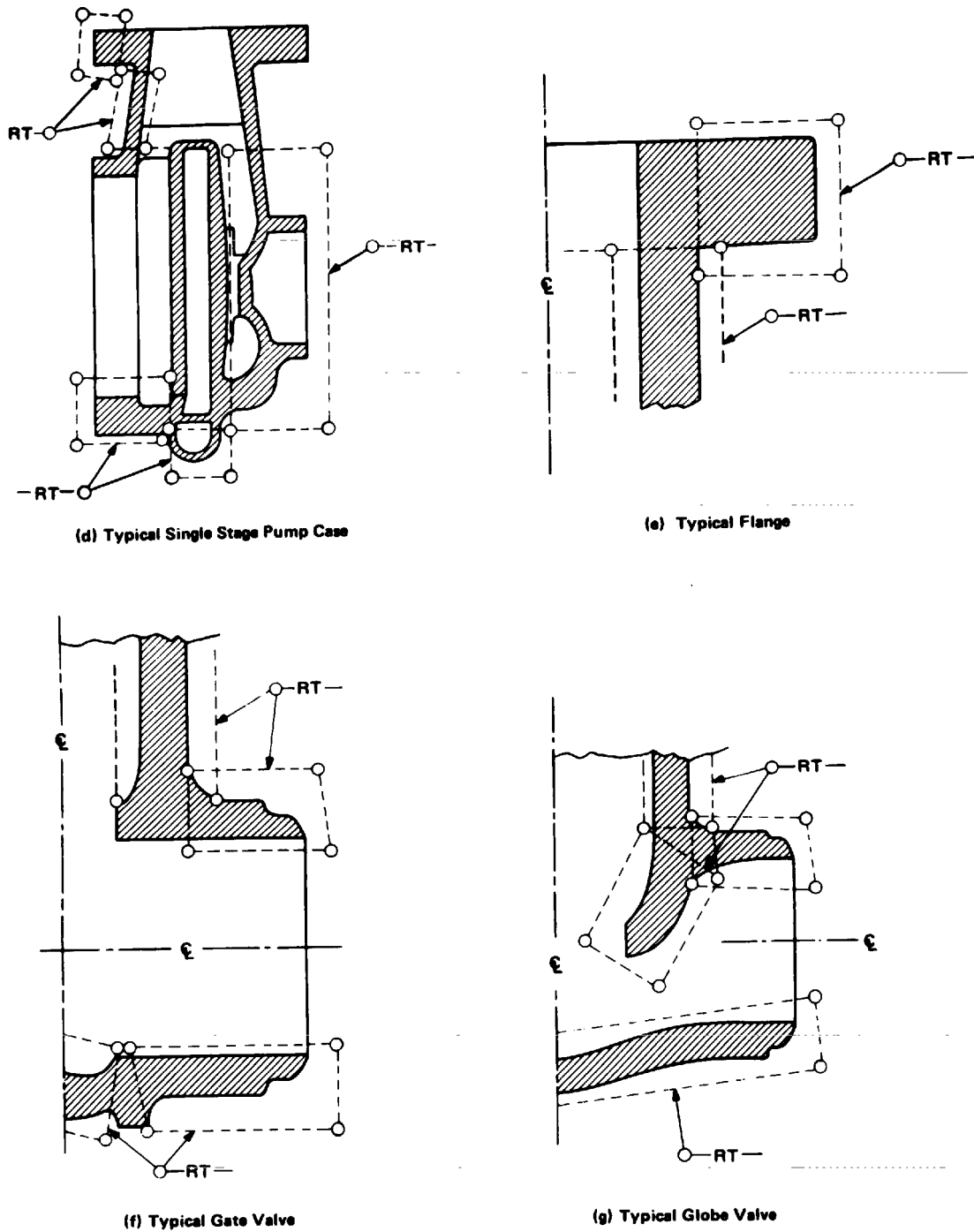


FIG. NE-2575.2-1 TYPICAL PRESSURE RETAINING PARTS OF PUMPS AND VALVES (CONT'D)

FIG. NE-2575.2-1 TYPICAL PRESSURE RETAINING PARTS OF PUMPS AND VALVES (CON'T)

(f) When radiographing weld ends of cast valves NPS 4 and less, double-wall radiography may be used subject to the conditions of (a) and (b) below.

(1) The penetrameter thickness shall be based on the design section thickness of the double-wall, excluding the weld preparation lip.

(2) Acceptance standards shall be based on nominal single-wall thickness.

NE-2575.4 Procedure Requirements.

Radiographic examination shall be performed in accordance with a written procedure. Each manufacturer shall certify that the procedure is in accordance with the requirements of NB-2575. The procedure shall be available for the interpretation of the films and shall be submitted together with the radiographs. Each procedure shall include at least the following information:

(a) the type of material to be radiographed;

(b) the material thickness ranges to be radiographed;

(c) the type of radiation source, actual or maximum source size or focal spot, X-ray equipment voltage rating and manufacturer. The equipment manufacturer's or supplier's publications, such as technical manuals, decay curves, or written statements documenting the actual or maximum source size or focal spot, shall be acceptable as source size verification. For X-ray machines 320 kV and less, the focal spot size may be determined by the pinhole method.¹³

(d) type and thickness of intensifying screens and filters;

(e) minimum source-to-film distance.

NE-2575.5 Radiographic Setup Information.

To aid in proper interpretation of radiographs, details of the radiographic examination setup used shall accompany each group of radiographs. As a minimum, the information shall include:

(a) film brand and the type and number of films in the cassette;

(b) for multiple film technique, state whether viewing is to be single or superimposed;

(c) blocking or masking technique, if used;

(d) isotope or X-ray voltage used;

(e) source-to-film distance used;

(f) distance between film and object when film/cassette is not in contact with object;

13 Nondestructive Testing Handbook, Volume 1, First Edition, pp. 14.32, 14.33, "Measuring Focal-spot Size." Also, pp. 20, 21 of Radiography in Modern Industry, Fourth Edition.

(g) geometric arrangement for the radiograph(s) (sketch);

(h) orientation of location markers;

(i) description of how internal markers, when used, locate area of interest;

(j) location markers, such as lead numbers or letters, which shall appear as radiographic images on the film, shall be permanently stamped on the surface of the casting being radiographed in a manner permitting the area of interest on a radiograph to be accurately located on the casting and providing evidence on the radiograph that the extent of coverage required by NE-2575.2 has been obtained. On castings or sections of castings where stamping is not feasible, the radiographic procedure shall so state in which case a radiographic film location map shall be provided.

NE-2575.6 Acceptance Criteria.

Castings shall meet the acceptance requirements of Severity Level 2 of ASTM E 446-72, E 446-75, or E 446-78, Reference Radiographs for Steel Castings up to 2 in. (51 mm) in Thickness; ASTM E 186-67, E 186-73, or E 186-75, Reference Radiographs for Heavy-Walled [2 in. to 4 $\frac{1}{2}$ in. (51 mm to 114 mm)] Steel Castings; or ASTM E 280-68, E 280-72, or E 280-75, Reference Radiographs for Heavy-Walled [4 $\frac{1}{2}$ in. to 12 in. (114 mm to 305 mm)] Steel Castings; as applicable for the thickness being radiographed, except that Category D, E, F, or G defects are not acceptable. The requirements of ASTM E 280-68, E 280-72, or E 280-75 shall apply for castings over 12 in. (305 mm) in thickness.

NE-2576 Liquid Penetrant Examination

(a) Castings shall be examined, if required, on all accessible surfaces by the liquid penetrant method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by bleeding out of the penetrant; however, localized surface discontinuities as may occur from machining marks, scale, or dents may produce indications which are not relevant. Any indication in excess of the acceptance standards believed to be nonrelevant shall be reexamined to verify whether actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation that would mask indications of defects are unacceptable. Relevant indications are those which result from imperfections and have a major dimension greater than $\frac{1}{16}$ in. Linear indications are those whose length is more than three times the width. Rounded

Page 46

indications are those which are circular or elliptical with the length less than three times the width.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for materials less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for materials from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for materials 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (3.2 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

NE-2577 Magnetic Particle Examination (for Fretted Steel Products Only)

(a) Castings of magnetic material shall be examined, if required, on all accessible surfaces by a magnetic particle method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by retention of the examination medium. All indications are not necessarily defects since certain metallurgical discontinuities and magnetic permeability variations may produce indications that are not relevant. Any indication in excess of the acceptance standard believed to be nonrelevant shall be reexamined to verify whether actual defects are present. Nonrelevant indications which would mask indications of defects are unacceptable. Surface conditioning may precede the reexamination. Relevant indications are those which result from imperfections and have a major dimension greater than $\frac{1}{16}$ in. Linear indications are those whose length is more than three times there with. Rounded indications are those which are circular or elliptical with the length less than three times the width.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for materials less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for materials from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for materials 2 in. (51 mm) thick and greater;

(2)

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{1}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

NE-2580 EXAMINATION OF BOLTS, STUDS, AND NUTS

NE-2581 Requirements

All bolting material shall be visually examined in accordance with NE-2582.

NE-2582 Visual Examination

Visual examination shall be applied to the areas of threads, shanks, and heads of final machined parts. Harmful discontinuities such as laps, seams, or cracks that would be detrimental to the intended service are unacceptable.

NE-2600 MATERIAL ORGANIZATIONS' QUALITY SYSTEM PROGRAMS

NE-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS

(a) Except as provided in (b) below, Material Organizations shall have a Quality System Program or an Identification and Verification Program, as applicable, which meets the requirements of NCA-3800.

(b) The requirements of NCA-3862 shall be met as required by NE-2130. The other requirements of NCA-3800 need not be used by Material Organizations for small products, as defined in (c) below, and for material which is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Assurance Program (NCA-4000) shall include measures to provide assurance that the material is furnished in accordance with the material specification and with the applicable special requirements of this Subsection.

Page 47

(c) For the purpose of this paragraph, small products are defined as given in (1) through (3) below:

(1) pipe, tube, pipe fittings, and flanges NPS 2 (DN 50) and less;

(2) bolting materials, including studs, nuts, and bolts of 1 in. (25 mm) nominal diameter and less;

(3) bars with a nominal cross-sectional area of 1 sq in. (645 mm²) and less.

NE-2700 DIMENSIONAL STANDARDS

NE-2710 STANDARDS AND SPECIFICATIONS

Dimensions of standard items shall comply with the standards and specifications listed in Table NE-3132-1.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NE-3000

ARTICLE NE-3000 DESIGN

Page 49

NE-3100 GENERAL DESIGN

NE-3110 LOADING CRITERIA

NE-3111 Loading Conditions

The loadings that shall be taken into account in designing a vessel shall include, but are not limited to, those in (a) through (i) below:

- (a) internal and external pressure;
- (b) impact loads, including rapidly fluctuating pressure;
- (c) weight of the vessel and normal contents under all conditions, including additional pressure due to static and dynamic head of liquids;
- (d) superimposed loads such as other components, operating equipment, insulation, corrosion resistant or erosion resistant linings, and piping;
- (e) wind loads, snow loads, and vibration loads where specified;
- (f) reactions of supporting lugs, rings, saddles, or other types of supports;
- (g) temperature effects;
- (h) reactions to steam and water jet impingement;
- (i) earthquake loads.

NE-3112 Design Loadings

The containment vessel or portions thereof may be exposed to more than one pressure, temperature, and mechanical load condition as provided in the Design Specifications. The specified design parameters for Design Loadings shall be called Design Pressure, Design Temperature, and Design Mechanical Loads. These specified design parameters shall be used in computations to show compliance with the requirements on Design Loadings in NE-3220.

NE-3112.1 Design Pressure.

The design internal pressure shall not be less than 100% of the maximum containment internal pressure under conditions for which the containment function is required. The design external pressure shall not be less than 100% of the maximum containment external pressure. Stability of the vessel shell may be provided by structures bearing directly against the shell or by structural attachments.

NE-3112.2 Design Temperature

(a) The Design Temperature shall not be less than the maximum containment temperature at the coincident maximum containment pressure. The Design Temperature shall be used in all computations involving Design Pressure and coincidental Design Mechanical Loads.

(b) Where a vessel is heated by external or internal heat generation, the effect of such heating shall be incorporated in the establishment of the vessel Design Temperature.

NE-3112.3 Design Mechanical Loads.

The values of dead loads and any hydrostatic loads coincident with Design Pressure shall be designated as Design Mechanical Loads. These mechanical loads shall be used in all computations involving Design Pressure and Design Temperature.

NE-3112.4 Allowable Stress Intensity and Stress Values.

The rules for allowable stress intensities and allowable stresses are given in NE-3200 for vessels designed by analysis where the allowable stress intensity S_{mc} is 1.1 times the S value given in Section II, Part D, Subpart 1, Tables 1A and 1B, except S_{mc} shall not exceed 90% of the material's yield strength at temperature, shown in Section II, Part D, Table Y-1.

The allowable stress S to be used in the equations of NE-3300 shall be 1.1 times those listed in Section II, Part D, Subpart 1, Tables 1A and 1B for the materials permitted in Table NE-2121(a)-1, except S shall not exceed 90% of the material's yield strength at temperature, shown in Section II, Part D, Table Y-1. The material shall not be used at metal and design temperatures above those for which stress intensity values are listed. The values in the Tables may be interpolated for intermediate temperatures.

NE-3113 Service Limits

Each Service Loading to which the component may be subjected shall be categorized in accordance with the following definitions and shall be described in the Design Specifications (NCA-3250) in such detail as will provide a complete basis for construction in accordance with these rules. The Service Limit categories shall be as defined in the next four subparagraphs.

NE-3113.1 Level A Service Limits.

Level A Service Limits apply to all sustained loads in combination with the plant or system design basis accident loads for which the containment function is required. Other loads, either separately or in combination with the above loads, may also be considered under this service limit.

NE-3113.2 Level B Service Limits.

This service limit applies to those applicable loads subject to Level A Service Limits in combination with loads due to natural phenomena for which the plant must remain operational. Other loads, either separately or in combination with the above loads, may also be considered under this service limit.

NE-3113.3 Level C Service Limits.

This service limit applies to those applicable loads subject to Level A and B Service Limits in combination with loads due to natural phenomena for which safe shutdown of the plant is required. Other loads, either separately or in combination with the above loads, may also be considered under this service limit.

NE-3113.4 Level D Service Limits.

This service limit applies to those loads subject to other service limits in combination with loadings of a local dynamic nature, such as jet impingement, pipe whip, and pipe reaction loads resulting from a postulated pipe rupture, for which the containment function is required.

NE-3113.5 Service Limits.

The Service Limits for design by analysis are specified in NE-3200. The Service Limits for design by formula are specified in NE-3300.

NE-3114 Testing Conditions

Testing conditions are those tests in addition to the ten hydrostatic or pneumatic tests permitted by NE-6222 and NE-6322, including leak tests or subsequent hydrostatic or pneumatic tests.

NE-3120 SPECIAL CONSIDERATIONS

NE-3121 Corrosion

Material subject to thinning by corrosion, erosion, mechanical abrasion, or other environmental effects shall have provision made in the Design Specifications for these effects by indicating the increase in the thickness of the base metal over that determined by the design formulas (NE-2160). Material added or included for these purposes need not be of the same thickness for all areas of the component if different rates of attack are indicated for the various areas. It should be noted that the tests on which the design fatigue curves (Figs. I-9.0) are based did not include tests in the presence of corrosive environments which might accelerate fatigue failure.

NE-3122 Cladding

The rules of this paragraph apply to the design and analysis of clad components constructed of material permitted under this Subsection. When corrosion or erosion of the cladding material is expected, the cladding thickness shall be increased by an amount that in the judgment of the Owner will provide the desired service life.

NE-3122.1 Primary Stresses.

When stress analysis is required, no structural strength shall be attributed to the cladding in satisfying NE-3221.

NE-3122.2 Design Dimensions.

The dimensions given in (a) and (b) below shall be used in the design of the component.

(a) For components subjected to internal pressure, the inside diameter shall be taken at the nominal inner face of the cladding.

(b) For components subjected to external pressure, the outside diameter shall be taken at the outer face of the base metal.

NE-3122.3 Bearing Stresses.

In satisfying NE-3227.1, the presence of cladding shall be included.

NE-3122.4 Maximum Allowable Stress Values

(a) *Integrally Clad Plate Without Credit for Full Cladding Thickness.* Except as permitted in NE-3122.4(b) below, design calculations shall be based on the total thickness of the clad plates less the specified nominal minimum thickness of cladding. A reasonable excess thickness either of the actual cladding or of the same thickness of corrosion resistant weld metal may be included in the design calculations as an equal thickness of base plate. The maximum allowable stress value shall be 1.1 times that given for the base plate

Page 57

material in Section II, Part D, Subpart 1, Tables 1A and 1B.

(b) *Integrally Clad Plate With Credit for Cladding Thickness.* When clad plate conforms to one of the specifications listed in NE-2127(a) and the joints are completed by depositing corrosion resisting weld metal over the weld in the base plate to restore the cladding, the design calculations may be based on a thickness equal to the nominal thickness of the base plate plus S_c/S_b times the nominal thickness of the cladding after any allowance provided for corrosion has been deducted, where

S_c = maximum allowable stress value for the cladding at the Design Temperature, psi

S_b = maximum allowable stress value for the base plate at the Design Temperature, psi

When S_c is greater than S_b , the multiplier S_c/S_b shall be taken equal to unity. The maximum allowable stress value shall be 1.1 times that given for the base plate material in Section II, Part D, Subpart 1, Tables 1A and 1B.

NE-3122.5 Maximum Allowable Temperature

(a) When the design calculations are based on the thickness of base plate exclusive of cladding thickness, the maximum service metal temperature of the vessel shall be that allowed for the base plate material.

(b) When the design calculations are based on the full thickness of clad plate as permitted in NE-3122.4(b), the maximum service metal temperature shall be the lower of the values allowed for the base plate material and the cladding material.

NE-3123 Welds Between Dissimilar Metals

In satisfying the requirements of this Subarticle, caution should be exercised in design and construction involving dissimilar metals having different coefficients of thermal expansion.

NE-3125 Configuration

Accessibility to permit the examinations required by the Edition and Addenda of Section XI as specified in the Design Specification for the component shall be provided in the design of the component.

NE-3130 GENERAL DESIGN RULES

NE-3131 General Requirements

(a) The containment vessel design shall be such that the rules of NE-3200 are satisfied. However, in the absence of substantial¹ mechanical or thermal loads other than pressure, the rules of NE-3300 may be used in lieu of the rules of NE-3200 for those configurations which are explicitly treated in NE-3300.

(b) For vessels, or portions thereof, designed to the rules of NE-3200, the provisions of NE-3133 may be used, if applicable, in lieu of the rules of NE-3222. For those portions designed to the rules of NE-3300, the requirements of NE-3133 shall be met.

NE-3132 Dimensional Standards for Standard Products

Dimensions of standard products shall comply with the standards and specifications listed in Table NE-3132-1 when the standard or specification is referenced in the specific design Subarticle. However, compliance with these standards does not replace or eliminate the requirements for stress analysis when called for by the design Subarticle for a specific component.

NE-3133 Components Under External Loading

NE-3133.1 General.

Rules are given in this paragraph for determining the thickness under external pressure loading in spherical shells, cylindrical shells with or without stiffening rings, and tubular products consisting of pipes, tubes, and fittings. Charts for determining the stresses in shells, hemispherical heads, and tubular products are given in Section II, Part D, Subpart 3.

1 For the purpose of this provision, substantial loads are defined as those which cumulatively result in stresses which exceed 10% of the primary stresses induced by the Design Pressure, such stresses being defined as maximum principal stresses.

NE-3133.2 Nomenclature.

The symbols used in this paragraph are defined as follows:

A	= factor determined from Fig. VII-1100-1 in Section II, Part D, Subpart 3 and used to enter the applicable material chart in Section II, Part D, Subpart 3. For the case of cylinders having D_o/T values less than 10, see NE-3133.3(b). Also, factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a stiffening ring, corresponding to the factor B and the design metal temperature for the shell under consideration.
A_s	= cross-sectional area of a stiffening ring, sq in.
B	= factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a shell or stiffening ring at the design metal temperature, psi

D_o	= outside diameter of the cylindrical shell course or tube under consideration, in.
E	= modulus of elasticity of material at Design Temperature, psi. For external pressure and axial compression design in accordance with this section, the modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 3. (Interpolation may be made between lines for intermediate temperatures.) The modulus of elasticity values shown in Section II, Part D, Subpart 3 for material groups may differ from those values listed in Section II, Part D, Subpart 2, Table TM for specific materials. Section II, Part D, Subpart 3 values shall be applied only to external pressure and axial compression design.
I	= available moment of inertia of the stiffening ring about its neutral axis, parallel to the axis of the shell, in. ⁴
I'	= available moment of inertia of the combined ring-shell cross section about its neutral axis, parallel to the shell, in. ⁴ The width of the shell which is taken as contributing to the combined moment of inertia shall not be greater than $1.10 \sqrt{D_o} \bar{T}_n$ and shall be taken as lying one-half on each side of the centroid of the ring. Portions of shell plates shall not be considered as contributing area to more than one stiffening ring.
I_s	= required moment of inertia of the stiffening ring about its neutral axis parallel to the axis of the shell, in. ⁴
I'_s	= required moment of inertia of the combined

	ring-shell section about its neutral axis parallel to the axis of the shell, in. ⁴
L	= total length of a tube between tubesheets, or the design length of a vessel section, taken as the largest of the following: (1) the distance between head tangent lines plus one-third of the depth of each head if there are no stiffening rings (2) the greatest center-to-center distance between any two adjacent stiffening rings, or (3) the distance from the center of the first stiffening ring to the head tangent line plus one-third of the depth of the head, all measured parallel to the axis of the vessel, in.
L_s	= one-half of the distance from the center line of the stiffening ring to the next line of support on one side, plus one-half of the center line distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the component, in. A line of support is: (1) a stiffening ring that meets the requirements of this paragraph

(2) a circumferential line on a head at one-third the depth of the head from the head tangent line, or

(3) a circumferential connection to a jacket for a jacketed section of a cylindrical shell

P	= external design pressure, psi (gage or absolute, as required)
P_a	= allowable external pressure, psi (gage or absolute, as required)
R	= inside radius of spherical shell, in.
S	= the lesser of 2 times the allowable stress at design metal temperature from Section II, Part D, Subpart 1, Tables 1A and 1B or 0.9 times the tabulated yield strength at design metal temperature from Section II, Part D, Subpart 2, Table Y-1, psi
T	= minimum required thickness of cylindrical shell or tube, or spherical shell, in.
T_n	= nominal thickness used, less corrosion allowance, of a cylindrical shell or tube, in.

TABLE NE-3132-1
DIMENSIONAL STANDARDS

Standard	Designation
Pipe and Tubes	
Welded and Seamless Wrought Steel Pipe.....	ANSI B36.10M-1985
Stainless Steel Pipe	ANSI B36.19M-1985
Fittings, Flanges, and Gaskets	
Steel Pipe Flanges and Flanged Fittings	ANSI B16.5-1988
Factory Made Wrought Steel Butt welding Fittings	ANSI B16.9-1986 [Note (1)]
Forged Steel Fittings, Socket-Welding and Threaded	ANSI B16.11-1980
Ring-Joint Gaskets and Grooves for Steel Pipe Flanges	ANSI B16.20-1973
Nonmetallic Gaskets for Pipe Flanges	ANSI B16.21-1978
Butt welding Ends	ANSI B16.25-1986
Wrought Steel Butt welding Short Radius Elbows and Returns	ANSI B16.28-1986 [Note (2)]
Refrigeration Flare Type Fittings	SAE J513-F-1981
Stainless Steel Butt welding Fittings.....	MSS SP-43-1982 (R 1986)
Steel Pipeline Flanges.....	MSS SP-44-1985
Large Diameter Carbon Steel Flanges.....	API 605-1980
Standard for Steel Pipe Flanges.....	AWWA C207-1978
Bolting	
Square and Hex Bolts and Screws, Including Askew Head Bolts, Hex Cap Screws, and Lag Screws	ANSI B18.2.1-1982
Square and Hex Nuts	ANSI B18.2.2-1987
Socket Cap, Shoulder, and Set Screws.....	ANSI B18.3-1986
Threads	
Unified Inch Screw Threads (UN and UNR Thread Form).....	ANSI B1.1-1981
Pipe Threads (Except Dryseal).....	ANSI B1.20.1-1983
Dryseal Pipe Threads	ANSI B1.20.3-1976 (R 1982)
Valves	
Valves-Flanged and Butt welding End.....	ANSI B16.34-1988

NOTES:

- (1) Analysis per ANSI B16.9, para. 2.2, is acceptable only for caps and reducers.
(2) Analysis per ANSI B16.28, para. 2.2, is not acceptable.

TABLE NE-3132-1 DIMENSIONAL STANDARDS

NE-3133.3 Cylindrical Shells.

The thickness of a cylindrical shell under external pressure shall be determined by the procedure given in (a) or (b) below.

(a) Cylinders having D_o/T values ≥ 10 :

Step 1: Assume a value for T and determine the ratios L/D_o and D_o/T .

Step 2: Enter Section II, Part D, Subpart 3, Fig. G at the value of L/D_o determined in Step 1. For values of L/D_o greater than 50, enter the chart at a value of $L/D_o = 50$. For values of L/D_o less than 0.05, enter the chart at a value of L/D_o of 0.05.

Step 3: Move horizontally to the line for the value of D_o/T determined in Step 1. Interpolation may be made for intermediate values of D_o/T . From this point of intersection, move vertically downward to determine the value of factor A .

Step 4: Using the value of A calculated in Step 3, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 7.

Step 5: From the intersection obtained in Step 4, move horizontally to the right and read the value of B .

Step 6: Using this value of B , calculate the value of the maximum allowable external pressure P_a using the following formula:

$$P_a = \frac{4B}{3(D_o/T)}$$

Step 7: For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated by using the following formula:

$$P_a = \frac{2AE}{3(D_o/T)}$$

Step 8: Compare P_a with P . If P_a is smaller than P , select a larger value for T and repeat the design procedure until a value of P_a is obtained that is equal to or greater than P .

(b) Cylinders having D_o/T values <10:

Step 1: Using the same procedure as given in (a) above, obtain the value of B . For values of D_o/T less than 4, the value of A can be calculated using the following formula:

$$A = \frac{1.1}{(D_o/T)^2}$$

For values of A greater than 0.10, use a value of 0.10.

Step 2: Using the value of B obtained in Step 1, calculate a value P_{a1} using the following formula:

$$P_{a1} = \left[\frac{2.167}{(D_o/T)} - 0.0833 \right] B$$

Step 3: Calculate a value P_{a2} using the following formula:

$$P_{a2} = \frac{2S}{D_o/T} \left[1 - \frac{1}{D_o/T} \right]$$

Step 4: The smaller of the values of P_{a1} calculated in Step 2, or P_{a2} calculated in Step 3, shall be used for the maximum allowable external pressure P_a . Compare P_a with P . If P_a is smaller than P , select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P .

NE-3133.4 Spherical Shells and Formed Heads

(a) *Spherical Shells*. The minimum required thickness of a spherical shell under external pressure, either seamless or of built-up construction with butt joints, shall be determined by the procedure given in Steps 1 through 6.

Step 1: Assume a value for T and calculate the value of factor A using the following formula:

$$A = \frac{0.125}{(R/T)}$$

Step 2: Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values at A falling to the left of the material/temperature line, see Step 5.

Step 3: From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B .

Step 4: Using the value of B obtained in Step 3, calculate the value of the maximum allowable external pressure P_a using the following formula:

$$P_a = \frac{B}{(R/T)}$$

Step 5: For values of A falling to the left of the applicable material/temperature line for the Design Temperature, the value of P_a can be calculated using the following formula:

$$P_a = \frac{0.0625E}{(R/T)^2}$$

Step 6: Compare P_a obtained in Steps 4 or 5 with P . If P_a is smaller than P , select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P .

(b) The nomenclature defined below is used in the formulas of (c) through (e) below.

D_o	= outside diameter of the head skirt or the outside diameter of a cone head at the point under consideration, measured perpendicular to the longitudinal axis of the cone, in.
K_1	= a factor depending on the ellipsoidal head proportions, given in Table NE-3332.2-1
R	= for hemispherical heads, the inside radius in the corroded condition, in. = for ellipsoidal heads, the equivalent inside spherical radius taken as $K_1 D_o$ in the corroded condition, in. = for torispherical heads, the inside radius of the crown portion of the head in the corroded condition, in.
T	= minimum required thickness of head after forming, exclusive of corrosion allowance, in.

(c) *Hemispherical Heads.* The required thickness of a hemispherical head having pressure on the convex side shall be determined in the same manner as outlined in (a) above for determining the thickness for a spherical shell.

(d) *Ellipsoidal Heads.* The required thickness of an ellipsoidal head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the following procedure:

Page 61

Step 1: Assume a value for T and calculate the value of factor A using the following formula:

$$A = \frac{0.125}{(R/T)}$$

Step 2: Using the value of A calculated in Step 1, follow the same procedure as that given for spherical shells in (a) above, Steps 2 to 6.

(e) *Torispherical Heads*. The required thickness of a torispherical head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the same design procedure as is used for ellipsoidal heads given in (d) above, using the appropriate value for R .

NE-3133.5 Stiffening Rings for Cylindrical Shells

(a) The required moment of inertia of a circumferential stiffening ring shall not be less than that determined by one of the following two formulas:

$$I_s = \frac{D_o^2 L_s \left(T + \frac{A_s}{L_s} \right) A}{14}$$

$$I'_s = \frac{D_o^2 L_s \left(T + \frac{A_s}{L_s} \right) A}{10.9}$$

If the stiffeners should be so located that the maximum permissible effective shell sections overlap on either or both sides of a stiffener, the effective shell section for the stiffener shall be shortened by one-half of each overlap.

(b) The available moment of inertia I or I' for a stiffening ring shall be determined by the following procedure.

Step 1: Assuming that the shell has been designed and $D_o L_s$ and T_n are known, select a member to be used for the stiffening ring and determine its cross-sectional area A_s . Then calculate factor B using the following formula:

$$B = 3/4 \left(\frac{PD_o}{T_n + A_s/L_s} \right)$$

Step 2: Enter the right side of the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening ring, use the material chart resulting in the larger value of A in Step 4 or 5 below.

Step 3: Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5.

Step 4: Move vertically to the bottom of the chart and read the value of A .

Step 5: For values of B falling below the left end of the material/temperature line for the Design Temperature, the value of A can be calculated using the formula:

$$A = \frac{2B}{E}$$

Step 6: Compute the value of the required moment of inertia from the formulas for I_s or I'_s above.

Step 7: Calculate the available moment of inertia I or I' of the stiffening ring using the section corresponding to that used in Step 6.

Step 8: If the required moment of inertia is greater than the moment of inertia for the section selected in Step 1, a new

section with a larger moment of inertia must be selected and a new moment of inertia determined. If the required moment of inertia is smaller than the moment of inertia for the section selected in Step 1, that section should be satisfactory.

(c) For fabrication and installation requirements for stiffening rings, see NE-4437.

NE-3133.6 Cylinders Under Axial Compression.

The maximum allowable compressive stress to be used in the design of cylindrical shells and tubular products subjected to loadings that produce longitudinal compressive stresses in the shell shall be the smaller of the following values:

(a) 1.1 times the S_m value for the applicable material at Design Temperature given in Section II, Part D, Subpart 1, Tables 1A and 1B.

(b) the value of B determined from the applicable chart in Section II, Part D, Subpart 3, using the following definitions for the symbols on the charts:

T = minimum required thickness of the shell or tubular product, exclusive of the corrosion allowance, in.

R = the inside radius of the cylindrical shell or tubular product, in.

Page 62

The value of B shall be determined from the applicable chart contained in Section II, Part D, Subpart 3 as given in Steps 1 through 5.

Step 1: Using the selected values of T and R , calculate the value of factor A using the following formula:

$$A = \frac{0.125}{(R/T)}$$

Step 2: Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the

falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 4.

Step 3: From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B . This is the maximum allowable compressive stress for the values of T and R used in Step 1.

Step 4: For values of A falling to the left of the applicable material/temperature line, the value of B shall be calculated using the following formula:

$$B = \frac{AE}{2}$$

Step 5: Compare the value of B determined in Steps 3 or 4 with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of T and R . If the value of B is smaller than the computed compressive stress, a greater value of T must be selected and the design procedure repeated until a value of B is obtained which is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

NE-3133.7 Conical Heads.

The required thickness of a conical head under pressure on the convex side shall not be less than that determined by (a), (b), and (c) below.

(a) When one-half of the included apex angle of the cone is equal to or less than $22\frac{1}{2}$ deg, the thickness of the cone shall be the same as the required thickness of a cylindrical shell, the length of which equals the axial length of the cone or the axial distance center-to-center of stiffening rings, if used, and the outside diameter of which is equal to the outside diameter at the large end of the cone or section between stiffening rings.

(b) When one-half of the included apex angle of the cone is greater than $22\frac{1}{2}$ deg and not more than 60 deg, the thickness of the cone shall be the same as the required thickness of a cylindrical shell, the outside diameter of which equals the largest inside diameter of the cone measured perpendicular to the cone axis, and the length of which equals an axial length that is the lesser of either the distance center-to-center of stiffening rings, if used, or the largest inside diameter of the section of the cone considered.

(c) When one-half of the included apex angle of the cone is greater than 60 deg, the thickness of the cone shall be the same as the required thickness for a flat head under external pressure, the diameter of which equals the largest inside diameter of the cone (NE-3325).

NE-3134 Material Properties

Values for intermediate temperatures may be found by interpolation.

NE-3134.1 Yield Strength Values.

The values of yield strength S_y shall be those given in Section II, Part D, Subpart 2, Table Y-1.

NE-3134.2 Ultimate Tensile Strength Values.

The values of ultimate tensile strength shall be those given in Section II, Part D, Subpart 2, Table TCD.

NE-3134.3 Coefficients of Thermal Conductivity and Thermal Diffusivity.

The values shall be those given in Section II, Part D, Subpart 2, Table TCD.

NE-3134.4 Coefficients of Thermal Expansion.

The values of thermal expansion coefficients shall be those given in Section II, Part D, Subpart 2, Table TE.

NE-3134.5 Modulus of Elasticity Values.

The values of modulus of elasticity shall be those given in Section II, Part D, Subpart 2, Table TM.

NE-3134.6 Allowable Stress Intensity and Stress Values.

The allowable stress intensity S_{m1} shall be the S_m listed in Section II, Part D, Subpart 1, Tables 2A and 2B, and the allowable stress intensity S_{mc} shall be 1.1 times the S_m listed in Section II, Part D, Subpart 1, Tables 1A and 1B. The basis for establishing allowable

Page 63

stress intensity and stress values is given in Appendix III.

NE-3135 Attachments

(a) Except as in (c) and (d) below, attachments and connecting welds within the jurisdictional boundary of the containment vessel as defined in NE-1130 shall meet the stress limits of NE-3200 or NE-3300.

(b) The design of the containment vessel shall include consideration of the interaction effects and loads transmitted through the attachment to and from the pressure retaining portion of the vessel. Thermal stresses, stress concentrations, and restraint of the pressure retaining portion of the vessel shall be considered.

(c) Beyond $2t$ from the pressure retaining portion of the containment vessel, where t is the nominal thickness of the pressure retaining material, the appropriate design rules of NF-3000 may be used as a substitute for the design rules of NE-3000 for portions of attachments which are in the vessel support load path.

(d) Nonstructural attachments shall meet the requirements of NE-4435.

NE-3200 DESIGN BY ANALYSIS

NE-3210 DESIGN CRITERIA

NE-3211 General Requirements for Acceptability

The requirements for the acceptability of a design by analysis are given in (a) and (b) below.

(a) The design shall be such that stress intensities do not exceed the applicable limits at temperature described in this Subarticle.

(b) In addition to the requirement in (a) above, the buckling stress shall be considered in accordance with NE-3222.

NE-3212 Basis for Determining Stresses

The theory of failure used in the rules of this Subsection for combining stresses is the maximum shear stress theory. The maximum shear stress at a point is equal to one-half the difference between the algebraically largest and the algebraically smallest of the three principal stresses at the point.

NE-3213 Terms Relating to Stress Analysis

Terms used in this Subsection relating to stress analysis are defined in the following subparagraphs.

NE-3213.1 Stress Intensity.²

Stress intensity is the equivalent intensity of combined stress, or, in short, the stress intensity is defined as twice the maximum shear stress. In other words, the stress intensity is the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tensile stresses are considered positive and compressive stresses are considered negative.

NE-3213.2 Gross Structural Discontinuity.

Gross structural discontinuity is a geometric or material discontinuity which affects the stress or strain distribution through the entire wall thickness of the pressure retaining member. Gross discontinuity type stresses are those portions of the actual stress distributions that produce net bending and membrane force resultants when integrated through the wall thickness. Examples of gross structural discontinuities are head-to-shell and flange-to-shell junctions, nozzles, and junctions between shells of different diameters or thicknesses.

NE-3213.3 Local Structural Discontinuity.

Local structural discontinuity is a geometric or material discontinuity which affects the stress or strain distribution through a fractional part of the wall thickness. The stress distribution associated with a local discontinuity causes only very localized types of deformation or strain and has no significant effect on the shell-type discontinuity deformations. Examples are small fillet radii, small attachments, and partial penetration welds.

NE-3213.4 Normal Stress.

Normal stress is the component of stress normal to the plane of reference. This is also referred to as direct stress. Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to be made up in turn of two components, one of which is uniformly distributed and equal to the average value of stress across the thickness under consideration, and the other of which varies from this average value with the location across the thickness.

NE-3213.5 Shear Stress.

Shear stress is the component of stress tangent to the plane of reference.

NE-3213.6 Membrane Stress.

Membrane stress is the component of normal stress which is uniformly distributed and equal to the average of stress across the thickness of the section under consideration.

² This definition of stress intensity is not related to the definition of stress intensity applied in the field of Fracture Mechanics.

NE-3213.7 Bending Stress.

Bending stress is the variable component of normal stress described in NE-3213.4.

The variation may or may not be linear across the thickness.

NE-3213.8 Primary Stress.

Primary stress is any normal stress or a shear stress developed by an imposed loading which is necessary to satisfy the laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses which considerably exceed the yield strength will result in failure or, at least, in gross distortion. A thermal stress is not classified as a primary stress. Primary membrane stress is divided into general and local categories. A general primary membrane stress is one which is so distributed in the structure that no redistribution of load occurs as a result of yielding. Examples of primary stresses are:

- (a) general membrane stress in a circular, cylindrical, or a spherical shell due to internal pressure or to distributed live loads;
- (b) bending stress in the central portion of a flat head due to pressure.

NE-3213.9 Secondary Stress.

Secondary stress is a normal stress or a shear stress developed by the constraint of adjacent material or by self-constraint of the structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions which cause the stress to occur, and failure from one application of the stress is not to be expected. Examples of secondary stresses are:

- (a) general thermal stresses [NE-3213.13(a)];
- (b) bending stress at a gross structural discontinuity.

[98]

NE-3213.10 Local Primary Membrane Stress.

Cases arise in which a membrane stress produced by pressure or other mechanical loading and associated with a discontinuity would, if not limited, produce excessive distortion in the transfer of load to other portions of the structure. Conservatism requires that such a stress be classified as a local primary membrane stress even though it has some characteristics of a secondary stress. A stressed region may be considered local if the distance over which the membrane stress intensity exceeds $1.1S_{mc}$ does not extend in the meridional direction more than $1.0\sqrt{Rt}$, where R is the minimum midsurface radius of curvature and t is the minimum thickness in the region considered. Regions of local primary stress intensity involving axisymmetric membrane stress distributions which exceed $1.1S_{mc}$ shall not be closer in the meridional direction than $2.5\sqrt{Rt}$, where R is defined as $(R_1 + R_2)/2$ and t is defined as $(t_1 + t_2)/2$, where t_1 and t_2 are the minimum thicknesses at each of the regions considered, and R_1 and R_2 are the minimum midsurface radii of curvature at these regions where the membrane stress intensity exceeds $1.1S_{mc}$. Discrete regions of local primary membrane stress intensity, such as those resulting from concentrated loads acting on brackets, where the membrane stress intensity exceeds $1.1S_{mc}$ shall be spaced so that there is no overlapping of the areas in which the membrane stress intensity exceeds $1.1S_{mc}$.

[98]

NE-3213.11 Peak Stress.

Peak stress is that increment of stress which is additive to the primary plus secondary stresses by reason of local discontinuities or local thermal stress [NE-3213.13(b)] including the effects, if any, of stress concentrations. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture. A stress which is not highly localized falls into this category if it is of a type which cannot cause noticeable distortion. Examples of peak stresses are:

- (a) the thermal stress in the austenitic steel cladding of a carbon steel component;
- (b) certain thermal stresses which may cause fatigue, but not distortion;
- (c) the stress at a local structural discontinuity;
- (d) surface stresses produced by thermal shock.

NE-3213.12 Load Stress.

Load stress is the stress resulting from the application of a load, such as internal pressure or the effects of gravity, as distinguished from thermal stress.

NE-3213.13 Thermal Stress.

Thermal stress is a self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally should under a change in temperature. For the purpose of establishing allowable stresses, two types of thermal stress are recognized, depending on the volume or area in which distortion takes place, as described in (a) and (b) below.

(a) General thermal stress is associated with distortion of the structure in which it occurs. If a stress of this type, neglecting stress concentrations, exceeds twice the yield strength of the material, the elastic analysis may be invalid, and successive thermal cycles may produce incremental distortion. Therefore, this type is classified as secondary stress in Table NE-3217-1. Examples of general thermal stresses are:

(1) stress produced by an axial temperature distribution in a cylindrical shell;

Page 65

(2) stress produced by the temperature difference between a nozzle and the shell to which it is attached;

(3) the equivalent linear stress³ produced by the radial temperature distribution in a cylindrical shell.

(b) Local thermal stress is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses shall be considered only from the fatigue standpoint and are therefore classified as local stresses in Table NE-3217-1. In evaluating local thermal stresses, the procedures of NE-3228.1(c) shall be used. Examples of local thermal stresses are:

(1) the stress in a small hot spot in a vessel wall;

(2) the difference between the actual stress and the equivalent linear stress resulting from a radial temperature distribution in a cylindrical shell;

(3) the thermal stress in a cladding material which has a coefficient of expansion different from that of the base metal.

NE-3213.14 Total Stress.

Total stress is the sum of the primary, secondary, and peak stress contributions. Recognition of each of the individual contributions is essential to establishment of appropriate stress limitations.

NE-3213.15 Service Cycle.

Service cycle is defined as the initiation and establishment of new conditions followed by a return to the conditions which prevailed at the beginning of the cycle. The types of service conditions which may occur in a containment vessel are further illustrated in NE-3113.

NE-3213.16 Stress Cycle.

Stress cycle is a condition in which the alternating stress difference (NE-3221.5) goes from an initial value through an algebraic maximum value and an algebraic minimum value and then returns to the initial value. A single operational cycle may result in one or more stress cycles. Dynamic effects shall also be considered as stress cycles.

NE-3213.17 Fatigue Strength Reduction Factor.

Fatigue strength reduction factor is a stress intensification factor which accounts for the effect of a local structural discontinuity (stress concentration) on the fatigue strength. Values for some specific cases, based on experiment, are given in NE-3338. In the absence of experimental data, the theoretical stress concentration factor may be used.

³ Equivalent linear stress is defined as the linear stress distribution which has the same net bending moment as the actual stress distribution.

NE-3213.18 Shakedown.

Shakedown is the absence of a continuing cycle of plastic deformation. A structure shakes down if, after a few cycles of load application, the deformation stabilizes and subsequent structural response is elastic, excluding creep effects.

NE-3213.19 Free End Displacement.

Free end displacement consists of the relative motions that would occur between a fixed attachment and connected piping if the two members were separated and permitted to move.

NE-3213.20 Expansion Stresses.

Expansion stresses are those stresses resulting from restraint of free end displacement of the piping system.

NE-3213.21 Limit Analysis - Collapse Load.

The methods of limit analysis are used to compute the maximum load or combination of loads a structure made of ideally plastic (nonstrain-hardening) material can carry. The deformations of an ideally plastic structure increase without bound at this load, which is termed the *collapse load*. Among the methods used in limit analysis is a technique which assumes elastic, perfectly plastic, material behavior and a constant level of moment or force in those redundant structural elements in which membrane yield, plastic hinge, or critical buckling load has been reached. Any increase in load must be accompanied by a stable primary structure until a failure mechanism defined by the lower bound theorem of limit analysis is reached in the primary structure.

NE-3213.22 Collapse Load - Lower Bound.

If, for a given load, any system of stresses can be found which everywhere satisfies equilibrium and nowhere exceeds the material yield strength, the load is at or below the collapse load. This is the lower bound theorem of limit analysis which permits calculations of a lower bound to the collapse load.

NE-3214 Stress Analysis

When required by NE-3130, a detailed stress analysis of all major structural components shall be prepared in sufficient detail to show that each of the stress limitations of NE-3220 and NE-3230 is satisfied when the vessel is subjected to the loadings of NE-3110. As an aid to the evaluation of these stresses, formulas and methods for the solution of certain recurring problems have been placed in Appendix A.

NE-3215 Derivation of Stress Intensities

One requirement for the acceptability of a design (NE-3210) is that the calculated stress intensities shall not exceed specified allowable limits. These limits differ

Page 66

depending on the stress category (primary, secondary, etc.) from which the stress intensity is derived. This paragraph describes the procedure for the calculation of the stress intensities which are subject to the specified limits. The steps in the procedure are stipulated in (a) through (e) below.

(a) At the point on the component which is being investigated, choose an orthogonal set of coordinates such as tangential, longitudinal, and radial, and designate them by the subscripts t , l , and r . The stress components in these directions are then designated σ_t , σ_l , and σ_r for direct stresses and τ_{lr} , $\tau_{lr'}$, and τ_{rt} for shear stresses.

(b) Calculate the stress components for each type of loading to which the part will be subjected and assign each set of stress values to one or a group of the following categories:⁴

- (1) general primary membrane stress P_m (NE-3213.8)
- (2) local primary membrane stress P_L (NE-3213.10)
- (3) primary bending stress P_b (NE-3213.7 and NE-3213.8)

(4) expansion stress P_e (NE-3213.20)

(c) For each category, calculate the algebraic sum of the values of σ_i which result from the different types of loadings and similarly for the other five stress components. Certain combinations of the categories must also be considered.

(d) Translate the stress components for the t , l , and r directions into principal stresses σ_1 , σ_2 , and σ_3 . In many pressure component calculations, the t , l , and r directions may be so chosen that the shear stress components are zero and σ_1 , σ_2 , and σ_3 are identical to σ_p , σ_l , and σ_r .

(e) Calculate the stress differences S_{12} , S_{23} , and S_{31} from the relations:

$$S_{12} = \sigma_1 - \sigma_2$$

$$S_{23} = \sigma_2 - \sigma_3$$

$$S_{31} = \sigma_3 - \sigma_1$$

The stress intensity S_m is the largest absolute value of S_{12} , S_{23} , and S_{31} .

NOTE: Membrane stress intensity is derived from the stress components averaged across the thickness of the section. The averaging shall be performed at the component level, in (b) or (c) above.

⁴ See Table NE-3217-1 and Note (1) of Fig. NE-3221-1.

NE-3216 Derivation of Stress Differences

If the specified operation of the component does not meet the conditions of NE-3221.5(d), the ability of the component to withstand the specified cyclic service without fatigue failure shall be determined as provided in NE-3221.5(e). The determination shall be made on the basis of the stresses at the point of the component, and the allowable stress cycles shall be adequate for the specified service at every point. Only the stress differences due to cyclic Service Loadings as specified in the Design Specifications need be considered.

NE-3216.1 Constant Principal Stress Direction.

For any case in which the directions of the principal stresses at the point being considered do not change during the cycle, the steps stipulated in (a), (b), and (c) below shall be taken to determine the alternating stress intensity.

(a) *Principal Stresses.* Consider the values of the three principal stresses at the point versus time for the complete stress cycle, taking into account both the gross and local structural discontinuities and the thermal effects which vary during the cycle. These are designated as σ_1 , σ_2 , and σ_3 for later identification.

(b) *Stress Differences.* Determine the stress differences $S_{12} = \sigma_1 - \sigma_2$, $S_{23} = \sigma_2 - \sigma_3$, $S_{31} = \sigma_3 - \sigma_1$ versus time for the complete cycle. In what follows, the symbol S_{ij} is used to represent any one of these three stress differences.

(c) *Alternating Stress Intensity.* Determine the extremes of the range through which each stress difference S_{ij} fluctuates and find the absolute magnitude of this range for each S_{ij} . Call this magnitude S_{rij} and let $S_{altij} = 0.5 S_{rij}$. The alternating stress intensity S_{alt} is the largest S_{altij} .

NE-3216.2 Varying Principal Stress Direction.

For any case in which the directions of the principal stresses at the point being considered do change during the stress cycle, it is necessary to use the more general procedure of (a) through (e) below.

(a) Consider the values of the six stress components σ_p , σ_l , σ_r , τ_{lp} , τ_{lr} , τ_{rl} versus time for the complete stress cycle, taking into account both the gross and local structural discontinuities and the thermal effects which vary during the cycle.

(b) Choose a point in time when the conditions are one of the extremes for the cycle (either maximum or minimum, algebraically) and identify the stress components at this time by the subscript i . In most cases it will be possible to choose at least one time during the cycle when the conditions are known to be extreme. In some cases it may be necessary to try different

points in time to find the one which results in the largest value of alternating stress intensity.

(c) Subtract each of the six stress components $\sigma_{1p}, \sigma_{2p}, \sigma_{3p}, \sigma_{4p}, \sigma_{5p}, \sigma_{6p}$ etc., from the corresponding stress components $\sigma_p, \sigma_p, \sigma_p$ etc., at each point in time during the cycle and call the resulting components $\sigma'_p, \sigma'_p, \sigma'_p$ etc.

(d) At each point in time during the cycle, calculate the principal stresses $\sigma'_1, \sigma'_2, \sigma'_3$ derived from the six stress components $\sigma_p, \sigma_p, \sigma_p$ etc. Note that the directions of the principal stresses may change during the cycle but each principal stress retains its identity as it rotates.

(e) Determine the stress differences $S_{12} = \sigma'_1 - \sigma'_2, S_{23} = \sigma'_2 - \sigma'_3, S_{31} = \sigma'_3 - \sigma'_1$ versus time for the complete cycle and find the largest absolute magnitude of any stress difference at any time. The alternating stress intensity S_{alt} is one-half of this magnitude.

NE-3217 Classification of Stresses

Table NE-3217-1 provides assistance in the determination of the category to which a stress should be assigned.

NE-3220 STRESS INTENSITY AND BUCKLING STRESS VALUES FOR OTHER THAN BOLTS

NE-3221 Stress Intensity Values

(a) The stress intensity values for materials of Class MC components are as established in NE-3134. The materials shall not be used at temperatures above those for which stress intensity values are given. The values in the tables may be interpolated for intermediate temperatures.

(b) The stress intensity limits which must be satisfied for the Design and Service Loadings stated in the Design Specifications are the limits of this paragraph and the Special Stress Limits of NE-3227. The provisions of NE-3228 may provide relief from certain of these stress limits if plastic analysis techniques are applied. The stress intensity limits are summarized in Table NE-3221-1 and Fig. NE-3221-1, Fig. NE-3221-2, Fig. NE-3221-3, and Fig. NE-3221-4.

NE-3221.1 General Primary Membrane Stress Intensity.

(Derived from P_m in Fig. NE-3221-1, Fig. NE-3221-2, Fig. NE-3221-3, and Fig. NE-3221-4.) This stress intensity is derived from the average value across the thickness of a section of the general primary stresses (NE-3213.8), produced by pressure and other specified mechanical loads but excluding all secondary and peak stresses. Averaging is to be applied to the stress components prior to determination of the stress intensity values. The allowable Design Limit and the allowable for each of the Service Limits is as given below.

(a) *Design Limit and Level A and B Service Limits.* P_m shall not exceed $1.0S_{mc}$.

(b) *Level C Service Limits*

(1) P_m shall not exceed the greater of $1.2S_{mc}$ or $1.0S_y$ for regions of the vessel which are integral and continuous.

(2) P_m shall not exceed $1.0S_{mc}$ for regions of the vessel which are not integral and continuous, such as bolted flanges and mechanical joints.

(c) *Level D Service Limits*

(1) P_m shall not exceed the greater of the following two values for regions of the containment which are integral and continuous.

(a) 85% of the value permitted in Appendix F. In the application of the rules of Appendix F, S_{m1} , if applicable, shall be as specified in Section II, Part D, Subpart 1, Tables 2A and 2B.

(b) The value established in NE-3221.1(b)(1) for Service Level C limits.

(2) P_m shall not exceed the greater of $1.2S_{mc}$ or $1.0S_y$ for regions of the vessel which are not integral and continuous and at partial penetration welds.

NE-3221.2 Local Membrane Stress Intensity.

(Derived from P_L in Fig. NE-3221-1, Fig. NE-3221-2, Fig. NE-3221-3, and Fig. NE-3221-4.) This stress intensity is derived from the average value across the thickness of a section of the local primary stresses (NE-3213.10) produced by pressure and specified mechanical loads, but excluding all secondary and peak stresses. Averaging is to be applied to the stress components prior to determination of the stress intensity values. The allowable value of this stress intensity is 1.5 times the values given in NE-3221.1, except that the 1.5 factor is not permitted for Level D Service Limits when inelastic component analysis is used as permitted in Appendix F.

NE-3221.3 Primary General or Local Membrane Plus Primary Bending Stress Intensity.

(Derived from $P_L + P_b$ in Fig. NE-3221-1, Fig. NE-3221-2, Fig. NE-3221-3, and Fig. NE-3221-4.) This stress intensity is derived from the highest value, across the thickness of a section, of the general or local primary membrane stress plus primary bending stresses produced by pressure and other loads but excluding all secondary and peak stresses. The allowable Design Limit and the allowable Service Limits are as given in (a) through (d) below.

Page 68

Page 70

Pages 69-69

TABLE NE-3217-1
CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES¹

Vessel Component	Location	Origin of Stress	Type of Stress	Classification
Cylindrical or spherical shell	Shell plate remote from discontinuities	Internal pressure	General membrane Gradient through plate thickness	P_m Q
		Axial thermal gradient	Membrane Bending	Q Q
	Junction with head or flange	Internal pressure	Membrane Bending	P_L Q [Note (2)]
Any shell or head	Any section across entire vessel	External load or moment, or internal pressure	General membrane averaged across full section	P_m
		External load or moment	Bending across full section	P_m
	Near nozzle or other opening	External load or moment, or internal pressure	Local membrane Bending Peak (fillet or corner)	P_L Q F
	Any location	Temperature difference between shell and head	Membrane Bending	Q Q
Dished head or conical head	Crown	Internal pressure	Membrane Bending	P_m P_b
	Knuckle or junction to shell	Internal pressure	Membrane Bending	P_L [Note (3)] Q
Flat head	Center region	Internal pressure	Membrane Bending	P_m P_b
	Junction to shell	Internal pressure	Membrane Bending	P_L Q [Note (2)]
Perforated head or shell	Typical ligament in a uniform pattern	Pressure	Membrane (through cross section) Bending (through width of ligament, but gradient through plate) Peak	P_m P_b F
	Isolated or atypical ligament	Pressure	Membrane Bending Peak	Q F F

(Table NE-3217-1 continues on next page)

TABLE NE-3217-1 (CONT'D)
CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES¹

Vessel Component	Location	Origin of Stress	Type of Stress	Classification
Nozzle (NE-3227.5)	Within the limits of reinforcement defined by NB-3334	Pressure and external loads and moments, including those attributable to restrained free end displacements of attached piping	General membrane Bending (other than gross structural discontinuity stresses) averaged through nozzle thickness	P_m P_m
		Pressure and external axial, shear, and torsional loads other than those attributable to restrained free end displacements of the attached piping	General membrane stresses	P_m
	Outside the limits of reinforcement defined by NE-3334	Pressure and external loads and moments other than those attributable to restrained free end displacements of the attached piping	Membrane Bending	P_L P_b
		Pressure, and all external loads and moments	Membrane Bending Peak	P_L Q F
	Nozzle wall	Gross structural discontinuities	Local membrane Bending Peak	P_L Q F
		Differential expansion	Membrane Bending Peak	Q Q F
Cladding	Any	Differential expansion	Membrane Bending	F F
Any	Any	Radial temperature distribution [Note (4)]	Equivalent linear stress [Note (5)]	Q
			Nonlinear portion of stress distribution	F
Any	Any	Any	Stress concentration (notch effect)	F

NOTES:

- (1) Q and F classifications of stresses refer to other than design condition (Fig. NE-3221-2).
- (2) If the bending moment at the edge is required to maintain the bending stress in the middle to within acceptable limits, the edge bending is classified as P_b . Otherwise, it is classified as Q .
- (3) Consideration must also be given to the possibility of wrinkling and excessive deformation in vessels with a large diameter-thickness ratio.
- (4) Consider possibility of thermal stress ratchet.
- (5) Equivalent linear stress is defined as the linear.

TABLE NE-3217-1 (CONT'D) CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES¹

TABLE NE-3221-1
SUMMARY OF STRESS INTENSITY LIMITS

Symbol	Design Stress Intensity Limit	Loading Condition				
		Level A Service Stress Intensity Limit	Level B Service Stress Intensity Limit and Level C Service Stress Limit Where the Structure Is Not Integral and Continuous	Level C Service Stress Intensity Limit Where the Structure Is Integral and Continuous, and Level D Service Stress Limit Where the Structure Is Not Integral and Continuous, and at Partial Penetration Welds [Note (1)]	Level D Service Stress Intensity Limit Where the Structure Is Integral and Continuous (Elastic Analysis) [Note (2)]	Level D Service Stress Intensity Limit Where the Structure is Integral and Continuous (Inelastic Analysis) [Note (2)]
P_m	$1.0 S_{mc}$	$1.0 S_{mc}$	$1.0 S_{mc}$	$1.2 S_{mc}$ or $* 1.0 S_y$	S_f	S_f
P_L	$1.5 S_{mc}$	$1.5 S_{mc}$	$1.5 S_{mc}$	$1.8 S_{mc}$ or $* 1.5 S_y$	$1.5 S_f$	S_f —
$P_L + P_b$ [Note(3)]	$1.5 S_{mc}$	$1.5 S_{mc}$	$1.5 S_{mc}$	$1.8 S_m$ or $* 1.5 S_y$	$1.5 S_f$	S_f
$P_L + P_b + Q$	N/A [Note(4)]	$3.0 S_{m1}$	$3.0 S_{m1}$ [Note (5)]	N/A [Note (4)]	N/A [Note (4)]	N/A [Note (4)]
$P_L + P_b + Q + F$	N/A [Note(4)]	S_a	S_a [Note (5)]	N/A [Note (4)]	N/A [Note (4)]	N/A [Note (4)]

NOTES:

- (1) Limits identified by (*) indicate a choice of the larger of two limits.
- (2) S_f is 85% of the general primary membrane allowable permitted in Appendix F. In the application of the rules of Appendix F, S_{m1} , if applicable, shall be as specified in Section II, Part D, Subpart 1, Tables 2A and 2B.
- (3) Values shown are for a solid rectangular section. See NE-3221.3(d) for other than a solid rectangular section.
- (4) N/A — No evaluation required.
- (5) Evaluation not required for Level C Service.

TABLE NE-3221-1 SUMMARY OF STRESS INTENSITY LIMITS

(a) *Design Limit and Level A and B Service Limits.* For solid rectangular sections, 1.5 times the value given in NE-3221.1.

(b) *Level C Service Limits*

(1) For solid rectangular sections where the structure is integral and continuous, 1.5 times the value given in NE-3221.1 for P_L less than or equal to $0.67 S_y$, and $(2.5 - 1.5 P_L / S_y)$ times the value given in NE-3221.1 for P_L greater than $0.67 S_y$. S_y is tabulated yield strength at temperature.

(2) For solid rectangular sections when the structure is not integral and continuous, 1.5 times the value given in NE-3221.1

(c) *Level D Service Limits*

(1) When elastic analysis is used for solid rectangular sections where the structure is integral and continuous, 1.5 times the value given in NE-3221.1.

(2) When elastic analysis is used for solid rectangular sections where the structure is not integral and continuous, 1.5 times the value given in NE-3221.1 for P_L less than or equal to $0.67 S_y$ and $(2.5 - 1.5 P_L / S_y)$ times the value given in NE-3221.1 for P_L greater than $0.67 S_y$.

(3) When inelastic component analysis is used, this Service Limit shall be 85% of the value permitted in Appendix F.

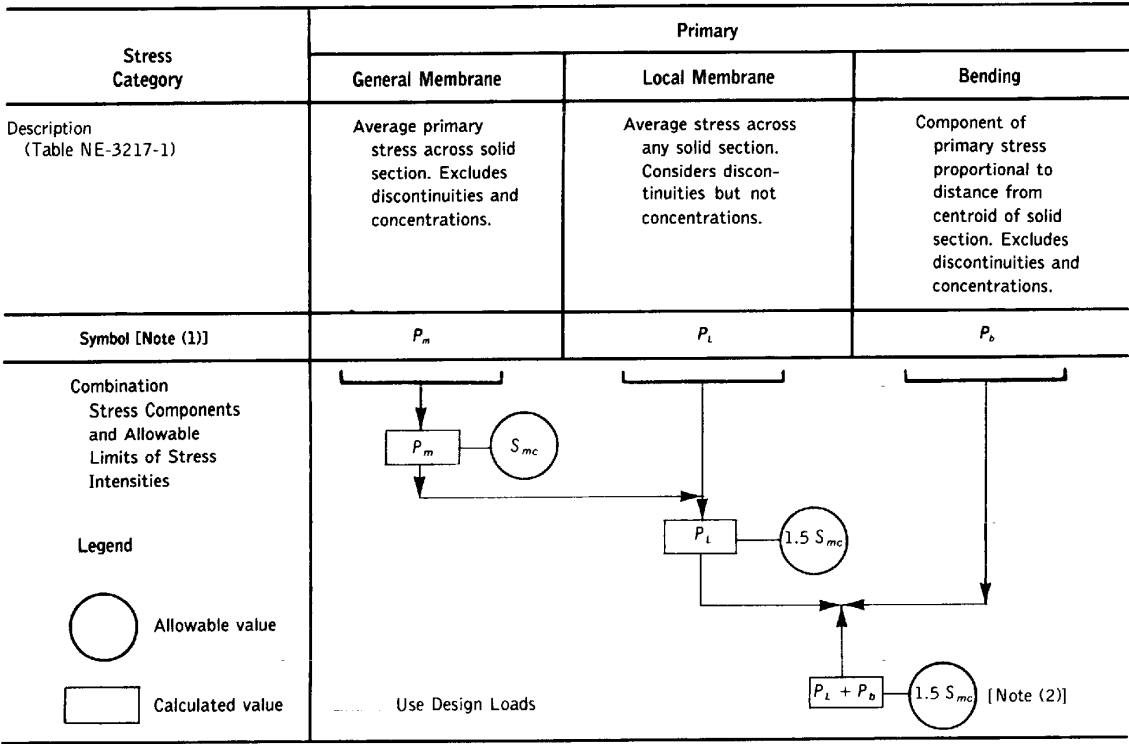
(d) For other than solid rectangular sections, a value of α times the limit established in NE-3221.1 may be used, where the factor α is defined as the ratio of the load set producing a fully plastic section divided by the load set producing initial yielding in the extreme fibers of the section. In the evaluation of the initial yield and fully plastic section capacities, the ratios of each individual load in the respective load set to each other load in that load set shall be the same

as the respective ratios of the individual loads in the specified design load set. The value of α shall not exceed the value calculated for bending only ($P_m = 0$). In no case shall the value of α exceed 1.5. The propensity for buckling of the part of the section that is in compression shall be investigated. The α factor is not permitted for Level D Service Limits when inelastic component analysis is used as permitted in Appendix F.

NE-3221.4 Primary Plus Secondary Stress Intensity.

This stress intensity is derived from the highest value, at any point across the thickness of a section, of the general or local primary membrane stresses, plus primary bending stresses plus secondary stresses, produced by the specified conditions. The allowable

value of the maximum range⁵ of this stress intensity is $3.0S_{m1}$ for Level A and B Service Limits. Secondary stresses need not be evaluated for Design Loadings or for Level C and D Service Limits.



- NOTES:
- (1) The symbols P_m , P_L , and P_b do not represent single quantities, but rather sets of six quantities representing the six stress components σ_x , σ_y , σ_z , τ_{xy} , τ_{yz} , and τ_{zx} .
- (2) Value shown is for a solid rectangular section. See NE-3221.3(d) for other than a solid rectangular section.

FIG. NE-3221-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR DESIGN CONDITIONS

FIG. NE-3221-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR DESIGN CONDITIONS

⁵ The concept of stress differences discussed in NE-3216 is essential to determination of the maximum range, since algebraic signs must be retained in the computation. Note that this limitation on range is applicable to the entire history of service conditions, not just to the stresses resulting from each individual service condition.

[98]

NE-3221.5 Analysis for Cyclic Operation

(a) *Suitability for Cyclic Condition.* The suitability of a vessel or part for specified Service Loadings involving cyclic application of loads and thermal conditions shall be determined by the methods described herein, except that the suitability of high strength bolts shall be determined by the methods of NE-3232.3(b) and the possibility of thermal stress ratchet shall be investigated in accordance with NE-3221.6. If the specified Service Loadings for the component meet all of the requirements of NE-3221.5(d), no analysis for cyclic service is required, and it may be assumed that the limits on peak stress intensities as governed by fatigue have been satisfied by compliance with the applicable requirements for materials, design, fabrication, examination, and testing of this Subsection. If the specified Service Loadings do not meet all the conditions of NE-3221.5(d), a fatigue analysis shall be made in accordance with NE-3221.5(e) or a fatigue test shall be made in accordance with Appendix II-1200.

(b) *Peak Stress Intensity.* This stress intensity is derived from the highest value at any point across the thickness of a section of the combination of all primary, secondary, and peak stresses produced by specified service pressures and other mechanical loads, and by

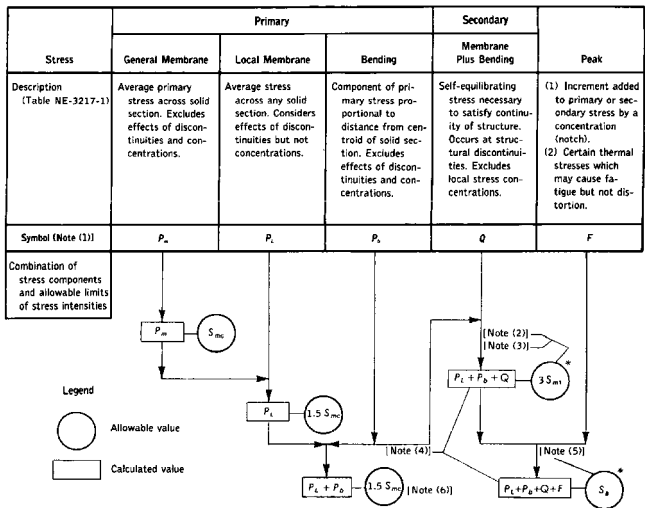
Page 72

Page 73

Page 74

Page 75

general and local thermal effects associated with Service Conditions, and including the effects of gross and local structural discontinuities.



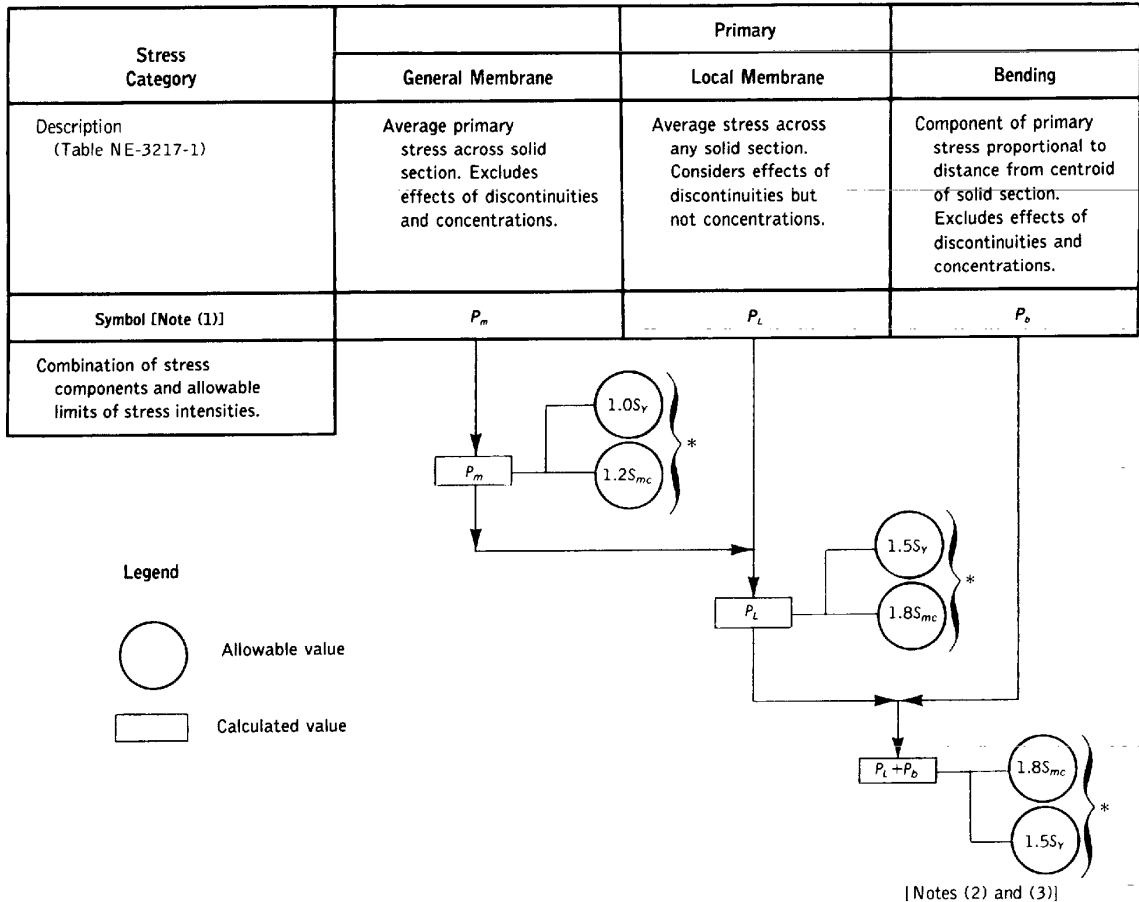
NOTES:

- (1) The symbols P_m , P_t , Q , and F do not represent single quantities, but sets of six quantities representing the six stress components σ_x , σ_y , σ_z , τ_{xy} , τ_{yz} , and τ_{zx} .
- (2) When the secondary stress is due to a temperature transient at the point at which the stresses are being analyzed, the value of S_m shall be taken as the average of the tabulated S_m values for the highest and the lowest temperatures of the metal during the transient. When part or all of the secondary stress is due to mechanical load, the value of S_m shall not exceed the value for the highest temperature of metal during the transient.
- (3) Special rules for exceeding $3 S_m$ are provided in NE-3228.3.
- (4) The stresses in category Q are those parts of the total stress that are produced by thermal gradients, structural discontinuities, and they do not include the primary stresses that may also exist at the same point. However, it should be noted that a detailed stress analysis frequently gives the combination of primary and secondary stresses directly and, when appropriate, the calculated value represents the total of $P_m + P_t + Q$ and not Q alone. Similarly, if the stress in category F is produced by a stress concentration, the quantity F is the additional stress produced by the notch over and above the nominal stress. For example, if a point has a nominal stress intensity P_m and has a notch with a stress concentration factor K , then $P_m \leq S_m$, $P_t = Q = F = P_m (K-1)$, and the peak stress intensity equals $P_m + P_t (K-1) = K P_m$. However, P_t is the total membrane stress that results from mechanical loads, including discontinuity effects, rather than a stress increment. Therefore, the P_t value always includes the P_m contribution.
- (5) S_t is obtained from the fatigue curves, Figs. 1-9-0. The allowable stress intensity for the full range of fluctuations is $2 S_t$.
- (6) Value shown is for a solid rectangular section. See NE-3221.3(d) for other than a solid rectangular section.

* Evaluation not required for level C Service limits.

FIG. NE-3221-2 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR LEVEL A AND B SERVICE LIMITS; AND FOR LEVEL C SERVICE LIMITS WHERE THE STRUCTURE IS NOT INTEGRAL AND CONTINUOUS

FIG. NE-3221-2 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR LEVEL A AND B SERVICE LIMITS; AND FOR LEVEL C SERVICE LIMITS WHERE THE STRUCTURE IS NOT INTEGRAL AND CONTINUOUS



NOTES:

- (1) The symbols P_m , P_L , and P_b do not represent single quantities, but sets of six quantities representing the six stress components σ_{xx} , σ_{yy} , τ_{xy} , τ_{yz} , τ_{zx} , τ_{xy} .
- (2) Values shown are for a solid rectangular section. See NE-3221.3(d) for other than a solid rectangular section.
- (3) Values shown are applicable when $P_L \leq 0.67S_y$. When $P_L > 0.67S_y$, use the larger of the two limits,

$$[2.5 - 1.5 (P_L / S_y)] 1.2S_{mc}$$

or

$$[2.5 - 1.5 (P_L / S_y)] S_y$$

*Use greater of values specified

FIG. NE-3221-3 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR LEVEL C SERVICE LIMITS WHERE THE STRUCTURE IS INTEGRAL AND CONTINUOUS; AND FOR LEVEL D SERVICE LIMITS WHERE THE STRUCTURE IS NOT INTEGRAL AND CONTINUOUS, AND AT PARTIAL PENETRATION WELDS

FIG. NE-3221-3 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR LEVEL C SERVICE LIMITS WHERE THE STRUCTURE IS INTEGRAL AND CONTINUOUS; AND FOR LEVEL D SERVICE LIMITS WHERE THE STRUCTURE IS NOT INTEGRAL AND CONTINUOUS, AND AT PARTIAL PENETRATION WELDS

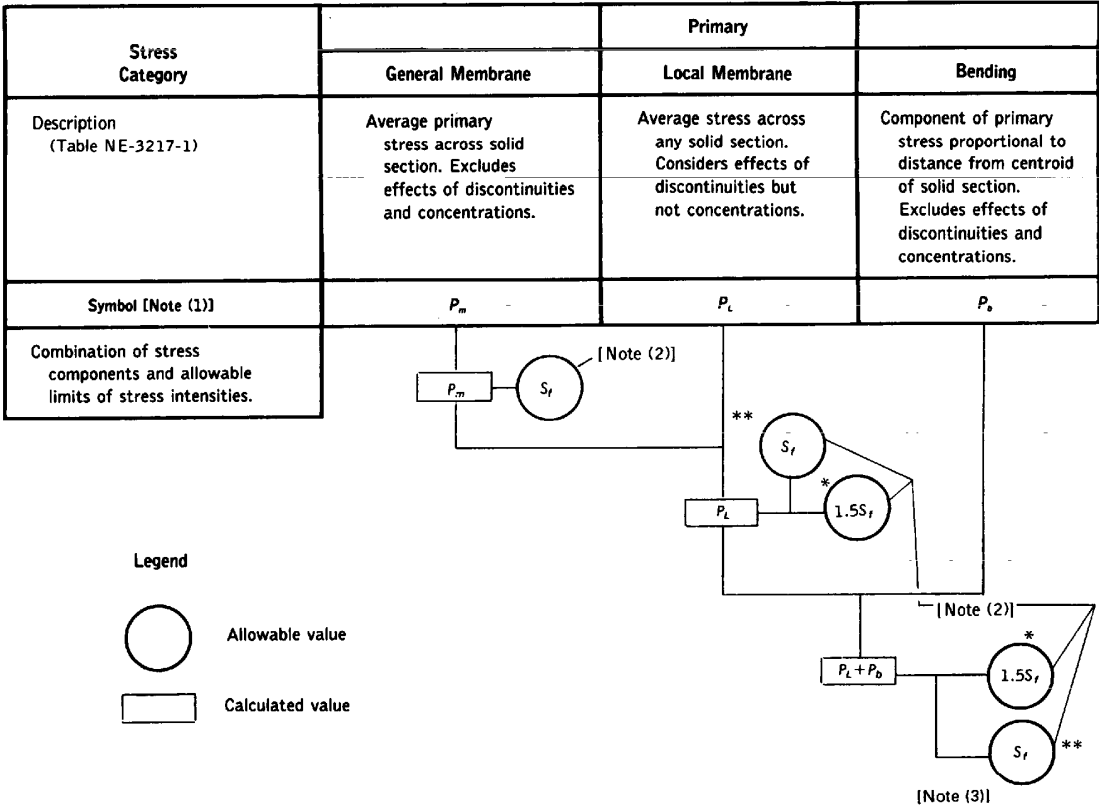


FIG. NE-3221-4 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR LEVEL D SERVICE LIMITS WHERE THE STRUCTURE IS INTEGRAL AND CONTINUOUS

FIG. NE-3221-4 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR LEVEL D SERVICE LIMITS WHERE THE STRUCTURE IS INTEGRAL AND CONTINUOUS

(c) *Conditions and Procedures.* The conditions and procedures of NE-3221.5(e) are based on a comparison of peak stress intensities with strain cycling fatigue data. The strain cycling fatigue data are represented by design fatigue strength curves of Figs. I-9.0. These curves show the allowable amplitude S_a of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles. This stress intensity amplitude is calculated on the assumption of elastic behavior and, hence, has the dimensions of stress, but it does not represent a real

stress when the elastic range is exceeded. The fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable stress intensity amplitude directly comparable. The curves have been adjusted, where necessary, to include the maximum effects of mean stress, which is the condition where the stress fluctuates about a mean value which is different from zero. As a consequence of this procedure, it is essential that the requirements of NE-3221.4 be satisfied at all times with transient stresses included, and that the calculated value of the alternating stress intensity be proportional to the actual strain amplitude. To evaluate the effect of alternating stresses of varying amplitudes, a linear damage relation is assumed in NE-2221(e)(4).

(d) *Vessels Not Requiring Analysis for Cyclic Service.* An analysis for cyclic service is not required, and it may be assumed that the limits on peak stress intensities as governed by fatigue have been satisfied for a vessel by compliance with the applicable requirements for construction in this Subsection, provided the specified Service Loadings of the vessel or portion thereof meet all the conditions stipulated in (1) through (6) below.

(1) *Atmospheric-to-Service Pressure Cycle.* The specified number of times (including startup and shutdown) that the pressure will be cycled from atmospheric pressure to service pressure and back to atmospheric pressure during service does not exceed the number of cycles on the applicable fatigue curve of Figs. I-9.0 corresponding to an S_a value of 3 times the S_{m1} value for the material at service temperature.

(2) *Normal Service Pressure Fluctuation.* The specified full range of pressure fluctuations during service does not exceed the quantity $(1/3) \times \text{Design Pressure} \times (S_a/S_{m1})$ where S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant pressure fluctuations and S_{m1} is the allowable stress intensity for the material at service temperature. If the total specified number of significant pressure fluctuations exceeds the maximum number of cycles defined on the applicable design fatigue curve, the S_a value corresponding to the maximum number of cycles defined on the curve may be used. Significant pressure fluctuations are those for which the total excursion exceeds the quantity:

$$\text{Design Pressure} \times \frac{1}{3} \times \frac{S}{S_{m1}}$$

where S is defined as follows:

(a) if the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles;

(b) if the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(3) *Temperature Difference - Startup and Shutdown.* The temperature difference in °F between any two adjacent points⁶ of the vessel during service does not exceed $S_a/2E\alpha$, where S_a is the value obtained from the applicable design

fatigue curves for the specified number of startup-shutdown cycles, α is the value of the instantaneous coefficient of thermal expansion and E is the value of Young's Modulus at the mean value of the temperatures at the two points as given by Section II, Part D, Subpart 2, Tables TE and TM.

(4) Temperature Difference - Similar Material. The temperature difference in °F between any two adjacent points⁶ does not change⁷ during service by more than the quantity $S_d/(2E\alpha)$, where S_d is the value obtained from the applicable design fatigue curve of Figs. I-9.0 for the total specified number of significant temperature difference fluctuations. A temperature difference fluctuation shall be considered to be significant if its total algebraic range exceeds the quantity $S/E\alpha$, where S is defined as follows.

⁶ Adjacent points are defined as follows.

(a) For surface temperature differences:

(1) on surfaces of revolution in the meridional direction, adjacent points are defined as points which are less than the distance $2\sqrt{Rt}$, where R is the radius measured normal to the surface from the axis of rotation to the mid-wall and t is the thickness of the part at the point under consideration. If the product of Rt varies, the average value of the points shall be used;

(2) on surfaces of revolution in the circumferential direction, and on flat parts such as flanges and flat heads, adjacent points are defined as any two points on the same surface.

(b) For through-thickness temperature differences, adjacent points are defined as any two points on a line normal to any surface.

⁷ The algebraic range of the difference shall be used.

Page 76

(a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_d obtained from the applicable design fatigue curve for 10^6 cycles.

(b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_d obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(5) Temperature Difference - Dissimilar Materials. For components fabricated from materials of differing moduli of elasticity or coefficients of thermal expansion, the total algebraic range of temperature fluctuation in °F experienced by the component during service does not exceed the magnitude $S_d/2(E_1\alpha_1 - E_2\alpha_2)$, where S_d is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature fluctuations, E_1 and E_2 are the moduli of elasticity, and α_1 and α_2 are the values of the instantaneous coefficients of thermal expansion at the mean temperature value involved for the two materials of construction (Section II, Part D, Subpart 2, Tables TE and TM). A temperature fluctuation shall be considered to be significant if its total excursion exceeds the quantity $S/2(E_1\alpha_1 - E_2\alpha_2)$, where S is defined as follows:

(a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_d obtained from the applicable design fatigue curve for 10^6 cycles.

(b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_d obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve. If the two materials used have different applicable design fatigue curves, the lower value of S_d shall be used in applying the rules of this paragraph.

(6) Mechanical Loads. The specified full range of mechanical loads, excluding pressure but including pipe reactions, does not result in load stress intensities whose range exceeds the S_d value obtained from the applicable design fatigue curve of Figs. I-9.0 for the total specified number of significant load fluctuations. If the total specified number of significant load fluctuations exceeds the maximum number of cycles defined on the applicable design fatigue curve, the S_d value corresponding to the maximum number of cycles defined on the curve may be used. A load fluctuation shall be considered to be significant if the total excursion of load stress exceeds the quantity S , where S is defined as follows.

(a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_d obtained from the applicable design fatigue curve for 10^6 cycles.

(b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_d obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(e) Procedure for Analysis for Cyclic Loading. If the specified service loadings for the vessel do not meet the

conditions of NE-3221.5(d), the ability of the vessel to withstand the specified cyclic service without fatigue failure shall be determined as provided herein. The determination shall be made on the basis of the stresses at a point, and the allowable stress cycles shall be adequate for the specified service loadings at every point. Only the stress differences due to service cycles as specified in the Design Specifications need be considered. Compliance with these requirements means only that the component is suitable from the standpoint of possible fatigue failure; complete suitability for the specified Service Loadings is also dependent on meeting the general stress limits of NE-3221 and any applicable special stress limits of NE-3227.

(1) *Stress Differences.* For each condition of specified service, determine the stress differences and the alternating stress intensity S_a in accordance with NE-3216.

(2) *Local Structural Discontinuities.* These effects shall be evaluated for all Service Loadings using stress concentration factors determined from theoretical, experimental, or photoelastic studies, or stress analysis techniques. Experimentally determined fatigue strength reduction factors may be used when determined in accordance with the procedures of Appendix II-1600, except for high strength alloy steel bolting for which the requirements of NE-3232.3 (c) shall apply when using the design fatigue curve of Fig. I-9.4. Except for the case of crack-like defects, no fatigue strength reduction factor greater than 5 need be used.

(3) *Design Fatigue Curves.* Figures I-9.0 contain the applicable fatigue design curves for the materials permitted by this Subsection. When more than one curve is presented for a given material, the applicability of each curve to materials of various strength levels is identified. Linear interpolation may be used for intermediate strength levels of these materials. As used herein, the strength level is the specified minimum room temperature value.

(4) *Effect of Elastic Modulus.* Multiply S_{alt} (as determined in NE-3216.1 or NE-3216.2) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve of Figs. I-9.0 at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the service cycle being considered is the only one which produces significant fluctuating stresses, this is the allowable number of cycles.

Page 77

(5) *Cumulative Damage.* If there are two or more types of stress cycles which produce significant stresses, their cumulative effect shall be evaluated as stipulated in Steps (1) through (6) below.

Step 1: Designate the specified number of times each type of stress cycle of types 1, 2, 3, ..., n will be repeated during the life of the component as $n_1, n_2, n_3, \dots, n_n$ respectively.

NOTE: In determining $n_1, n_2, n_3, \dots, n_n$, consideration shall be given to the superposition of cycles of various origins which produce a total stress difference range greater than the stress difference ranges of the individual cycles. For example, if one type of stress cycle produces 1000 cycles of a stress difference variation from zero to +60,000 psi and another type of stress cycle produces 10,000 cycles of a stress difference variation from zero to -50,000 psi, the two types of cycle to be considered are defined by the following parameters:

$$\begin{aligned} \text{Type 1 cycle: } n_1 &= 1000, \\ S_{alt1} &= (60,000 + 50,000)/2 = 55,000 \text{ psi} \\ \text{Type 2 cycle: } n_2 &= 9000, \\ S_{alt2} &= (50,000 + 0)/2 = 25,000 \text{ psi} \end{aligned}$$

Step 2: For each type of stress cycle, determine the alternating stress intensity S_{alt} by the procedures of NE-3216.1 or NE-3216.2 above. Call these quantities $S_{alt1}, S_{alt2}, S_{alt3}, \dots, S_{altn}$.

Step 3: For each value $S_{alt1}, S_{alt2}, S_{alt3}, \dots, S_{altn}$, use the applicable design fatigue curve to determine the maximum number of repetitions which would be allowable if this type of cycle were the only one acting. Call these values $N_1, N_2, N_3, \dots, N_n$.

Step 4: For each type of stress cycle, calculate the usage factors $U_1, U_2, U_3, \dots, U_n$ from $U_1 = n_1/N_1, U_2 = n_2/N_2, U_3 = n_3/N_3, \dots, U = n/N$.

Step 5: Calculate the cumulative usage factor U from $U = U_1 + U_2 + U_3 + \dots + U_n$.

Step 6: The cumulative usage factor U shall not exceed 1.0.

[98]

NE-3221.6 Thermal Stress Ratchet.

It should be noted that under certain combinations of steady state and cyclic loadings there is a possibility of large distortions developing as the result of ratchet action; that is, the deformation increases by a nearly equal amount for each cycle. Examples of this phenomenon are treated in this subparagraph and in NE-3227.3.

(a) The limiting value of the maximum cyclic thermal stress permitted in a portion of an axisymmetric shell loaded by steady state internal pressure in order to prevent cyclic growth in diameter is as follows. Let:

y'	= maximum allowable range of thermal stress computed on an elastic basis divided by the yield strength ⁸ S_y
x	= maximum general membrane stress due to pressure divided by the yield strength ⁸ S_y

Case 1: Linear variation of temperature through the wall:

$$y' = 1/x \text{ for } 0 < x < 0.5$$

$$y' = 4(1 - x) \text{ for } 0.5 < x < 1.0$$

Case 2: Parabolic constantly increasing or constantly decreasing variation of temperature through the wall:

$$y' = 5.2(1 - x) \text{ for } 0.615 < x < 1.0$$

and approximately for $x < 0.615$ as follows:

$$y' = 4.65, 3.55, \text{ and } 2.70 \text{ for } x = 0.3, 0.4, \text{ and } 0.5, \text{ respectively.}$$

(b) Use of yield strength S_y in the above relations instead of the proportional limit allows a small amount of growth during each cycle until strain hardening raises the proportional limit to S_y . If the yield strength of the material is higher than the endurance limit⁹ for the material, the latter value shall be used if there is to be a large number of cycles because strain softening may occur.

NE-3221.7 Deformation Limits.

Any deformation limits prescribed by the Design Specifications shall be satisfied.

NE-3222 Buckling Stress Values

NE-3222.1 Basic Compressive Allowable Stress.

The maximum buckling stress values to be used for the evaluation of instability shall be either of the following:

(a) one-third the value of critical buckling stress determined by one of the methods given below:

(1) rigorous analysis which considers the effects of gross and local buckling, geometric imperfections, nonlinearities, large deformations, and inertial forces (dynamic loads only);

⁸ It is permissible to use $1.5S_{md}$ whenever it is greater than S_y .

⁹ The endurance limit shall be taken as 2 times the S_a value at 10^6 cycles in the applicable fatigue curve of Figs. I-9.0, except that for the curves of Figs. I-9.2 the endurance limit shall be taken as two times the S_a value at 10^{11} cycles obtained from Curve A.

(2) classical (linear) analysis reduced by margins which reflect the difference between theoretical and actual load

capacities;

(3) tests of physical models under conditions of restraint and loading the same as those to which the configuration is expected to be subjected;

(b) the value determined by the applicable rules of NE-3133.

NE-3222.2 Stability Stress Limits

(a) For Design Conditions and Level A and B Service Limits, the value given in NE-3222.1 shall not be exceeded.

(b) For Level C Service Limits, 120% of the value given in NE-3222.1 shall not be exceeded.

(c) For Level D Service Limits, 150% of the value given in NE-3222.1 shall not be exceeded.

[98]

NE-3226 Testing Limits

The evaluation of pressure test loadings (NCA-2142.3) shall be in accordance with (a) through (f) below.

(a) If the minimum required hydrostatic test pressure defined in NE-6221 is to be exceeded at any point in a containment vessel or appurtenance by more than 6%, the maximum permissible hydrostatic test pressure shall be established by the engineer responsible for the Design Report using an analysis which includes all loadings which may exist during the test. The calculated primary general membrane stress intensity P_m shall not exceed 90% of the tabulated yield strength S_y at the test temperature. For solid rectangular sections, the primary membrane plus primary bending stress intensity $P_m + P_b$ shall not exceed the applicable limits given in (1) or (2) below:

(1) For $P_m \leq 0.67S_y$:

$$P_m + P_b \leq 1.35S_y$$

(2) For $0.67S_y < P_m \leq 0.90S_y$:

$$P_m + P_b \leq (2.15S_y - 1.2P_m)$$

where S_y is the tabulated yield strength at test temperature.

For other than solid rectangular sections, $P_m + P_b$ shall not exceed a value of α times $0.9S_y$, where the factor α is defined as the ratio of the load set producing a fully plastic section divided by the load set producing initial yielding in the extreme fibers of the section.

(b) The maximum permissible pneumatic test pressure of a completed vessel or appurtenance shall not exceed that value which results in a calculated primary general membrane stress intensity P_m of 75% of the tabulated yield strength at the test temperature. For solid rectangular sections, the primary membrane plus primary bending stress intensity $P_m + P_b$ shall not exceed 115% of the tabulated yield strength S_y at the test temperature. For other than solid rectangular sections, $P_m + P_b$ shall not exceed a value of α times $0.75S_y$, where the factor α is defined as the ratio of the load set producing a fully plastic section divided by the load set producing initial yielding in the extreme fibers of the section.

(c) In the evaluation of the initial yield and fully plastic section capacities in (a) and (b) above, the ratio of each individual load in the respective load set to each other load in that load set shall be the same as the respective ratios of the individual loads in the specified design load set. The value of α shall not exceed the value calculated for bending only ($P_m = 0$). In no case shall the value of α exceed 1.5. The propensity for buckling of the part of the section that is in compression shall be investigated.

(d) In multichamber vessels, pressure may be simultaneously applied to the appropriate adjacent chamber to meet the stress limits in (a) and (b) above.

(e) External pressure shall not exceed 125% of the value determined by the rules of NE-3222.

(f) The number of hydrostatic tests in accordance with NE-6220, pneumatic tests in accordance with NE-6320, or any

combination of such tests, shall not exceed ten unless a fatigue evaluation is made when required by NE-3221.5. In this fatigue evaluation, the limits on primary plus secondary stress intensity range (NE-3221.4) may be taken as the larger of $3S_{m1}$ or $2S_y$, when at least one extreme of the stress intensity range is determined by the test loadings.
[98]

NE-3227 Special Stress Limits

The following stress limits are provided to cover special conditions or configurations. Some of these limits are more restrictive and some less restrictive than the stress intensity limits of NE-3221. In cases of conflict between these requirements and those of NE-3221, the rules of NE-3227 take precedence. The rules of NE-3227 shall apply to Design Loadings and Level A and B Service Loadings. These rules shall also apply to Level C and D Service Loadings unless otherwise justified in the Design Report.

NE-3227.1 Bearing Loads

(a) The average bearing stress for resistance to crushing under the maximum load, experienced as a result

Page 79

of Design Loadings or of any of the service or testing loadings, shall be limited to S_y at temperature, except that when the distance to a free edge is larger than the distance over which the bearing load is applied, a stress of $1.5S_y$ at temperature is permitted. For clad surfaces, the yield strength of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.

(b) When bearing loads are applied near free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. In the case of load stress only (NE-3213.12), the average shear stress shall be limited to $0.6S_{mc}$. In the case of load stress plus secondary stress (NE-3213.9), the average shear stress shall not exceed (1) or (2) below:

(1) for materials to which Note (2) of Section II, Part D, Subpart 1, Tables 1A and 1B applies, the lower of $0.5S_y$ at 100°F (38°C) and $0.675S_y$ at temperature;

(2) for all other materials, $0.5S_y$ at temperature.

(c) For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

(d) When considering bearing stresses in pins and similar members, the S_y at temperature value is applicable, except that a value of $1.5S_y$ may be used if no credit is given to bearing area within one pin diameter from a plate edge.

NE-3227.2 Pure Shear

(a) The average primary shear stress across a section loaded in pure shear experienced as a result of Design Loadings (for example, keys, shear rings, screw threads) shall be limited to $0.6S_{mc}$.

(b) The maximum primary shear experienced as a result of Design Loadings shall be limited to $0.8S_{mc}$.

NE-3227.3 Progressive Distortion of Nonintegral Connections.

Screw-on caps, screwed-in plugs, shear-ring closures, and breech-lock closures are examples of nonintegral connections which are subject to failure by bell mouting or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete service cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore, primary plus secondary stress intensities (NE-3221.4) which result in slippage between the parts of a nonintegral connection in which disengagement could occur as a result of progressive distortion shall be limited to the value S_y (Section II, Part D, Subpart 2, Table Y-1).

NE-3227.4 Triaxial Stresses.

The algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) shall not exceed four times the tabulated value of S_{mc} .

NE-3227.5 Nozzle Piping Transition.

Within the limits of reinforcement given by NE-3334, whether or not nozzle reinforcement is provided, the P_m classification is applicable to stress intensities resulting from pressure induced general membrane stresses as well as stresses, other than discontinuity stresses, due to external loads and moments including those attributable to restrained free end displacements of the attached pipe. Also, within the limits of reinforcement, a P_L classification shall be applied to local primary membrane stress intensities derived from discontinuity effects plus primary bending stress intensities due to combined pressure and external loads and moments including those attributable to restrained free end displacements of the attached pipe; and a $P_L + P_b + Q$ classification shall apply to primary plus secondary stress intensities resulting from a combination of pressure, temperature, and external loads and moments including those due to restrained free end displacements of the attached pipe. Beyond the limits of reinforcement, a P_m classification is applicable to stress intensities resulting from pressure induced general membrane stresses as well as the average stress across the nozzle thickness due to externally applied nozzle axial, shear, and torsional loads other than those attributable to restrained free end displacement

Page 80

of the attached pipe may also be excluded. The range of membrane plus bending stress intensity attributable solely to the restrained free end displacements of the attached piping shall be $\leq 3S_{ml}$. The nozzle, outside the reinforcement limit, shall not be thinner than the larger of the pipe thickness or the quantity $t_p(S_{mp}/S_{mn})$ where t_p is the nominal thickness of the mating pipe, S_{mp} is the allowable stress intensity value for the pipe material, and S_{mn} is the allowable stress intensity value for the nozzle material.

NE-3227.6 Applications of Elastic Analysis for Stresses Beyond the Yield Strength.

Certain of the allowable stresses permitted in the criteria are such that the maximum stress calculated on an elastic basis may exceed the yield strength of the material. The limit on primary plus secondary stress intensity of $3S_{ml}$ (NE-3221.4) has been placed at a level which assures shakedown to elastic action after a few repetitions of the stress cycle, except in regions containing significant local structural discontinuities or local thermal stresses. These last two factors are considered only in the performance of a fatigue evaluation. Therefore, the procedures of (a) and (b) below shall be used.

(a) In evaluating stresses for comparison with the stress limits on other than fatigue allowables, stresses shall be calculated on an elastic basis.

(b) In evaluating stresses for comparison with fatigue allowables, all stresses except those which result from local thermal stresses [NE-3213.13(b)] shall be evaluated on an elastic basis. In evaluating local thermal stresses, the elastic equations shall be used, except that the numerical value substituted for Poisson's ratio shall be determined from the expression:

$$\nu = 0.5 - 0.2 \frac{S_y}{S_a} \text{ but not less than } 0.3$$

where

S_y

= the yield strength of the material at the mean value of the temperature of the cycle

S_a

= the value obtained from the applicable design fatigue curve (Figs. I-9.0) for the specified number of cycles of the condition being considered

NE-3228 Applications of Plastic Analysis

The following subparagraphs provide guidance in the application of plastic analysis and some relaxation of the stress limits of NE-3221 which are allowed if plastic analysis is used.

NE-3228.1 Plastic Analysis.

The limits on local membrane stress intensity (NE-3221.2), primary plus secondary stress intensity (NE-3221.4), thermal stress ratchet in shell (NE-3221.6), and progressive distortion of nonintegral connections (NE-3227.3) need not be satisfied at a specific location if, at the location, the procedures of (a) through (c) below are used.

(a) In evaluating stresses for comparison with the remaining stress limits, the stresses are calculated on an elastic basis.

(b) In lieu of satisfying the specific requirements of NE-3221.2, NE-3221.4, NE-3221.6, and NE-3227.3 at a specific location, the structural action is calculated on a plastic basis and the design shall be considered to be acceptable if shakedown occurs (as opposed to continuing deformation) and if the deformations which occur prior to shakedown do not exceed specified limits.

(c) In evaluating stresses for comparison with fatigue allowables, the numerically maximum principal total strain range which occurs after shakedown shall be multiplied by one-half of the modulus of elasticity of the material (Section II, Part D, Subpart 2, Table TM) at the mean value of the temperature of the cycle.

NE-3228.2 Limit Analysis.

The limits on local membrane stress intensity (NE-3221.2) and primary membrane plus primary bending stress intensity (NE-3221.3) need not be satisfied at a specific location if it can be shown by means of limit analysis or by tests that the specified loadings do not exceed two-thirds of the lower bound collapse load except for those materials of Section II, Part D, Subpart 1, Tables 2A and 2B to which Note (2) of those tables is applicable. For these latter materials the specified loading shall not exceed the product of the applicable permanent strain limiting factor of Section II, Part D, Subpart 2, Table Y-2 times the lower bound collapse load.

NE-3228.3 Simplified Elastic-Plastic Analysis.

The $3S_{m1}$ limit on the range of primary plus secondary stress intensity (NE-3221.4) may be exceeded provided the requirements of (a) through (f) below are met.

(a) The range of primary plus secondary membrane plus bending stress intensity, excluding thermal bending stresses, shall be $\leq 3S_{m1}$.

(b) The value of S_n used for entering the design fatigue curve is multiplied by the factor K_e where:

$$\begin{aligned} K_e &= 1.0, \text{ for } S_n \leq 3S_{m1} \\ &= 1.0 + [(1 - n)/n(m - 1)][(S_n/3S_{m1}) - 1], \text{ for } 3S_{m1} < S_n < 3mS_{m1} \\ &= 1/n, \text{ for } S_n \geq 3mS_{m1} \\ S_n &= \text{range of primary plus secondary stress intensity} \end{aligned}$$

**TABLE NE-3228.3(b)-1
VALUES OF m , n , AND $T_{\max}$ FOR VARIOUS
CLASSES OF PERMITTED MATERIALS**

Materials	m	n	$T_{\max}$, °F
Low alloy steel	2.0	0.2	700
Martensitic stainless steel	2.0	0.2	700
Carbon steel	3.0	0.2	700
Austenitic stainless steel	1.7	0.3	800
Nickel-Chromium-Iron	1.7	0.3	800
Nickel-Copper	1.7	0.3	800

TABLE NE-3228.3(b)-1 VALUES OF m , n , AND $T_{\max}$ FOR VARIOUS CLASSES OF PERMITTED MATERIALS

The values of the material parameters m and n are given for the various classes of materials in Table NE-3228.3(b)-1.

(c) The rest of the fatigue evaluation stays the same as required in NE-3221.5, except that the procedure of NE-3227.6 need not be used.

(d) The component meets the thermal ratcheting requirement of NE-3221.6.

(e) The temperature does not exceed those listed in Table NE-3228.3(b)-1 for the various classes of materials.

(f) The material shall have a specified minimum yield strength to specified minimum tensile strength ratio of less than 0.80.

NE-3228.4

NE-3228.4 Impulse Loads.

A plastic analysis or test may be used to justify relaxation of the Level A, Level B, Level C, and Level D Service Limits given in NE-3221.1, NE-3221.2, NE-3221.3, and NE-3221.4 if the applied loading is impulsive in nature. The plastic analysis or test shall demonstrate that the factor against failure under the applied impulsive loading is not less than the factor against failure provided by Level A Service Limits for sustained loads. This demonstration shall be included in the Design Report for review by the Owner or the Owner's designee for acceptability to the regulatory authority having jurisdiction at the nuclear power plant site.

NE-3230 STRESS LIMITS FOR BOLTS

NE-3231 Design Conditions

(a) The number and cross-sectional area of bolts required to resist the Design Pressure shall be determined in accordance with the procedures of Appendix XI, using the larger of the bolt loads given by the equations of Appendix XI as a Design Mechanical Load. The allowable bolt design stresses shall be 1.1 times the values given in Section II, Part D, Subpart 1, Table 3 for bolting materials.

(b) When sealing is effected by a seal weld instead of a gasket, the gasket factor m and the minimum design seating stress y may be taken as zero.

(c) When gaskets are used for preservice testing only, the design is satisfactory if the above requirements are satisfied for $m = y = 0$.

NE-3232 Combined Loads

Actual service stresses in bolts, such as those produced by the combination of preload, pressure, and differential thermal expansion, may be higher than the allowable stresses given in NE-3231(a).

NE-3232.1 Average Stress.

The maximum value of service stress, averaged across the bolt cross section and neglecting stress concentrations, shall not exceed 2.2 times the stress values of Section II, Part D, Subpart 1, Table 3.

NE-3232.2 Maximum Stress.

The maximum value of service stress, except as restricted by NE-3232.3, at the periphery of the bolt cross section resulting from direct tension plus bending and neglecting stress concentrations shall not exceed 3.3 times the stress values of Section II, Part D, Subpart 1, Table 3. Stress intensity, rather than maximum stress, shall be limited to this value when the bolts are tightened by methods other than heaters, stretchers, or other means which minimize residual torsion.

NE-3232.3 Fatigue Analysis of Bolts.

Unless the components on which they are installed meet all the conditions of NE-3221.5(d) and thus require no fatigue analysis, the suitability of bolts for cyclic service shall be determined in accordance with the procedures of (a) through (e) below.

(a) *Bolting Having Less Than 100.0 ksi (689 MPa) Tensile Strength.* Bolts made of materials which have specified minimum tensile strengths of less than 100.0 ksi (689 MPa) shall be evaluated for cyclic service by the methods of NE-3221.5(e) using the applicable design fatigue curve of Fig. I-9.4 and an appropriate fatigue strength reduction factor [NE-3232.3(c)].

(b) *High Strength Alloy Steel Bolting.* High strength alloy steel bolts and studs may be evaluated for cyclic service by the methods of NE-3221.5(e) using the design fatigue curve of Fig. I-9.4, provided the requirements of (1), (2), and (3) below are met.

(1) The maximum value of the service stress (NE-3232.2) at the periphery of the bolt cross section (resulting from direct tension plus bending) and neglecting

stress concentration shall not exceed $2.7S_{ml}$, if the higher of the two fatigue design curves given in Fig. I-9.4 is used. The $2S_{ml}$ limit for direct tension is unchanged.

(2) Threads shall be of a V-type having a minimum thread root radius no smaller than 0.003 in. (0.08 mm).

(3) Fillet radii at the end of the shank shall be such that the ratio of fillet radius to shank diameter is not less than 0.060.

(c) *Fatigue Strength Reduction Factor (NE-3213.17)*. Unless it can be shown by analysis or tests that a lower value is appropriate, the fatigue strength reduction factor used in the fatigue evaluation of threaded members shall not be less than 4.0. However, when applying the rules of NE-3232.3(b) for high strength alloy steel bolts, the value used shall not be less than 4.

(d) *Effect of Elastic Modulus*. Multiply S_{alt} (as determined in NE-3216.1 or NE-3216.2) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve at this value on the ordinate axis and find the corresponding numbers of cycles on the abscissa. If the service cycle being considered is the only one which produces significant fluctuating stresses, this is the allowable number of cycles.

(e) *Cumulative Damage*. The bolts shall be acceptable for the specified cyclic application of loads and thermal stresses provided the cumulative usage factor U as determined in NE-3221(e)(5) does not exceed 1.0.

NE-3236 Design Stress Values

The design stress intensity values S_{mc} and allowable stress values S are 1.1 times the values given in Section II, Part D, Subpart 1, Table 3 for bolting. Values for intermediate temperatures may be found by interpolation. The basis for establishing stress values is given in Appendix III.

NE-3300 DESIGN BY FORMULA

NE-3310 DESIGN CRITERIA

NE-3311 Requirements for Acceptability

10 For the purpose of this provision, substantial loads are defined as those which cumulatively result in stresses which exceed 10% of the primary stresses induced by the Design Pressure, such stresses being defined as maximum principal stresses.

Rules are provided in this Subarticle for Design Loadings and Levels A and B Service Loadings which do not include substantial¹⁰ mechanical or thermal loads other than pressure. The design shall be such that the rules of this Subarticle are satisfied for any configurations and loadings explicitly treated.

(a) The allowable stress value at temperature S is 1.1 times that tabulated in Section II, Part D, Subpart 1, Tables 1A and 1B and is to be used.

NE-3320 DESIGN CONSIDERATIONS

NE-3324 Vessels Under Internal Pressure

NE-3324.1 General Requirements.

Equations are given in this paragraph for determining the minimum thicknesses under internal pressure loading in cylindrical and spherical shells and ellipsoidal, conical, and hemispherical heads.

NE-3324.2 Nomenclature.

The symbols used in Fig. NE-3324.2-1 are defined as follows:

t = minimum required thickness of shell or head, after forming,

	exclusive of corrosion allowance, in.
P	= Design Pressure, psi
R	= inside radius of the shell course under consideration before corrosion allowance is added, in.
R_o	= outside radius of the shell course under consideration, in.
S	= maximum allowable stress value, psi
D	= inside diameter of the head skirt; or inside length of the major axis of an ellipsoidal head; or inside diameter of a conical head at the point under consideration, measured perpendicular to the longitudinal axis, in.
D_o	= outside diameter of the head skirt; or outside length of the major axis of an ellipsoidal head; or outside diameter of a conical head at the point under consideration, measured perpendicular to the longitudinal axis, in.
D_1	= inside diameter of the conical portion of a toriconical head at its point of tangency to the knuckle, measured perpendicular to the axis of the cone, in.
L	= inside spherical or crown radius for torispherical and hemispherical heads, in.
L	= $K_1 D$ for ellipsoidal heads in which K_1 is obtained from Table NE-3332.2-1, in.
L_o	= outside spherical or crown radius, in.
r	= inside knuckle radius, in.
h	= one-half of the length of the minor axis of the ellipsoidal head or the inside depth of the ellipsoidal head measured from the tangent line head bend line, in.
K	= a factor in the equations for ellipsoidal heads depending on the head proportion $D/2h$ (Table NE-3324.2-1)

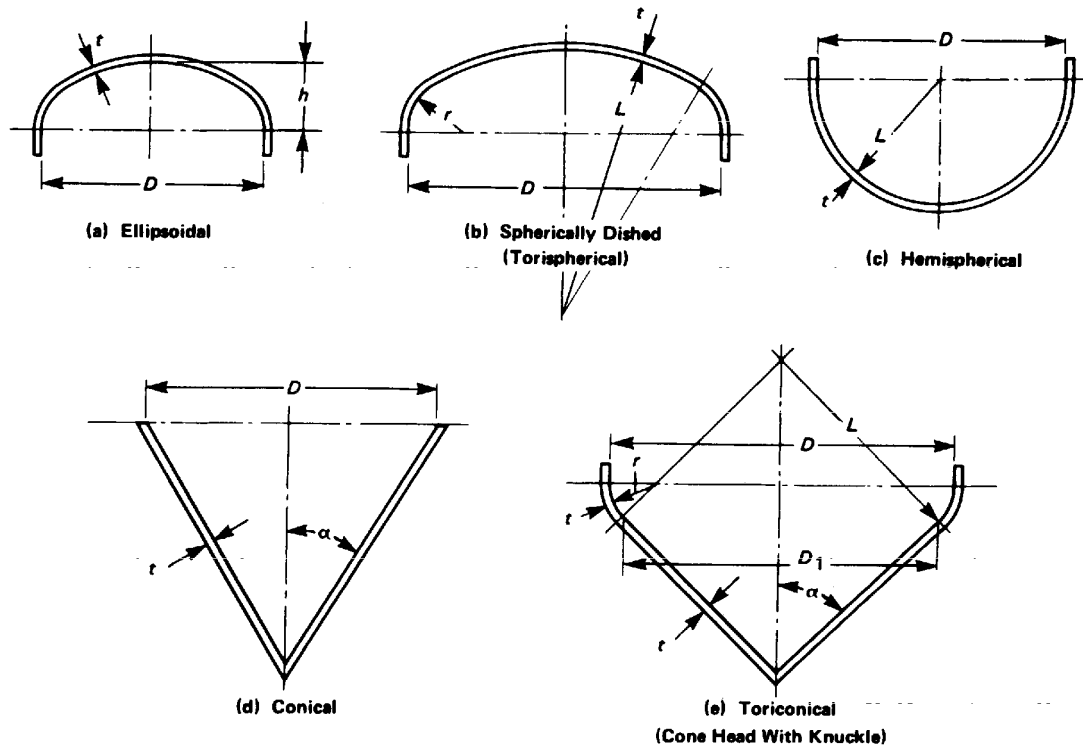


FIG. NE-3324.2-1 PRINCIPAL DIMENSIONS OF TYPICAL HEADS

FIG. NE-3324.2-1 PRINCIPAL DIMENSIONS OF TYPICAL HEADS

$D/2h$

= ratio of the major to the minor axis of ellipsoidal heads, which equals the inside diameter of the skirt of the head divided by twice the inside height of the head and is used in Table NE-3324.2-1

α

= one-half of the included apex angle of the cone at the center line of the head

TABLE NE-3324.2-1
VALUES OF FACTOR K
 Use Nearest Value of $D/2h$; Interpolation
 Unnecessary

$D/2h$	3.0	2.9	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.0
K	1.83	1.73	1.64	1.55	1.46	1.37	1.29	1.21	1.14	1.07	1.00
$D/2h$	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	...
K	0.93	0.87	0.81	0.76	0.71	0.66	0.61	0.57	0.53	0.50	...

TABLE NE-3324.2-1 VALUES OF FACTOR K

NE-3324.3 Cylindrical Shells.

The minimum thickness of cylindrical shells shall be the greater thickness as given by (a) through (d) below.

(a) *Circumferential Stress (Longitudinal Joints)*. When the thickness does not exceed one-half of the inside radius, or P does not exceed $0.385S$, the following equations shall apply:

$$t = \frac{PR}{S - 0.6P} \quad \text{or} \quad P = \frac{St}{R + 0.6t}$$

(b) *Longitudinal Stress (Circumferential Joints)*. When the thickness does not exceed one-half of the inside radius, or P does not exceed $1.25S$, the following equations shall apply:

$$t = \frac{PR}{2S + 0.4P} \quad \text{or} \quad P = \frac{2St}{R - 0.4t}$$

Page 84

(c) *Thickness of Cylindrical Shells*. The following equations, in terms of the outside radius, are equivalent to and may be used instead of those given in (a) above:

$$t = \frac{(PR_o)}{S + 0.4P} \quad \text{or} \quad P = \frac{St}{(R_o - 0.4t)}$$

(d) *Thick Cylindrical Shells*

(1) *Circumferential Stress (Longitudinal Joints)*. When the thickness of the cylindrical shell under internal pressure exceeds one-half of the inside radius, or when P exceeds $0.385S$, the following equations shall apply.

When P is known and t is desired:

$$t = R (Z^{1/2} - 1) = R_o \frac{(Z^{1/2} - 1)}{Z^{1/2}}$$

where

$$Z = \frac{S + P}{S - P}$$

When t is known and P is desired:

$$P = S \left(\frac{Z - 1}{Z + 1} \right)$$

where

$$Z = \left(\frac{R + t}{R} \right)^2 = \left(\frac{R_o}{R} \right)^2 = \left(\frac{R_o}{R_o - t} \right)^2$$

(2) *Longitudinal Stress (Circumferential Joints)*. When the thickness of the cylindrical shell under internal pressure exceeds one-half of the inside radius, or when P exceeds $1.25S$, the following equations shall apply.

When P is known and t is desired:

$$t = R (Z^{1/2} - 1) = R_o \frac{(Z^{1/2} - 1)}{Z^{1/2}}$$

where

$$Z = \left(\frac{P}{S} + 1 \right)$$

When t is known and P is desired:

$$P = S(Z - 1)$$

where

$$Z = \left(\frac{R + t}{R} \right)^2 = \left(\frac{R_o}{R} \right)^2 = \left(\frac{R_o}{R_o - t} \right)^2$$

NE-3324.4 Spherical Shells

(a) When the thickness of the shell of a spherical vessel does not exceed $0.356R$, or P does not exceed $0.665S$, the following equations shall apply. Any reduction in thickness within a shell course of a spherical shell shall be in accordance with NE-3361.

$$t = \frac{PR}{2S - 0.2P} \quad \text{or} \quad P = \frac{2St}{R + 0.2t}$$

(b) The following equations, in terms of the outside radius, are equivalent to and may be used instead of those given in (a) above:

$$t = \frac{PR_o}{2S + 0.8P}$$

$$P = \frac{2St}{R_o - 0.8t}$$

(c) When the thickness of the shell of a spherical vessel or of a hemispherical head under internal pressure exceeds $0.356R$, or when P exceeds $0.665S$, the following equations shall apply.

When P is known and t is desired:

$$t = R (Y^{1/3} - 1) = R_o \left(\frac{Y^{1/3} - 1}{Y^{1/3}} \right)$$

where

$$Y = \frac{2(S + P)}{2S - P}$$

When t is known and P is desired:

$$P = 2S \left(\frac{Y - 1}{Y + 2} \right)$$

where

$$Y = \left(\frac{R + t}{R} \right)^3 = \left(\frac{R_o}{R_o - t} \right)^3$$

NE-3324.5 Formed Heads, General Requirements.

Formed heads shall meet the requirements of (a) through (f) below.

(a) All formed heads, thicker than the shell and concave to pressure, for butt welded attachment, shall have a skirt length sufficient to meet the requirements of Fig. NE-3358.1(a)-1 when a tapered transition is required.

(b) Any taper at a welded joint within a formed head shall be in accordance with NE-3361. The taper at a circumferential welded joint connecting a formed head to a main shell shall meet the requirements of NE-3358 for the respective type of joint shown therein.

(c) All formed heads concave to pressure and for butt welded attachment need not have an integral skirt when the thickness of the head is equal to or less than the thickness of the shell. When a skirt is provided, its thickness shall be at least that required for a seamless shell of the same diameter.

(d) The inside crown radius to which a head is dished shall not be greater than the outside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall not be less than 6% of the outside diameter of the skirt of the head but in no case less than three times the head thickness.

(e) If a torispherical, ellipsoidal, or hemispherical head is formed with a flattened spot or surface, the diameter of the flat spot shall not exceed that permitted for flat heads as given by Eq. (1) or (2) of NE-3325.2 using $C = 0.25$.

(f) Openings in formed heads under internal pressure shall comply with the requirements of NE-3330.

NE-3324.6 Ellipsoidal Heads

(a) *Ellipsoidal Heads.* The required thickness of a dished head of semiellipsoidal form, in which one-half the minor axis, inside depth of the head minus the skirt, equals one-fourth the inside diameter of the head skirt, shall be determined by:

$$t = \frac{PD}{2S - 0.2P} \quad \text{or} \quad P = \frac{2St}{D + 0.2t}$$

(b) *Ellipsoidal Heads of Other Ratios.* The minimum required thickness of an ellipsoidal head of other than a 2:1 ratio shall be determined by:

$$t = \frac{PDK}{2S - 0.2P} \quad \text{or} \quad P = \frac{2St}{KD + 0.2t}$$

$$t = \frac{PD_o K}{2S + 2P(K - 0.1)} \quad \text{or} \quad P = \frac{2St}{KD_o - 2t(K - 0.1)}$$

where

$$K = \frac{1}{6} \left[2 + \left(\frac{D}{2h} \right)^2 \right]$$

Numerical values of the factor K are given in Table NE-3324.2-1.

NE-3324.7 Hemispherical Heads

(a) When the thickness of a hemispherical head does not exceed $0.356L$ or P does not exceed $0.665S$, the following equations shall apply:

$$t = \frac{PL}{2S - 0.2P} \quad \text{or} \quad P = \frac{2St}{L + 0.2t}$$

(b) When the thickness of the hemispherical head under internal pressure exceeds $0.356L$, or when P exceeds $0.665S$, the following equations shall apply:

$$t = L(Y^{1/3} - 1) = L_o \left(\frac{Y^{1/3} - 1}{Y^{1/3}} \right)$$

where

$$Y = \frac{2(S + P)}{2S - P}$$

or

$$P = 2S \left(\frac{Y - 1}{Y + 2} \right)$$

where

$$Y = \left(\frac{L + t}{L} \right)^3 = \left(\frac{L_o}{L_o - t} \right)^3$$

NE-3324.8 Torispherical Heads

(a) *Torispherical Heads With a 6% Knuckle Radius.* The required thickness of a torispherical head in which the knuckle radius is 6% of the inside crown radius shall be determined by:

$$t = \frac{0.885PL}{S - 0.1P} \quad \text{or} \quad P = \frac{St}{0.885L + 0.1t}$$

(b) *Torispherical Heads of Other Proportions.* The required thickness of a torispherical head in which the knuckle radius is other than 6% of the crown radius shall be determined by:

Page 86

$$t = \frac{PLM}{2S - 0.2P} \quad \text{or} \quad P = \frac{2St}{LM + 0.2t}$$

$$t = \frac{PL_oM}{2S + P(M - 0.2)}$$

TABLE NE-3324.8(b)-1
VALUES OF FACTOR M
 Use Nearest Value of L/r , Interpolation Unnecessary

L/r	1.0	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50
M	1.00	1.03	1.06	1.08	1.10	1.13	1.15	1.17	1.18	1.20	1.22
L/r	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
M	1.25	1.28	1.31	1.34	1.36	1.39	1.41	1.44	1.46	1.48	1.50
L/r	9.5	10.00	10.5	11.0	11.5	12.0	13.0	14.0	15.0	16.0	16.67
M	1.52	1.54	1.56	1.58	1.60	1.62	1.65	1.69	1.72	1.75	[Note (1)]
											1.77

NOTE:

(1) Maximum ratio allowed by NE-3324.5(d) when L equals the outside diameter of the skirt of the head.

TABLE NE-3324.8(b)-1 VALUES OF FACTOR M

or

$$P = \frac{2St}{ML_o - t(M - 0.2)}$$

where

$$M = \frac{1}{4} \left(3 + \sqrt{\frac{L}{r}} \right)$$

Numerical values of the factor M are given in Table NE-3324.8(b)-1.

(c) Torispherical heads made of materials having a specified minimum tensile strength exceeding 80 ksi (552 MPa) shall be designed using a value of S equal to 22 ksi (152 MPa) at room temperature and reduced in proportion to the ratio of the reduction in maximum allowable stress values from room temperature to design temperature for the material as shown in Section II, Part D, Subpart 1, Tables 1A and 1B.

NE-3324.9 Conical Heads Without Transition Knuckle.

The required thickness of conical heads or conical shell sections that have a half apex angle α not greater than 30 deg shall be determined by:

$$t = \frac{PD}{2 \cos \alpha (S - 0.6P)} \quad \text{or} \quad P = \frac{2St \cos \alpha}{D + 1.2t \cos \alpha}$$

For α greater than 30 deg, see NE-3324.11(b)(5). A compression ring shall be provided when required by the rule in NE-3324.11(b).

NE-3324.10 Toriconical Heads.

Toriconical heads in which the inside knuckle radius is neither less than 6% of the outside diameter of the head skirt nor less than three times the knuckle thickness shall be used when the angle α exceeds 30 deg except when the design complies with NE-3324.11. The required thickness of the knuckle shall be determined by the first equation of NE-3324.8 (b) in which:

$$L = \frac{D_1}{2 \cos \alpha}$$

The required thickness of the conical portion shall be determined by the equation in NE-3324.9, using D_1 in place of D .

NE-3324.11 Reducer Sections

(a) General Requirements

(1) The rules of NE-3324.11(a) apply to concentric reducer sections.

(2) The symbols used are defined as follows:

D_1	= inside diameter of reducer section at point of tangency to the knuckle or reverse curve, in.
A	= required area of reinforcement, sq in.
A_e	= effective area of reinforcement, due to excess metal thickness, sq in.
Δ	= value to indicate need for reinforcement at cone-to-cylinder intersection having a half-apex angle $\alpha \leq 30$ deg. When $\Delta \geq \alpha$, no reinforcement at the junction is required [Table NE-3324.11(b)(2)-1 and Table NE-3324.11(b)(3)-1].
m	= the lesser of

$$\left[\frac{t_s}{t} \cos (\alpha - \Delta) \right]$$

or

$$\left[\frac{t_c \cos \alpha \cos (\alpha - \Delta)}{t} \right]$$

R_L

= inside radius of larger cylinder, in.

R_s

= inside radius of smaller cylinder, in.

r_L

= inside radius of knuckle at larger cylinder, in.

r_s

= radius to the inside surface of flare at the small end, in.

t_s

= nominal thickness of cylinder at cone-to-cylinder junction, exclusive of corrosion allowance, in.

t_c

= nominal thickness of cone at cone-to-cylinder junction,

exclusive of corrosion allowance, in.

$$t_e = \text{the smaller of } (t_s - t) \text{ or } [t_c - (t/\cos \alpha)], \text{ in.}$$

(3) The thickness of each element of a reducer, as defined in (4) below, under internal pressure shall not be less than that computed by the applicable equation.

(4) A transition section reducer consisting of one or more elements may be used to join two cylindrical shell sections of different diameters but with a common axis, provided the requirements of (a) and (b) below are met.

(a) *Conical Shell Section.* The required thickness of a conical shell section or the allowable pressure for such a section of given thickness shall be determined by the equations given in NE-3324.9.

(b) *Knuckle Tangent to the Larger Cylinder.* Where a knuckle is used at the large end of a reducer section, its shape shall be that of a portion of an ellipsoidal, hemispherical, or torispherical head. The thickness and other dimensions shall satisfy the requirements.

(5) When elements of (4) above having different thicknesses are combined to form a reducer, the joints, including the plate taper required by NE-3361, shall lie entirely within the limits of the thinner element being joined.

(6) A reducer may be a simple conical shell section [Fig. NE-3324.11(a)(6)-1 sketch (a)] without knuckle, provided the half apex angle α is not greater than 30 deg, except as provided for in (b) below. A reinforcement ring shall be provided at either or both ends of the reducer when required by (b) below.

(7) A toriconical reducer [Fig. NE-3324.11 (a)(6)-1 sketch (b)] may be shaped as a portion of a toriconical shell, a portion of a hemispherical head plus a conical section, or a portion of an ellipsoidal head plus a conical section, provided the half apex angle α is not greater than 30 deg, except as provided for in (b) below. A reinforcement ring shall be provided at the small end of a conical reducer element when required by (b) below.

(8) Reverse curve reducers [Fig. NE-3324.11 (a)(6)-1 sketches (c) and (d)] may be shaped of elements other than those illustrated.

(b) Supplementary Requirements for Reducer Sections and Conical Heads Under Internal Pressure

(1) The equations of (2) and (3) below provide for the design of reinforcement, if needed, at the cone-to-cylinder junctions for reducer sections and conical heads where all the elements have a common axis and the half apex angle $\alpha \leq 30$ deg. In (5) below, provision is made for special analysis in the design of cone-to-cylinder intersections with or without reinforcing rings where α is greater than 30 deg.

(2) Reinforcement shall be provided at the junction of the cone with the large cylinder for conical heads and reducers without knuckles when the value of Δ obtained from Table NE-3324.11(b)(2)-1, using the appropriate ratio P/S , is less than α . Interpolation may be made in the table.

(a) The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following equation:

$$A = \frac{PR_L^2}{2S} \left(1 - \frac{\Delta}{\alpha} \right) \tan \alpha$$

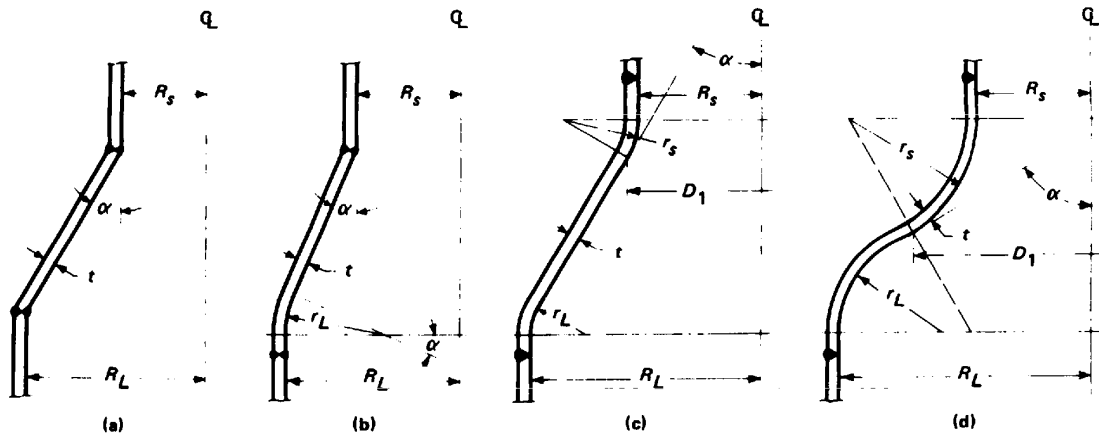
(b) When the thickness, less corrosion allowance, of both the reducer and cylinder exceeds that required by the applicable design equations, the minimum excess thickness may be considered to contribute to the required reinforcement ring in accordance with the following equation:

$$A_e = 4t_e \sqrt{R_L t_s}$$

(c) Any additional area of reinforcement which is required shall be situated within a distance of $\sqrt{R_L t_s}$ from the junction of the reducer and the cylinder. The centroid of the added area shall be within a distance of $\sqrt{0.5 R_L t_s}$ from the junction.

(3) Reinforcement shall be provided at the junction of the conical shell of a reducer without a flare and the small cylinder when the value of Δ obtained from Table NE-3324.11(b)(3)-1, using the appropriate ratio P/S , is less than α .

Page 88



GENERAL NOTES:

- (1) r_L shall not be less than the smaller of $0.12 (R_L + t)$ or $3t$
- (2) r_s has no dimensional requirement

FIG. NE-3324.11(a)(6)-1 LARGE HEAD OPENINGS: REVERSE CURVE AND CONICAL SHELL REDUCER SECTIONS

FIG. NE-3324.11(a)(6)-1 LARGE HEAD OPENINGS: REVERSE CURVE AND CONICAL SHELL REDUCER SECTIONS

**TABLE NE-3324.11(b)(2)-1
VALUES OF Δ FOR JUNCTIONS AT THE
LARGE CYLINDER FOR $\alpha \leq 30$ deg**

<i>P/S</i>	0.001	0.002	0.003	0.004	0.005
Δ , deg	11	15	18	21	23
<i>P/S</i>	0.006	0.007	0.008	0.009	...
				[Note (1)]	
Δ , deg	25	27	28.5	30	...

NOTE:

(1) $\Delta = 30$ deg for greater values of *P/S*.

TABLE NE-3324.11(b)(2)-1 VALUES OF Δ FOR JUNCTIONS AT THE LARGE CYLINDER FOR $\alpha \leq 30$ deg

**TABLE NE-3324.11(b)(3)-1
VALUES OF Δ FOR JUNCTIONS AT THE
SMALL CYLINDER FOR $\alpha \leq 30$ deg**

<i>P/S</i>	0.002	0.005	0.010	0.02
Δ , deg	4	6	9	12.5
<i>P/S</i>	0.04	0.08	0.10	0.125
				[Note (1)]
Δ , deg	17.5	24	27	30

NOTE:

(1) $\Delta = 30$ deg for greater values of P/S .

TABLE NE-3324.11(b)(3)-1 VALUES OF Δ FOR JUNCTIONS AT THE SMALL CYLINDER FOR $\alpha \leq 30$ deg

(a) The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following formula:

$$A = \frac{PR_s^2}{2S} \left(1 - \frac{\Delta}{\alpha} \right) \tan \alpha$$

(b) When the thickness, less corrosion allowance, of either the reducer or cylinder exceeds that required by the applicable design equation, the excess thickness may be considered to contribute to the required reinforcement ring in accordance with the following equation:

$$A_e = m \sqrt{R_s t} [t_c - (t/\cos \alpha) + (t_s - t)]$$

(c) Any additional area of reinforcement which is required shall be situated within a distance of $\sqrt{R_s t_s}$ from the junction, and the centroid of the added area shall be within a distance of $0.5\sqrt{R_s t_s}$ from the junction.

(4) Reducers not described in NE-3324.11(a)(3), such as those made up of two or more conical frustums having different slopes, may be designed in accordance with (5) below.

(5) When the half apex angle α is greater than 30 deg, cone-to-cylinder junctions without a knuckle

Page 89

may be used, with or without reinforcing rings, if the design is based on stress analysis. When a stress analysis is made, the calculated stresses shall be evaluated in accordance with NE-3200.

NE-3324.12 Nozzles

(a) The wall thickness of a nozzle or other connection shall not be less than the nominal thickness of the connecting piping. In addition, the wall thickness shall not be less than the thickness computed for the applicable loadings in NE-3111 plus the thickness added for corrosion. Except for access openings and openings for inspection only, the wall thickness shall not be less than the smaller of (1) and (2) below:

(1) the required thickness of the shell or head to which the connection is attached plus the corrosion allowance provided in the shell or head adjacent to the connection;

(2) the minimum thickness¹¹ of standard wall pipe plus the corrosion allowance on the connection; for nozzles larger than the largest pipe size included in ANSI B36.10, the wall thickness of that largest size plus corrosion allowance.

(b) The allowable stress value for shear in a nozzle neck shall be 70% of the allowable tensile stress for the vessel material.

NE-3325 Flat Heads and Covers

The minimum thickness of unstayed flat heads, cover plates, and blind flanges shall conform to the requirements given in this paragraph. These requirements apply to circular heads and covers. Some acceptable types of flat heads and covers are shown in Fig. NE-3325-1. In this figure the dimensions of the component parts and the dimensions of the welds are exclusive of extra metal required for corrosion allowance.

NE-3325.1 Nomenclature.

The symbols used are defined as follows:

C	= a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in NE-3325.3, dimensionless
d	= diameter, measured as indicated in Fig. NE-3325-1, in.
h_G	= gasket moment arm, equal to the radial distance from the center line of the bolts to the line of the gasket reaction, as shown in Table XI-3221.2-2, in.
l	= length of flange of flanged heads, measured from the tangent line of knuckle, as indicated in Fig. NE-3325-1 sketches (a) and (c), in.
m	= the ratio t_r/t_s
P	= Design Pressure, psi
r	= inside corner radius on a head formed by flanging or

¹¹ The minimum thickness for all pipe materials is the nominal wall thickness listed in Table 2 of ANSI B36.10, less 12 $\frac{1}{2}$ %. For diameters other than those listed in the table, this shall be based on the next largest pipe size.

	forging, in.
S	= maximum allowable stress, psi, from Section II, Part D, Subpart 1, Tables 1A and 1B, times 1.1
t	= minimum required thickness of flat head or cover, exclusive of corrosion allowance, in.
t_f	= actual thickness of the flange on a forged head, at the large end, exclusive of corrosion allowance, as indicated in Fig. NE-3325-1 sketches (b-1) and (b-2), in.
t_h	= actual thickness of flat head or cover, exclusive of corrosion allowance, in.
t_p	= the smallest dimension from the face of the head to the edge of the weld preparation, in.
t_r	= required thickness of shell, for pressure, in.
t_s	= actual thickness of shell, exclusive of corrosion allowance, in.
t_w	= thickness through the weld joining the edge of a head to the inside of a vessel, as indicated in Fig. NE-3325-1 sketch (f), in.
t_1	= throat dimension of the closure weld, as indicated in Fig. NE-3325-1 sketch (p), in.
W	= total bolt load, lb, given for circular heads for Eqs. (3) and (4), XI-3223

NE-3325.2 Thickness.

The thickness of flat unstayed heads, covers, and blind flanges shall conform to one of the following two requirements.
12

(a) Circular blind flanges of ferrous materials conforming to ANSI B16.5 shall be acceptable for the diameters and pressure temperature ratings in Tables 2 to 8 of that Standard, when of the types shown in Fig. NE-3325-1 sketches (j) and (k).

(b) The minimum required thickness of flat unstayed circular heads, covers, and blind flanges shall be calculated by the formula:

$$(1) t = d \sqrt{CP/S}$$

12 The formulas provide safe construction as far as stress is concerned. Greater thickness may be necessary if deflection would cause leakage at threaded or gasketed joints.

except when the head, cover, or blind flange is attached by bolts causing an edge moment [Fig. NE-3325-1 sketch (n)], in which case the thickness shall be calculated by:

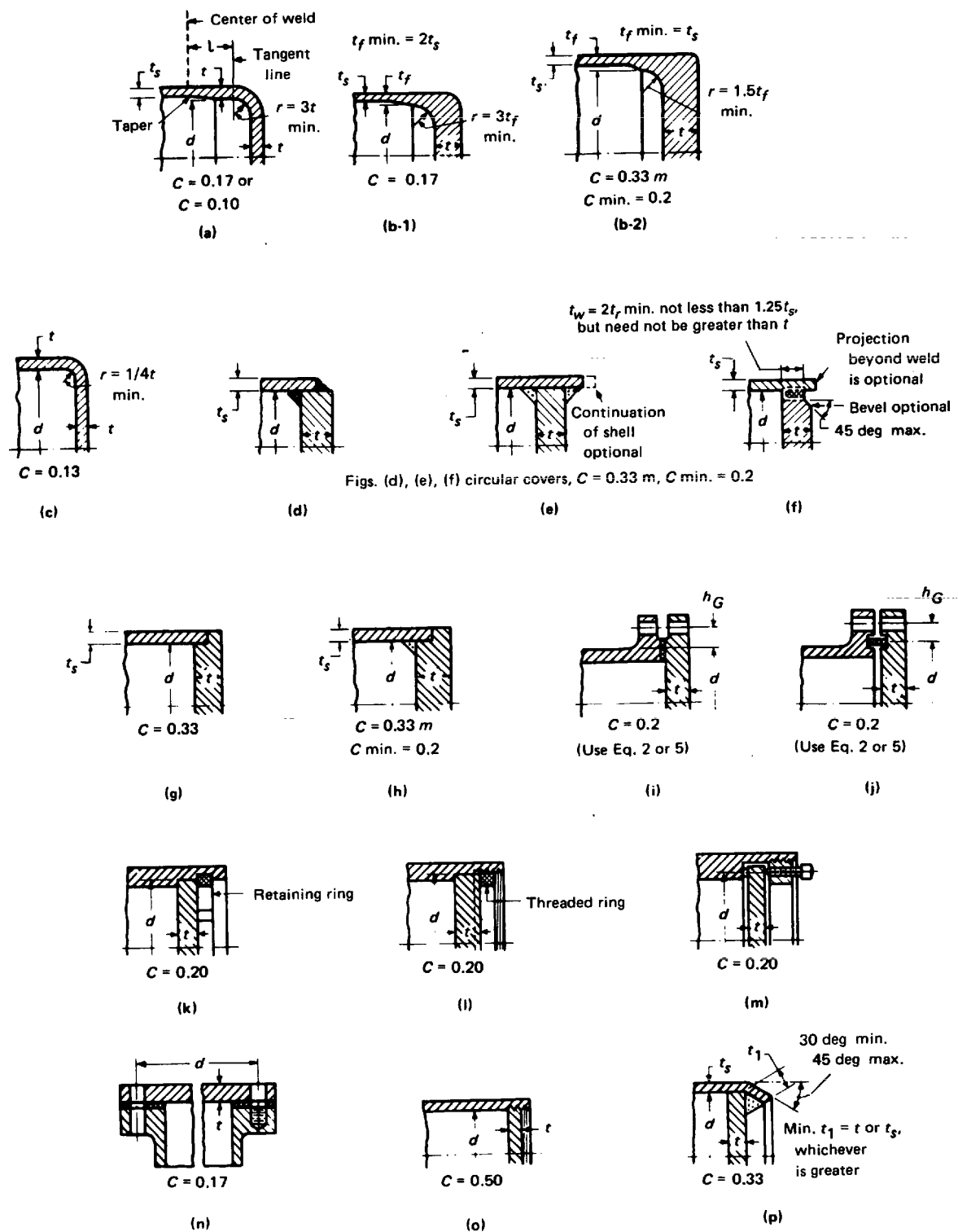


FIG. NE-3325-1 SOME ACCEPTABLE TYPES OF UNSTAYED FLAT HEADS AND COVERS

FIG. NE-3325-1 SOME ACCEPTABLE TYPES OF UNSTAYED FLAT HEADS AND COVERS

$$(2) t = d \sqrt{CP/S + 1.27 W h_G / S d^3}$$

When using Eq. (2), the thickness t shall be calculated for both Service Loadings and gasket seating, and the greater of the two values shall be used. For Service Loadings, the value of P shall be the Design Pressure, and the values of S at the Design Temperature and W from Formula (3) of XI-3223 shall be used. For gasket seating, P equals zero, and the values of S at atmospheric temperature and W from Eq. (4) of XI-3223 shall be used.

[98]

NE-3325.3 Values of C .

For the types of construction shown in Fig. NE-3325-1 and Fig. NE-4243.1-1, the minimum values of C to be used in Eqs. (1) and (2) shall be as given in (a) through (l) below for Fig. NE-3325-1 and in (m) below for Fig. NE-4243.1-1.

(a) In sketch (a), $C = 0.17$ for flanged circular heads forged integral with or butt welded to the vessel with an inside corner radius not less than three times the required head thickness, with no special requirement with regard to length of flange.

(1) $C = 0.10$ for circular heads, when the flange length for heads of the above design is not less than:

$$l = \left[1.1 - 0.8 \frac{t_s^2}{t_h^2} \right] \sqrt{d t_h} \quad (3)$$

(3)

(2) $C = 0.10$ for circular heads, when the flange length l is less than the requirement in Eq. (3) but the shell thickness is not less than:

$$t_s = 1.12 t_h \sqrt{1.1 - l / \sqrt{d t_h}} \quad (4)$$

(4)

for a length of at least $2\sqrt{d t_s}$.

(3) When $C = 0.10$ is used, the taper shall be 1:4.

(b) In sketch (b-1), $C = 0.17$ for forged circular heads integral with or butt welded to the vessel, where the flange thickness is not less than two times the shell thickness, the corner radius on the inside is not less than three times the flange thickness and the welding meets all the requirements of NE-4000.

(c) In sketch (b-2), $C = 0.33m$ but not less than 0.3 for forged circular heads integral with or butt welded to the vessel,

where the flange thickness is not less than the shell thickness and the corner radius on the inside is not less than 1.5 times the flange thickness. [See Fig. NE-4243.1-1 sketches (a) and (b) for the special case where $t_f = t_s$.]

(d) In sketch (c), $C = 0.13$ for integral flat circular heads when the dimension d does not exceed 24 in., the ratio of thickness of the head to the dimension d is not less than 0.05 nor greater than 0.25, the head thickness t_h is not less than the shell thickness t_s , the inside corner radius is not less than $0.25t_s$, and the construction is obtained by special techniques of upsetting and spinning the end of the shell, such as employed in closing header ends.

(e) In sketches (d), (e), and (f), $C = 0.33m$ but not less than 0.3 for circular plates welded to the inside of a vessel and otherwise meeting the requirements for the respective types of welded vessels. If a value of m less than 1 is used in calculating t , the shell thickness t_s shall be maintained along a distance inwardly from the inside face of the head equal to at least $2\sqrt{dt_s}$. The throat thickness of the fillet welds in sketch (e) shall be at least $0.7t_s$. The size of the weld t_w in sketch (f) shall not be less than two times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness but need not be greater than the head thickness; the weld shall be deposited in a welding groove with the root of the weld at the inner face of the head as shown in the figure.

(f) In sketch (g), $C = 0.33$ for circular plates welded to the end of the shell when t_s is at least $1.25t_r$ and the weld details conform to the requirements of NE-3358.3(e) and Fig. NE-4243-1 sketches (a) through (g).

(g) In sketch (h), $C = 0.33m$ but not less than 0.3 for circular plates if an inside fillet weld with minimum throat thickness of $0.7t_s$ is used and the details of the outside weld conform to the requirements of NE-3358.3(c) and Fig. NE-4243-1 sketches (a) through (g), in which the inside weld can be considered to contribute an amount equal to t_s to the sum of the dimensions a and b .

(h) In sketches (i) and (j), $C = 0.2$ for circular heads and covers bolted to the vessel as indicated in the figures. Note that Eq. (2) shall be used because of the extra moment applied to the cover by the bolting. When the cover plate is grooved for a peripheral gasket as shown in sketch (j), the net cover plate thickness under the groove or between the groove and the outer edge of the cover plate shall not be less than $d\sqrt{1.27Wh_G/Sd^3}$ for circular heads and covers.

(i) In sketches (k), (l), and (m), $C = 0.2$ for a circular plate inserted into the end of a vessel and held in place by a positive mechanical locking arrangement, and when all possible means of failure (either by shear, tension, compression, or radial deformation, including flaring, resulting from pressure and differential thermal expansion) are resisted using stresses consistent with this Article. Seal welding may be used, if desired.

(j) In sketch (n), $C = 0.17$ for circular covers, bolted with a full-face gasket, to shells, flanges, or side plates.

Page 92

(k) In sketch (o), $C = 0.50$ for circular plates screwed into the end of a vessel having an inside diameter d not exceeding 12 in. (305 mm), or for heads having an integral flange screwed over the end of a vessel having an inside diameter d not exceeding 12 in. (305 mm), and when the design of the threaded joint against failure by shear, tension, compression, or radial deformation, including flaring resulting from pressure and differential thermal expansion, is based on stresses consistent with this Article. Seal welding may be used.

(l) In sketch (p), $C = 0.33$ for circular plates having a dimension d not exceeding 18 in. (457 mm) inserted into the vessel as shown and otherwise meeting the requirements for the respective types of welded vessels. The end of the vessel shall be crimped over at least 30 deg but not more than 45 deg. The throat of the weld shall not be less than the thickness of the flat head or shell, whichever is greater.

(m) In Fig. NE-4243.1-1, $C = 0.33m$ but not less than 0.3 when the dimensional requirements of NE-3358.4 are met. [98]

NE-3326 Spherically Dished Covers With Bolting Flanges

NE-3326.1 Nomenclature.

The symbols used are defined as follows:

t	= minimum required thickness of head plate after forming, in.
L	= inside spherical or crown radius, in.
r	= inside knuckle radius, in.
P	= Design Pressure, psi
S	= maximum allowable stress value, psi
T	= flange thickness, in.
M_o	= the total moment, in.-lb, determined as in XI-3230 for heads concave to pressure, and XI-3260 for heads convex to pressure; except that for heads of the type shown in Fig. NE-3326.1-1 sketch (d), H_D and h_D shall be as defined below, and an additional moment $H_r h_r$ ¹³ shall be included
H_r	= radial component of the membrane load in the spherical segment = $H_D \cot \beta_1$, lb, acting at the intersection of the inside of the flange ring with the center line of the dished cover thickness
h_r	= lever arm of H_r about centroid of flange ring, in.

¹³ Since $H_r h_r$ in some cases will subtract from the total moment, the moment in the flange ring when the internal pressure is zero may be the determining loading for the flange design.

H_D	= axial component of the membrane load in the spherical segment, lb, acting at the inside of the flange ring = $0.785B^2P$
h_D	= radial distance from the bolt circle to the inside of the flange ring, in.
β_1	= angle formed by the tangent to the center line of the dished cover thickness at its point of intersection with the flange ring, and a line perpendicular to the axis of the dished cover, where

$$\beta = \arcsin \left(\frac{B}{2L + t} \right)$$

A	= outside diameter of flange, in.
B	= inside diameter of flange, in.
C	= bolt circle diameter, in.

[98]

NE-3326.2 Spherically Dished Heads With Bolting Flanges.

Circular spherically dished heads with bolting flanges, both concave and convex to the pressure and conforming to the several types illustrated in Fig. NE-3326.1-1, shall be designed in accordance with the requirements of (a) through (d) below. For heads convex to pressure, the spherical segments shall be thickened, if necessary, to meet the requirements of NE-3133. The actual value of the total moment M may calculate to be either plus or minus for both the heads concave to

pressure and the heads convex to pressure. However, for use in all of the formulas which follow, the absolute values for both P and M_o shall be used.

(a) Heads of the type shown in Fig. NE-3326.1-1 sketch (a):

(1) the thickness of the head t shall be determined by the appropriate equation in NE-3324;

(2) the head radius L or the knuckle radius r shall not exceed the limitations given in NE-3324;

(3) the flange shall comply with at least the requirements of Fig. XI-3120-1 and shall be designed in accordance with the applicable provisions of Appendix XI; within the range of ANSI B16.5, the flange facings and drillings should conform to those Standards and the thickness specified therein shall be considered as a minimum requirement.

(b) Heads of the type shown in Fig. NE-3326.1-1 sketch (b):

(1) head thickness t :

$$t = \frac{5PL}{6S} \quad (5)$$

(5)

(2) flange thickness T :

for ring gasket:

$$T = \sqrt{\frac{M_o}{SB} \left[\frac{A + B}{A - B} \right]} \quad (6)$$

(6)

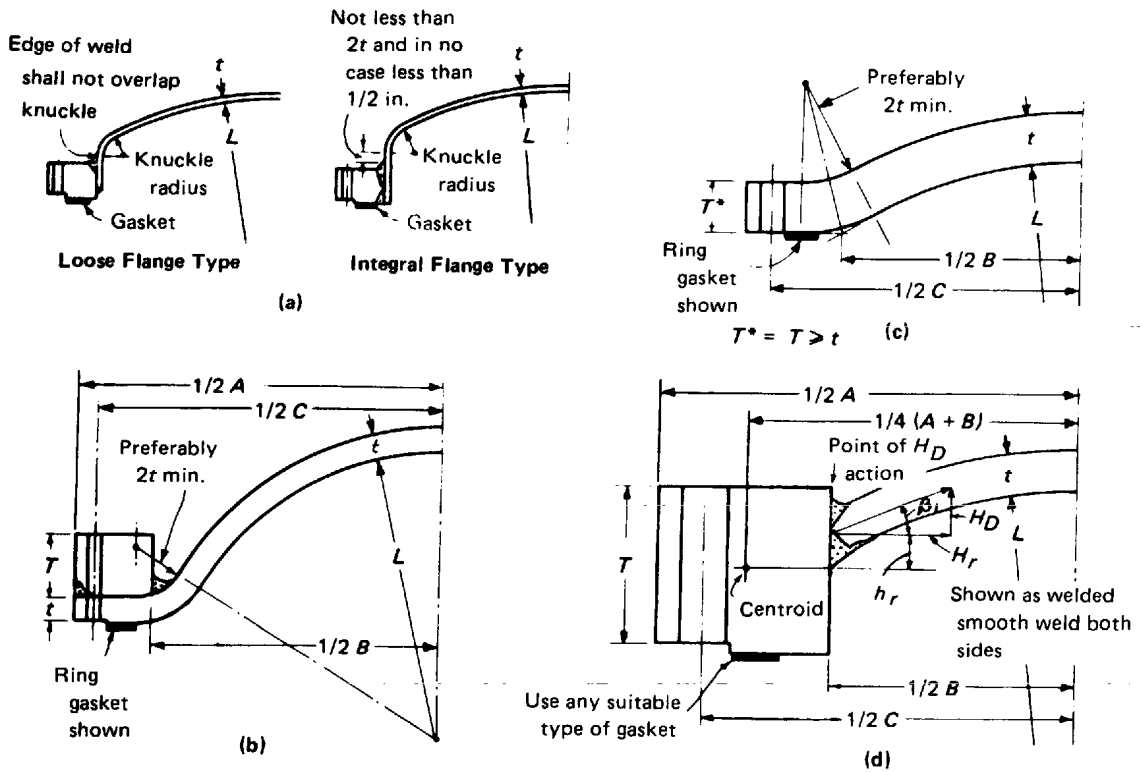


FIG. NE-3326.1-1 SPHERICALLY DISHED COVERS WITH BOLTING FLANGES

FIG. NE-3326.1-1 SPHERICALLY DISHED COVERS WITH BOLTING FLANGES

for full-faced gasket:

$$T = 0.6 \sqrt{\frac{P}{S} \left[\frac{B(A + B)(C - B)}{A - B} \right]} \quad (7)$$

(7)

NOTE: The radial components of the membrane load in the spherical segment are assumed to be resisted by its flange.

Within the range of ANSI B16.5, the flange facings and drillings should conform to those Standards, and the thickness specified therein shall be considered as a minimum requirement.

(c) Heads of the type shown in Fig. NE-3326.1-1 sketch (c):

(1) Head thickness:

$$t = \frac{5PL}{6S} \quad (8)$$

(8)

(2) Flange thickness for ring gaskets shall be calculated as follows:

(a) for heads with round bolting holes:

$$T = Q + \sqrt{\frac{1.875 M_o (C + B)}{SB(7C - 5B)}} \quad (9)$$

(9)

where

$$Q = \frac{PL}{4S} \left(\frac{C + B}{7C - 5B} \right) \quad (10)$$

(10)

(b) for heads with bolting holes slotted through the edge of the head:

$$T = Q + \sqrt{\frac{1.875 M_o (C + B)}{SB(3C - B)}} \quad (11)$$

(11)

where

Page 94

$$Q = \frac{PL}{4S} \left(\frac{C + B}{3C - B} \right) \quad (12)$$

(12)

(3) Flange thickness for full face gaskets shall be as calculated in Eq. (13):

$$T = Q + \sqrt{Q^2 + \frac{3BQ(C - B)}{L}} \quad (13)$$

(13)

The value of Q in Eq. (13) is calculated by Eq. (10) for round bolting holes or by Eq. (12) for bolting holes slotted through the edge of the head [see (c)(2) above].

(4) The required flange thickness shall be T as calculated in Eq. (6) or (7) above, but in no case less than the value of t as calculated in Eq. (5);

(d) Heads of the type shown in Fig. NE-3326.1-1 sketch (d):

(1) Head thickness t :

$$t = \frac{5PL}{6S} \quad (14)$$

(14)

(2) Flange thickness T :

$$(15) T = F + \sqrt{F^2 + J}$$

where

$$F = \frac{PB \sqrt{4L^2 - B^2}}{8S(A - B)} \quad (16)$$

(16)

$$J = \left(\frac{M_o}{SB} \right) \left(\frac{A + B}{A - B} \right) \quad (17)$$

(17)

NOTE: These equations are approximate in that they do not take into account continuity between the flange ring and the dished head. A more exact method of analysis which takes this into account may be used if it meets the requirements of NE-3200. Such a method may parallel the method of analysis and allowable stresses for flange design in Appendix XI.

[98]

NE-3327 Quick Actuating Closures

Closures other than the multibolted type designed to provide access to the contents space of a component shall have the locking mechanism or locking device so designed that failure of any one locking element or component in the locking mechanism cannot result in the failure of all other locking elements and the release of the closure. Quick actuating closures shall be so designed and installed that it may be determined by visual external observation that the holding elements are in good condition and that their locking elements, when the closure is in the closed position, are in full engagement.

NE-3327.1 Positive Locking Devices.

Quick actuating closures that are held in position by positive locking devices and that are fully released by partial rotation or limited movement of the closure itself or the locking mechanism, and any closure that is other than manually operated, shall be so designed that when the vessel is installed the conditions of (a) through (c) below are met.

(a) The closure and its holding elements are fully engaged in their intended operating position before pressure can be built up in the vessel.

(b) Pressure tending to force the closure clear of the vessel will be released before the closure can be fully opened for access.

(c) In the event that compliance with (a) and (b) above is not inherent in the design of the closure and its holding elements, provision shall be made so that devices to accomplish this can be added when the vessel is installed.

NE-3327.2 Other Quick Access and Safety Devices.

It is recognized that it is impractical to write detailed requirements to cover the multiplicity of devices used for quick access, or to prevent negligent operation or the circumventing of safety devices. Any device or devices which will provide the safeguards broadly described in NE-3327.1 will meet the intent of this Subsection.

NE-3327.3 Manual Operation.

Quick actuating closures that are held in position by a locking device or mechanism that requires manual operation and are so designed that there will be leakage of the contents of the vessel prior to disengagement of the locking elements and release of closure need not satisfy NE-3327.1, but such closures shall be equipped with an audible or visible warning device that will serve to warn the operator if pressure is applied to the vessel before the closure and its holding elements are fully engaged in their intended position and, further, will serve to warn the operator if an attempt is made to operate the locking mechanism or device before the pressure within the vessel is released.

NE-3327.4 Pressure Indicating Device.

When installed, all vessels having quick actuating closures shall be provided with a pressure indicating device visible from the operating area.

Page 95

NE-3328 Combination Units

When a pressure vessel unit consists of more than one independent pressure chamber, operating at the same or different pressures and temperatures, each such chamber shall be designed and constructed to withstand the most severe condition of coincident pressure and temperature expected in normal service. Only the parts of chambers which come within the scope of this Subsection need be constructed in compliance with its provisions.

NE-3330 OPENINGS AND REINFORCEMENT

NE-3331 General Requirements for Openings

(a) For vessels or parts thereof which are not in cyclic service, analysis showing satisfaction of the requirements of NE-3221.1, NE-3221.2, and NE-3221.3, and NE-3221.4 in the immediate vicinity of the openings is not required for pressure loading if the rules of NE-3330 are met.

(b) For vessels or parts thereof which are in cyclic service and do not meet the requirements of NE-3221.5(d) for the specified Service Loads so that a fatigue analysis is required, the rules contained in NE-3330 assure that the stresses resulting from pressure load satisfy only the requirements of NE-3221.1, NE-3221.2, and NE-3221.3 in the vicinity of openings, and no specific analysis showing satisfaction of those stress limits is required. The requirements of NE-3221.4 may also be considered to be satisfied if, in the vicinity of the nozzle, the stress intensity resulting from external nozzle loads and thermal effects, including gross but not local structural discontinuities, is shown by analysis to be less than $1.5S_m$. In this case, when evaluating the requirements of NE-3221.5(e), the peak stress intensities resulting from pressure loadings may be obtained by application of the stress index method of NE-3338.

(c) The provisions of (a) and (b) above are not intended to restrict the design to any specified section thicknesses or other design details, provided the basic stress limits are satisfied. If it is shown by analysis that all the stress requirements have been met, the rules of NE-3330 are waived.

(d) Openings shall be circular, elliptical, or of any other shape which results from the intersection of a circular or elliptical cylinder with a vessel.

(e) Properly reinforced openings in cylindrical and spherical shells are not limited as to size. Rules regarding metal available for reinforcement are given in NE-3335.

(f) All references to dimensions apply to the finished dimensions, excluding material added as corrosion allowance.

(g) Openings may be located in welded joints.

NE-3332 Reinforcement Requirements for Openings in Shells and Formed Heads

NE-3332.1 Openings Not Requiring Reinforcement.

Reinforcement shall be provided in amount and distribution such that the requirements for area of reinforcement are satisfied for all planes through the center of the opening and normal to the surface of the vessel, except that single circular openings need not be provided with reinforcement if the openings have diameters equal to or less than $2\frac{1}{2}$ in. (64 mm).

NE-3332.2 Required Area of Reinforcement.

The total cross-sectional area of reinforcement A required in any given plane for a vessel under internal pressure shall not be less than:

$$A = dt_r F$$

where

d	= finished diameter of a circular opening or finished dimension (chord length) of an opening on the plane being considered for elliptical and obround openings in corroded condition, in.
F	= a correction factor which compensates for the variation in pressure stresses on different planes with respect to the axis of a vessel. (A value of 1.00 shall be used for all configurations, except that Fig. NE-3332.2-1 may be used for integrally reinforced openings in cylindrical shells and cones.)
t_r	= the required thickness of a shell or head computed by the rules of this Article for the Design Pressure, in., except as given in (a), (b), and (c) below:

(a) when the opening and its reinforcement are entirely within the spherical portion of a torispherical head, t_r is the thickness required by NE-3324.8(b) using $M = 1$;

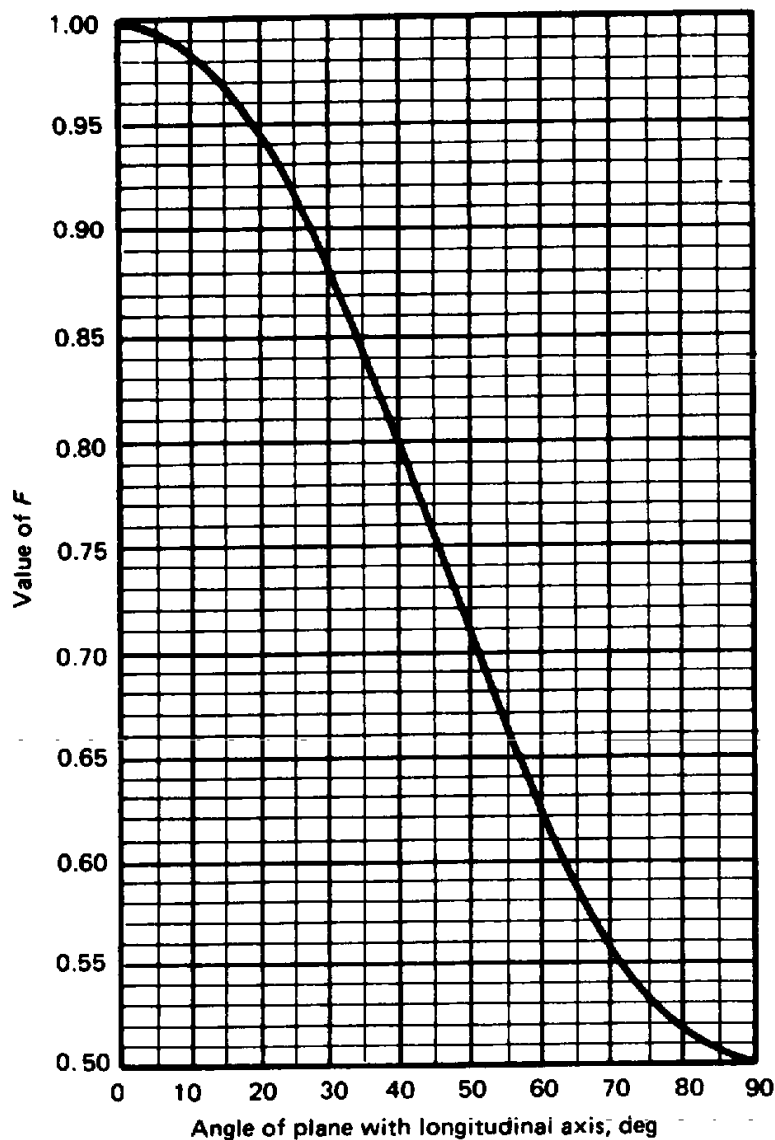
(b) when the opening is in a cone, t is the thickness required for a seamless cone of diameter D measured where the

nozzle axis pierces the inside wall of the cone;

(c) when the opening and its reinforcement are in an ellipsoidal head and are located entirely within a circle, the center of which coincides

Page 96

with the center of the head and the diameter of which is equal to 80% of the shell diameter, t_r is the thickness required for a seamless sphere of radius $K_1 D$, where D is the shell diameter and K_1 is given by Table NE-3332.2-1.



**FIG. NE-3332.2-1 CHART FOR DETERMINING
VALUES OF F**

FIG. NE-3332.2-1 CHART FOR DETERMINING VALUES OF F

At least one-half of the required reinforcing shall be on each side of the center line of the opening.

NE-3332.4 Reinforcement for External Pressure.

The reinforcement required for openings in vessels designed for external pressure need only be 50% of that required in the formula for area in NE-3332.2, except that t_r is the wall thickness required by the rules for components under external pressure.

NE-3332.5 Reinforcement for Both Internal and External Pressure.

Reinforcement of vessels subject to both internal and external pressures shall meet the requirements of NE-3332.2 for internal pressure and of NE-3332.4 for external pressure.

TABLE NE-3332.2-1
VALUES OF SPHERICAL RADIUS FACTOR K_1
Equivalent Spherical Radius = $K_1 D$; $D/2h$ = Axis Ratio.
Interpolation Permitted for Intermediate Values.

$D/2h$		3.0	2.8	2.6	2.4	2.2
K_1		1.36	1.27	1.18	1.08	0.99
$K/2h$	2.0	1.8	1.6	1.4	1.2	1.0
K_1	0.90	0.81	0.73	0.65	0.57	0.50

TABLE NE-3332.2-1 VALUES OF SPHERICAL RADIUS FACTOR K_1

NE-3333 Reinforcement Required for Openings in Flat Heads

(a) Flat heads that have an opening with a diameter that does not exceed one-half of the head diameter shall have a total cross-sectional area of reinforcement not less than that given by the formula:

$$A = 0.5dt_r$$

where d is as defined in NE-3332.2 and t_r is the thickness in inches which meets the requirements of NE-3325 in the absence of the opening.

(b) As an alternative to (a) above, the thickness of flat heads may be increased to provide the necessary opening reinforcement as follows:

(1) in Eq. (1) of NE-3325.2, by using $2C$ or 0.75 in place of C , whichever is less;

(2) in Eq. (2) of NE-3325.2, by doubling the quantity under the square root sign.

NE-3334 Limits of Reinforcement

The boundaries of the cross-sectional area in any plane normal to the vessel wall and passing through the center of the opening and within which metal shall be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane and are given in the following subparagraphs.

NE-3334.1 Limit of Reinforcement Along the Vessel Wall.

The limits of reinforcement, measured along the midsurface of the nominal wall thickness, shall meet the following.

(a) One hundred percent of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) the diameter of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus the sum of the thicknesses of the vessel wall and the nozzle wall.

(b) Two-thirds of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) $r + 0.5\sqrt{R}t$, where R is the mean radius of shell or head, t is the nominal vessel wall thickness, and r is the radius of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus two-thirds the sum of the thicknesses of the vessel wall and the nozzle wall.

NE-3334.2 Limit of Reinforcement Normal to the Vessel Wall.

The limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to the following limits as shown in Fig. NE-3334.2-1 and specified in (a), (b), and (c) below.

(a) For Fig. NE-3334.2-1 sketches (a), (b), (d), and (e):

$$\text{limit of reinforcement} = 0.5 \sqrt{r_m^2 - t_n^2} + 0.5r_2$$

where

$$r_m = \text{mean radius} = r_i + 0.5t_n$$

$$r_i = \text{inside radius, in.}$$

$$t_n = \text{nominal nozzle thickness, as indicated, in.}$$

$$r_2 = \text{transition radius between nozzle and wall, in.}$$

For the case of a nozzle with a tapered inside diameter, the limit shall be obtained by using r_i and t_n values at the nominal outside diameters of the vessel wall [Fig. NE-3334.2-1 sketch (e)].

(b) For Fig. NE-3334.2-1 sketches (c) and (f):

$$\text{limit of reinforcement} = 0.5 \sqrt{r_m^2 - t_n^2}$$

where

$$r_m = r_i + 0.5 t_n$$

$$r_i = \text{inside radius, in.}$$

$$t_n = t_p + 0.667X$$

t_p	= nominal thickness of the attached pipe, in.
X	= slope offset distance, in.
θ	= angle between vertical and slope, 45 deg or less

For the case of a nozzle with a tapered inside diameter, the limit shall be obtained by using r_i and t_n values at the center of gravity of nozzle reinforcement area. These values must be determined by a trial and error procedure [Fig. NE-3334.2-1 sketch (f)].

(c) When reinforcing pads or insert plates are used, the limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to $(0.5 \sqrt{r_m t_n} + t_e)$ or $(2.5 t_n + t_e)$, whichever is larger, where r_m is the mean nozzle radius, t_n is the nozzle thickness, and t_e is equal to the thickness of any added reinforcement or 1.5 times the vessel wall thickness, whichever is smaller.

NE-3335 Metal Available for Reinforcement

Metal may be counted as contributing to the area of reinforcing called for in NE-3332, provided it lies within the limits of reinforcement specified in NE-3334 and shall be limited to material which meets the following requirements:

- (a) metal forming a part of the vessel wall which is in excess of that required in accordance with NE-3130 and is exclusive of corrosion allowance;
- (b) similar excess metal in the nozzle wall, provided the nozzle is integral with the vessel wall or is joined to it by a full penetration weld;
- (c) weld metal which is fully continuous with the vessel wall;
- (d) the mean coefficient of thermal expansion of metal to be included as reinforcement under (b) or (c) above shall be within 15% of the value of the vessel wall material;
- (e) metal not fully continuous with the shell, as that in nozzles attached by partial penetration welds on only one side, shall not be counted as reinforcement;
- (f) metal available for reinforcement shall not be considered as applying to more than one opening;
- (g) not less than one-half the required material shall be on each side of the center line of the opening.

NE-3335.1 Reinforcement of Multiple Openings

(a) When any two openings in a group of two or more openings are spaced at less than two times their average diameter so that their limits of reinforcement overlap, the two openings shall be reinforced in the plane connecting the centers (Fig. NE-3335.1-1), in accordance with NE-3330 through NE-3336, with a combined reinforcement that has an area equal to the combined area of the reinforcements required for separate openings. No portion of the cross section is to be considered as applying to more than one opening, or to be evaluated more than once in a combined area. The following requirements shall also apply.

(1) When the distance between the centers of the openings is greater than $1\frac{1}{3}$ times their average diameter, the area of reinforcement between them shall be

not less than 50% of the total required for these openings.

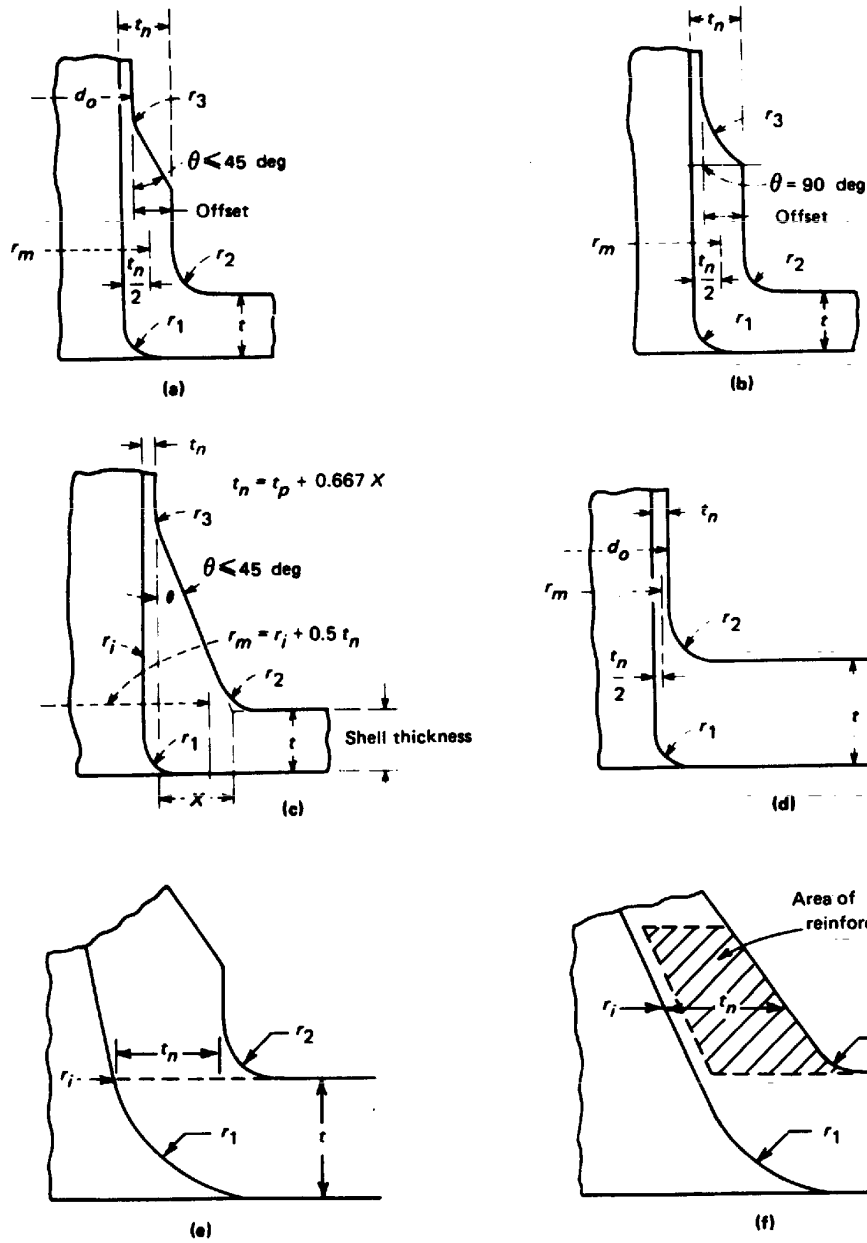
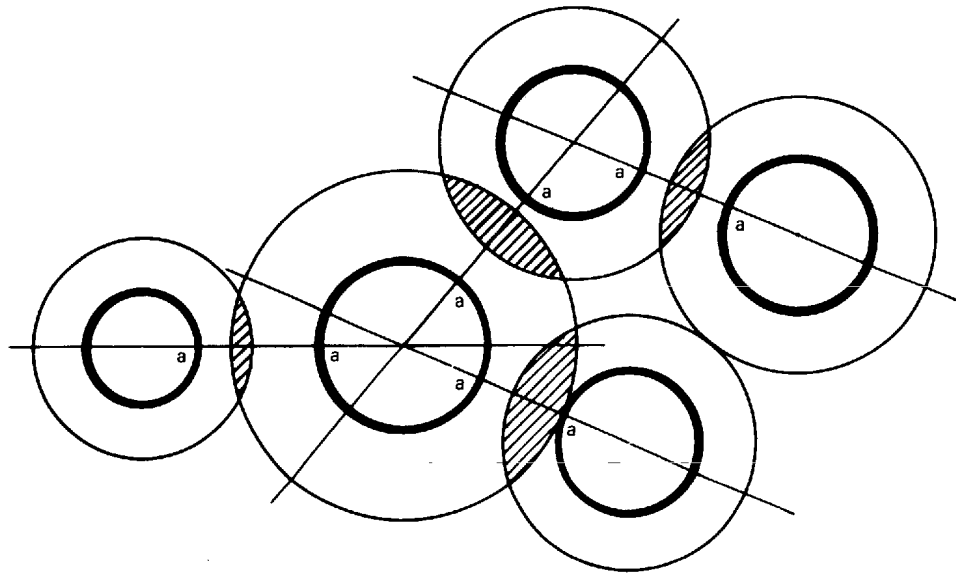


FIG. NE-3334.2-1 NOZZLE DIMENSIONS

FIG. NE-3334.2-1 NOZZLE DIMENSIONS



GENERAL NOTES:

- (1) Hatched area represents overlapping of the reinforcement limits.
- (2) Each cross section indicated by a straight line a-a must be investigated for adequacy of reinforcement.
- (3) Heavy circles represent openings, and light circles represent limits of reinforcement.

FIG. NE-3335.1-1 ARRANGEMENT OF MULTIPLE OPENINGS

FIG. NE-3335.1-1 ARRANGEMENT OF MULTIPLE OPENINGS

(2) When the distance between the centers of the openings is less than $1\frac{1}{3}$ times their average diameter, no credit for reinforcement shall be taken for any of the material between these openings, and the openings shall be reinforced as described in (b) below.

(b) Any number of adjacent openings, in any arrangement, may be reinforced for an assumed opening of a diameter enclosing all such openings. The diameter of the assumed opening shall not exceed the following:

(1) for vessels 60 in. (1520 mm) diameter and less, one-half the vessel diameter, but not to exceed 20 in. (508 mm);

(2) for vessels over 60 in. (1520 mm) diameter, one-third the vessel diameter, but not to exceed 40 in. (1000 mm)

(c) When a group of openings is reinforced by a thicker section butt welded into the shell or head, the edges of the inserted section shall be tapered as prescribed in NE-3361.

NE-3336 Strength of Reinforcing Material

Material used for reinforcement shall be preferably the same as that of the vessel wall. If the material of the nozzle wall or reinforcement has a lower design stress value S than the vessel material, the amount of area provided by the nozzle wall or reinforcement in satisfying the requirements of NE-3332 shall be taken as the actual area provided multiplied by the ratio of the nozzle or reinforcement design stress value to the vessel material design stress value. No reduction in the reinforcing required may be taken for the increased strength of reinforcing material and weld metal having higher design stress values than that of the material of the vessel wall. Deposited weld metal outside of either the vessel wall or any

reinforcing pad used as reinforcement shall be credited with an allowable stress value equivalent to the weaker of the materials connected by the weld. Vessel-to-nozzle or pad-to-nozzle attachment weld metal within the vessel wall or within the pad may be credited with a stress value equal to that of the vessel wall or pad, respectively.

Page 100

NE-3336.1 Strength of Weld.

On each side of the plane defined in NE-3334, the strength of the attachment joining the vessel wall and reinforcement or any two parts of the attached reinforcement shall be at least equal to the lesser of (a) or (b) below:

- (a) the strength in tension of the cross section of the element of reinforcement being considered; or
- (b) the strength in tension of the area defined in NE-3332 less the strength in tension of the reinforcing area which is integral in the vessel wall.

NE-3336.2 Strength of Attachment.

The strength of the attachment joint shall be considered for its entire length on each side of the plane of the area of reinforcement defined in NE-3334. For obround openings, consideration shall also be given to the strength of the attachment joint on one side of the plane transverse to the parallel sides of the opening which passes through the center of the semicircular end of the opening.

NE-3338 Pressure Stresses in Openings for Fatigue Evaluation Under Operating Conditions

NE-3338.1 General.

For the purpose of determining peak stresses around the opening, three acceptable methods are listed below.

(a) *Analytical Method.* This method uses suitable analytical techniques such as finite element computer analyses, which provide detailed stress distributions around openings. In addition to peak stresses due to pressure, the effects of other loadings shall be included. The total peak stress at any given point shall be determined by combining stresses due to pressure, thermal, and external loadings in accordance with the rules of NE-3200.

(b) *Experimental Stress Analysis.* This is based on data from experiments (Appendix II).

(c) *Stress Index Method.* This uses various formulas together with available data obtained from an extensive series of tests covering a range of variation of applicable dimensional ratios and configurations (NE-3338.2). This method covers only single, isolated openings. Stress indices may also be determined by theoretical or experimental stress analysis.

[98]

NE-3338.2 Stress Index Method

(a) The term *stress index*, as used herein, is defined as the numerical ratio of the stress components σ_r , σ_n , and σ_t under consideration to the computed membrane stress in the unpenetrated vessel material. However, the material which increases the thickness of a vessel wall locally at the nozzle shall not be included in the calculations of these stress components. When the thickness of the vessel wall is increased over that required to the extent provided hereinafter, the values of r_1 and r_2 in Fig. NE-3334.2-1 shall be referred to the thickened section.

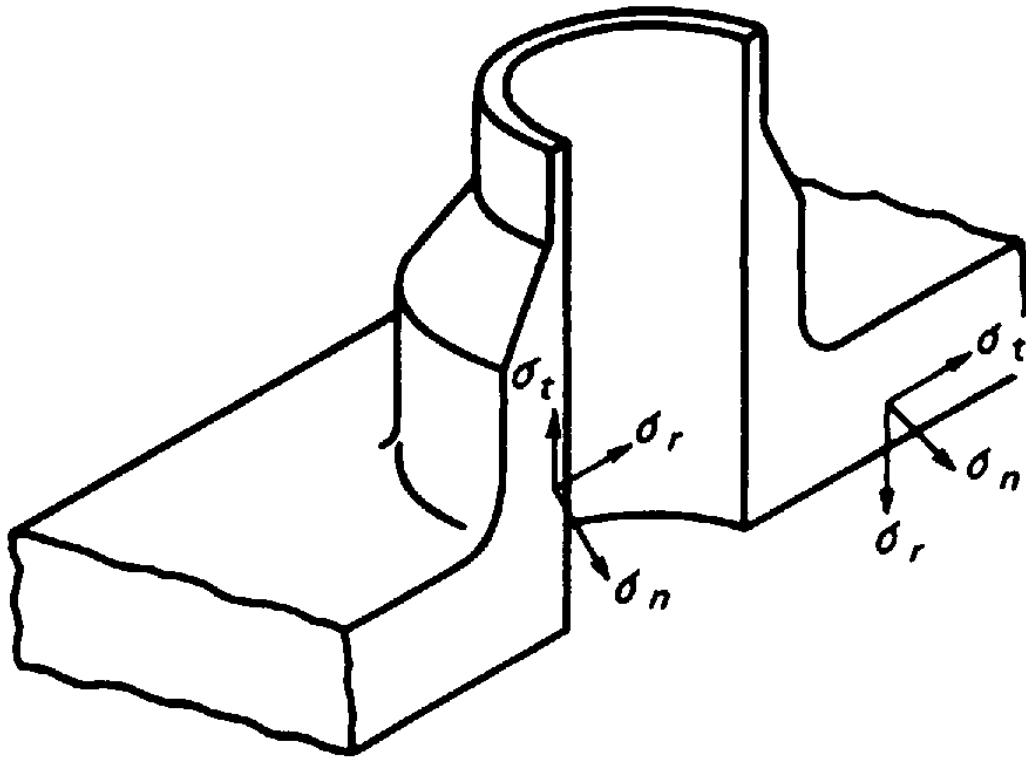


FIG. NE-3338.2-1 DIRECTION OF STRESS COMPONENTS

FIG. NE-3338.2-1 DIRECTION OF STRESS COMPONENTS

(b) The symbols for the stress components are shown in Fig. NE-3338.2-1 and are defined as follows:

σ_t	= the stress component in the plane of the section under consideration and parallel to the boundary of the section, psi
σ_n	= the stress component normal to the plane of the section (ordinarily the circumferential stress around the hole in the shell), psi
σ_r	= the stress component normal to the boundary of the section, psi
S	= the stress intensity (combined stress) at the point under consideration, psi

(c) When the conditions of (d) below are satisfied, the stress indices of Table NE-3338.2(c)-1 may be used for nozzles designed in accordance with the applicable rules of NE-3330. These stress indices deal only with the maximum stresses, at certain general locations, due to internal pressure. In the evaluation of stresses in or adjacent to vessel openings and connections, it is often necessary to consider the effect of stresses due to external loadings or thermal stresses. In such cases, the total stress at a given point may be determined by superposition. In the case of combined stresses due to internal pressure and nozzle loading, the maximum stresses for a given location should be considered as acting at the same point and added algebraically, unless positive evidence is available to the contrary.

Page 101

**TABLE NE-3338.2(c)-1
STRESS INDICES FOR NOZZLES**

Nozzles in Spherical Shells and Formed Heads		
Stress	Inside Corner	Outside Corner
σ_n	2.0	2.0
σ_t	-0.2	2.0
σ_r	$-2t_n/R$	0
S	2.2	2.0

Nozzles in Cylindrical Shells				
Stress	Longitudinal Plane		Transverse Plane	
	Inside	Outside	Inside	Outside
σ_n	3.1	1.2	1.0	2.1
σ_t	-0.2	1.0	-0.2	2.6
σ_r	$-t_n/R$	0	$-t_n/R$	0
S	3.3	1.2	1.2	2.6

TABLE NE-3338.2(c)-1 STRESS INDICES FOR NOZZLES

(d) The indices of Table NE-3338.2(c)-1 apply when the conditions stipulated in (1) through (6) below exist.

(1) The opening is for a circular nozzle whose axis is normal to the vessel wall. If the axis of the nozzle makes an angle ϕ with the normal to the vessel wall and if $d/D \leq 0.15$, an estimate of the σ_n index on the inside may be obtained

from one of the following equations.

For hillside connections in spheres or cylinders:

$$K_2 = K_1 (1 + 2 \sin^2 \varphi)$$

For lateral connections in cylinders:

$$K_2 = K_1 [1 + (\tan \varphi)^{4/3}]$$

where

K_1

= the σ_n inside stress index of Table NE-3338.2(c)-1 for a radial connection

K_2

= the estimated σ_n inside stress index for the nonradial connection

(2) The arc distance measured between the center lines of adjacent nozzles along the inside surface of the shell is not less than three times the sum of their inside radii for openings in a head or along the longitudinal axis of a shell and is not less than two times the sum of their radii for openings along the circumference of a cylindrical shell.

(3) The following dimensional ratios are met:

Ratio	Cylinder	Sphere
$\frac{\text{Inside shell diameter}}{\text{Shell thickness}} = \frac{D}{t}$	10 to 100	10 to 100
$\frac{\text{Inside nozzle diameter}}{\text{Inside shell diameter}} = \frac{d}{D}$	0.5, max.	0.5, max.
$\frac{d}{\sqrt{Dt}}$	—	0.8, max.
$d/\sqrt{Dt_n r_2/t}$	1.5, max.	—

TABLE - UNTITLED

In the case of cylindrical shells, the total nozzle reinforcement area on the transverse axis of the connections, including any outside of the reinforcement limits, shall not exceed 200% of that required for the longitudinal axis (compared to 50% permitted by Fig. NE-3332.2-1), unless a tapered transition section is incorporated into the reinforcement and the shell, meeting the requirements of NE-3361.

(4) The inside corner radius r_1 (Fig. NE-3334.2-1) is between 10% and 100% of the shell thickness t .

(5) The outer corner radius r_2 (Fig. NE-3334.2-1) is large enough to provide a smooth transition between the nozzles and the shell. In addition, for opening diameters greater than $1\frac{1}{2}$ times the shell thickness in cylindrical shells and 2:1 ellipsoidal heads and greater than three shell thicknesses in spherical shells, the value of r_2 shall not be less than one-half the thickness of the shell or nozzle wall, whichever is greater.

(6) The radius r_3 (Fig. NE-3334.2-1) is not less than the greater of the following:

(a) $0.002\theta d_o$ where d_o is the outside diameter of the nozzle and is as shown in Fig. NE-3334.2-1 and the angle θ is expressed in degrees;

(b) $2(\sin \theta)^3$ times offset for the configuration shown in Fig. NE-3334.2-1 sketches (a) and (b).

[98]

NE-3350 DESIGN OF WELDED CONNECTIONS

NE-3351 Welded Joint Categories

The term *Category* as used herein defines the location of a joint in a vessel but not the type of joint. The categories established by this paragraph are for specifying special requirements regarding joint type and degree of examination for certain welded pressure joints. Since these special requirements, which are based on service, material, and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in the categories. The

only when specifically stated. The joints included in each category are designated as joints of categories A, B, C, and D. Figure NE-3351-1 illustrates typical joint locations included in each category.

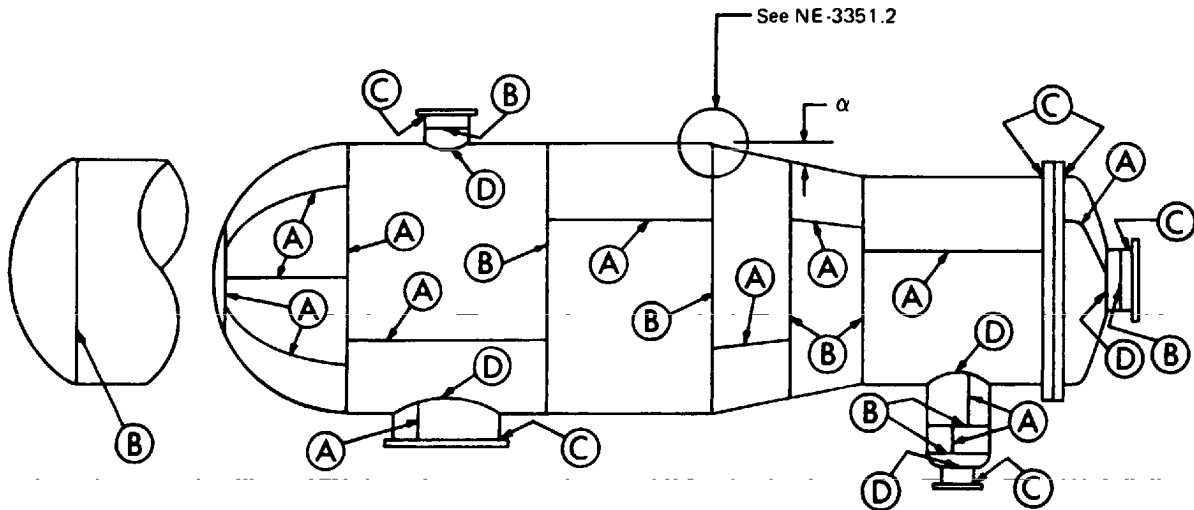


FIG. NE-3351-1 WELDED JOINT LOCATIONS TYPICAL OF CATEGORIES A, B, C, AND D

FIG. NE-3351-1 WELDED JOINT LOCATIONS TYPICAL OF CATEGORIES A, B, C, AND D

NE-3351.1 Category A.

Category A comprises longitudinal welded joints within the main shell or communicating chambers¹⁴ transitions in diameter or nozzles; welded joints within a sphere, within a formed or flat head, or within the side plates¹⁵ of a flat-sided vessel; circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameters, to nozzles, or to communicating chambers.

NE-3351.2 Category B.

Category B comprises circumferential welded joints within the main shell or communicating chambers¹⁴ nozzles or transitions in diameter including joints between the transition and a cylinder at either the large or small end; or circumferential welded joints connecting formed heads other than hemispherical to main shells, transitions in diameter, nozzles, or communicating chambers.

¹⁴ Communicating chambers are defined as appurtenances to the vessel which intersect the shell or heads of a vessel and form an integral part of the pressure retaining closure.

¹⁵ Side plates of a flat-sided vessel are defined as any of the flat plates forming an integral part of the pressure retaining enclosure.

NE-3351.3 Category C.

Category C comprises welded joints connecting flanges, Van Stone laps, tube sheets, or flat heads to the main shell, formed heads, transitions in diameter, nozzles, or communicating chambers¹⁴ any welded joint connecting one side plate¹⁵ to another side plate of a flat-sided vessel.

NE-3351.4 Category D.

Category D comprises welded joints connecting communicating chambers¹⁴ or nozzles to main shells, spheres, transitions in diameter, heads, or flat-sided vessels, and those joints connecting nozzles to communicating chambers. For nozzles at the small end of a transition in diameter, see Category B.

NE-3352 Permissible Types of Welded Joints

The design of the vessel shall meet the requirements for each category of joint. Butt joints are full penetration joints between plates or other elements that lie approximately in the same plane. Category B angle joints between plates or other elements that have an offset angle α not exceeding 30 deg are considered as meeting the requirements for butt joints. Figure NE-3352-1 shows typical butt welds for each category joint.

NE-3352.1 Joints of Category A.

All welded joints of Category A as defined in NE-3351 shall meet the fabrication requirements of NE-4241 and shall be capable of being examined in accordance with NE-5210.

NE-3352.2 Joints of Category B.

All welded joints of Category B as defined in NE-3351 shall meet the fabrication requirements of NE-4242 and shall be capable of being examined in accordance with NE-5220.

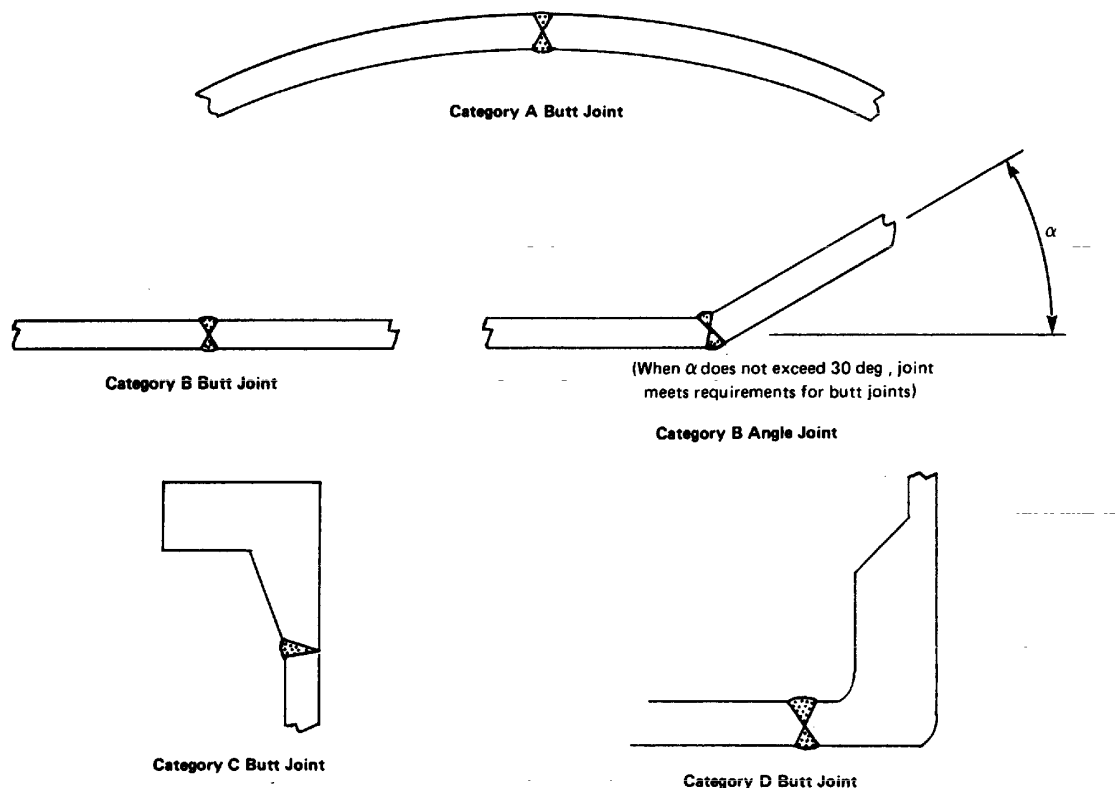


FIG. NE-3352-1 TYPICAL BUTT JOINTS

FIG. NE-3352-1 TYPICAL BUTT JOINTS

NE-3352.3 Joints of Category C.

All welded joints of Category C as defined in NE-3351 shall meet the fabrication requirements of NE-4243 and shall be capable of being examined in accordance with NE-5230. The minimum dimensions of Fig. NE-4243-1 and Fig. NE-4243-2 shall be met where

t_c	= $0.7 t_n$ or $\frac{1}{4}$ in., whichever is less
t_w	= the lesser of t_n or $t/2$
t, t_n	= nominal thickness, in.

NE-3352.4 Joints of Category D.

All welded joints of Category D as defined in NE-3351 shall be in accordance with the requirements of NE-3359 and one of (a) through (f) below.

(a) *Butt Welded Nozzles.* Nozzles shall meet the fabrication requirements of NE-4244(a) and shall be capable of being examined in accordance with NE-5241. The minimum dimensions and geometrical requirements of Fig. NE-4244(a)-1 shall be met where:

t	= nominal thickness of part penetrated, in.
t_n	= nominal thickness of penetrating part, in.
r_1	= $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2	= $\frac{1}{4}$ in. (6 mm) minimum

(b) *Full Penetration Corner Welded Nozzles.* Nozzles shall meet the fabrication requirements of NE-4244(b) and shall be capable of being examined as required in NE-5242. Inserted-type nozzles having added reinforcement in the form of a separate reinforcing plate shall be attached by welds at the outer edge of the reinforcement plate and at the nozzle periphery. The weld at the outer edge of the reinforcement shall be a fillet weld with a minimum throat dimension of $\frac{1}{2}t_{\min}$. The minimum dimensions of Fig. NE-4244(b)-1 shall be met where:

t	= nominal thickness of part penetrated, in.
t_n	= nominal thickness of penetrating part, in.
t_c	= $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less

Page 104

r_1	= $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2	= $\frac{1}{4}$ in. (6 mm) minimum
t_e	= thickness of reinforcing element, in.
$t_{\min}$	= the smaller of $\frac{3}{4}$ in. (19 mm) or the thickness of the thinner of the parts joined

(c) *Use of Deposited Weld Metal for Openings and Nozzles*

(1) Nozzles shall meet the requirements of NE-4244(c) and shall be capable of being examined in accordance with NE-5243.

(2) When the deposited weld metal is used as reinforcement, the coefficients of thermal expansion of the base metal, the weld metal, and the nozzle shall not differ by more than 15% of the lowest coefficient involved.

(3) The minimum dimensions of Fig. NE-4244(c)-1 shall be met where:

t	= nominal thickness of part penetrated, in.
t_n	= nominal thickness of penetrating part, in.
t_c	= $0.7t_n$ or $1/4$ in. (6 mm), whichever is less
r_1	= $1/4t$ or $3/4$ in. (19 mm), whichever is less

(4) The corners of the end of each nozzle extending less than $\sqrt{dt_n}$ beyond the inner surface of the part penetrated shall be rounded to a radius of one-half the thickness t_n of the nozzle or $3/4$ in. (19 mm), whichever is smaller.

(d) Attachment of Nozzles Using Partial Penetration Welds

(1) Welded From Both Sides

(a) Partial penetration welds used to connect nozzles from both sides shall meet the requirements of NE-4244(d). Typical details are shown in Fig. NE-4244(d)-1. For inserted nozzles without reinforcing elements, two partial penetration welds may be used of any desired combination of fillet, single bevel, and single J-welds. Inserted-type nozzles having added reinforcement in the form of a separate reinforcing plate are not permitted with partial penetration welding.

(b) The minimum dimensions of Fig. NE-4244(d)-1 shall be met where:

$t_1 + t_2$	= $1/4t_{\min}$
t_1 or t_2	= not less than the smaller of $1/4$ in. (6 mm) or $0.7t_{\min}$
$t_{\min}$	= the smaller of $3/4$ in. (19 mm) or the thickness of the thinner of the parts joined
t	= nominal thickness of part penetrated, in.
t_n	= nominal thickness of penetrating part, in.
t_c	= $0.7t_n$ or $1/4$ in. (6 mm), whichever is less
c	= $1/2t_{\min}$
t_w	= $0.7t_n$

(2) Welded From One Side

(a) Partial penetration welds used to connect nozzles from one side are allowed only for attachments on which there are no piping reactions. They shall meet the fabrication requirements of NE-4244(d) and shall be capable of being examined in accordance with the requirements of NE-5242.

(b) The minimum dimensions of Fig. NE-4244(d)-2 shall be met where:

t	= nominal thickness of part penetrated, in.
t_n	= nominal thickness of penetrating part [or the lesser of t_{n1} or t_{n2} in Fig. NE-4244(d)-2], in.
t_c	= $0.7t_n$ or $1/4$ in. (6 mm), whichever is less
r_1	= $1/4t_n$ or $3/4$ in. (19 mm), whichever is less
d	= outside diameter of nozzle [or of the inner cylinder as shown in Fig. NE-4244(d)-2], in.
c	= diametral clearance between nozzle and vessel penetration, in.

= 0.010 in. (0.25 mm) for $d \leq 1$ in. (25 mm).
 = 0.020 in. (0.51 mm) for $1 < d \leq 4$ in. (102 mm) and
 = 0.030 in. (0.76 mm) for $d > 4$ in. (102 mm) maximum,
 except that the above limits on maximum clearance need not
 be met for the full length of the opening, provided there is a
 region at the weld preparation and a region near the end of the
 opening opposite the weld which does meet the above limits
 on maximum clearance and the latter region is extensive
 enough (not necessarily continuous) to provide a positive stop
 for nozzle deflection

r_2	= $\frac{1}{16}$ in. (1.6 mm) minimum
r_3	= r_2 or equivalent chamfer, minimum
λ	= $\frac{1}{16}$ in. (1.6 mm) minimum
λ	= t_n maximum
r_4	= $\frac{1}{2}t_n$ or $\frac{3}{4}$ in. (19 mm), whichever is smaller

(3) The corners to the end of each nozzle extending less than $\sqrt{d}t_n$ beyond the inner surface of the part penetrated shall be rounded to a radius of one-half of the thickness t_n of the penetrating part or $\frac{3}{4}$ in. (19 mm), whichever is smaller.

(4) Weld groove design for partial penetration joints attaching nozzles may require special consideration to achieve the $1.25t_n$ minimum depth of weld and adequate access for welding examination. The welds shown in the sketches of Fig. NE-4244(d)-2 and Fig. NE-4244(d)-3 may be on either the inside or the outside of the shell. Weld preparation may be J-groove as shown in the figures or straight bevel.

(e) *Attachment of Fittings with Internal Threads.*¹⁶ The attachment of internally threaded fittings shall meet the requirements of (1) through (3) below.

¹⁶ This paragraph is written for fittings with internal threads, but is applicable to externally threaded or butt welded fittings.

(1) Except as provided for in (2) and (3) below, the provisions of NE-4244(e) shall be met. The minimum weld dimensions shall be as shown in Fig. NE-4244(e)-1 where:

$t_{\min}$	= lesser of $\frac{3}{4}$ in. (19 mm) or the thickness of the parts joined
t_c	= $\frac{1}{4}$ in. (6 mm), minimum

Details in sketches (a) and (b):

$$t_1 + t_2 = 1\frac{1}{4}t_{\min}$$

Detail in sketch (c):

t_w	= thickness of Sch. 160 pipe (ANSI-B36.10), in.
$t_1 + t_2$	= not less than smaller of $\frac{1}{4}$ in. (6 mm) or $0.7t_{\min}$

Detail in sketch (d):

c	= $\frac{1}{2}t_{\min}$
t_w	= $0.7t_{\min}$

(2) Fittings shown in Fig. NE-4244(e)-1 sketches (a-2), (b-2), (c-2), and (d) not exceeding NPS 2 may be attached by

welds that are exempt from size requirements other than those specified in NE-3359.

(3)(a) When internally threaded fittings and bolting pads not exceeding NPS 3 (DN 80) are attached to vessels having a wall thickness not greater than $\frac{3}{8}$ in. (10 mm) by a fillet weld deposited from the outside only, the welds shall comply with the dimensions shown in Fig. NE-4244(e)-2. These openings do not require reinforcement other than that inherent in the construction as permitted in NE-3332.1.

(b) If the opening exceeds NPS 5 (DN 125), it shall be reinforced in accordance with NE-3332 with the nozzle or other connections attached, using a suitable detail in Fig. NE-4244(e)-1.

(f) *Attachment of Tubed Connections.* Tubes recessed into thick walled vessels or headers, welded from only one side, shall have a welding groove in the vessel wall not deeper than t_n on the longitudinal axis of the opening. A recess $\frac{1}{16}$ in. (1.6 mm) deep shall be provided at the bottom of the groove in which to center the nozzle. The dimension t_w of the attachment weld shall not be less than t_n nor less than $\frac{1}{4}$ in. (6 mm). The minimum dimension for t_c shall be $\frac{1}{4}$ in. (6 mm) [Fig. NE-4244(f)-1 sketches (a) and (b)].

NE-3355 Welding Grooves

The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and penetration, except as otherwise permitted in NE-3352.4.

NE-3356 Fillet Welds

(a) Corner or T-joints for Category C welds may be made with fillet welds, provided the attachment is properly supported independently of such welds. Closures which meet the requirements of NE-3367 may be attached by fillet welds.

(b) The allowable load on fillet welds shall equal the product of the weld area based on minimum leg dimension, the allowable stress value in tension of the material being welded, and the factor 0.55.

(c) Except where specific details are permitted in other paragraphs, welded joints subject to bending stresses shall have fillet welds added where necessary to reduce stress concentration. Corner joints, with fillet welds only, shall not be used unless the plates forming the corner are properly supported independently of such welds.

NE-3358 Design Requirements for Head Attachments

NE-3358.1 Skirt Length of Formed Heads

(a) Ellipsoidal and other types of formed heads, concave or convex to the pressure, shall have a skirt length not less than that shown in Fig. NE-3358.1(a)-1. Heads that are fitted inside or over a shell shall have a driving fit before welding.

(b) A tapered transition, having a length not less than three times the offset between the adjacent surfaces of abutting sections as shown in Fig. NE-3358.1(a)-1, shall be provided at joints between formed heads and shells that differ in thickness by more than one-fourth the thickness of the thinner section or by more than $\frac{1}{8}$ in. (3.2 mm), whichever is less. When a taper is required on any formed head thicker than the shell and intended for butt welded attachment [Fig. NE-3358.1(a)-1], the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.

NE-3358.2 Unstayed Flat Heads Welded to Shells.

The requirements for the attachment of unstayed flat heads welded to shells are given in NE-3325, NE-3358.3, and NE-3358.4.

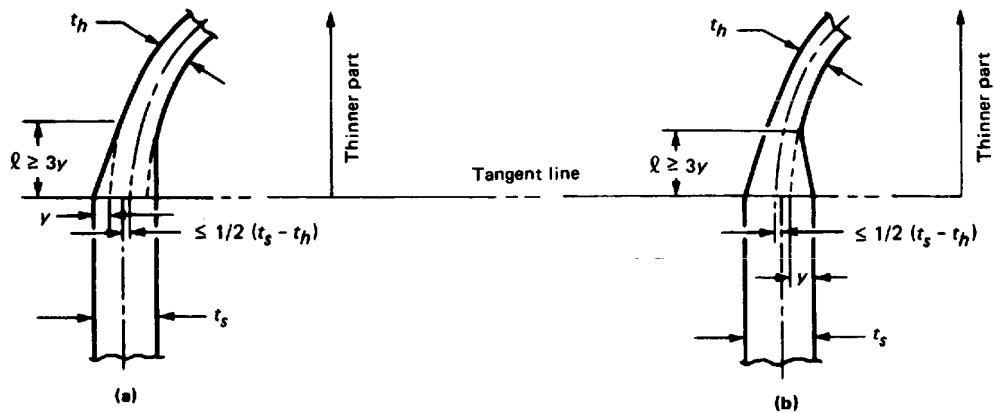
NE-3358.3 Head Attachments Using Corner Joints.

When shells, heads, or other pressure parts are welded to a forged or rolled plate to form a corner joint, as in Fig. NE-4243-1 and Fig. NE-4243-2, the joint shall meet the requirements of (a) through (e) below.

(a) On the cross section through the welded joint, the line of fusion between the weld metal and the forged or rolled plate being attached shall be projected on planes both parallel to and perpendicular to the

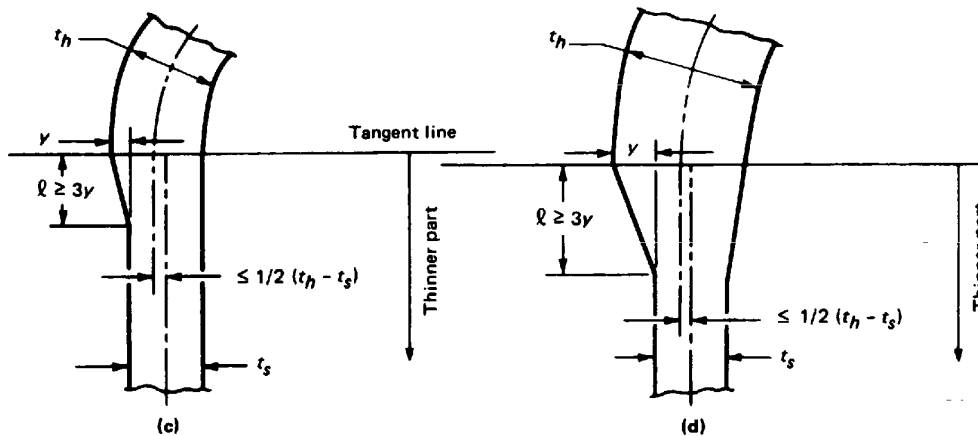
Page 106

surface of the plate being attached, in order to determine the dimensions a and b , respectively.



GENERAL NOTES [sketches (a) and (b)]:

- (a) Length of required taper l may include the width of the weld.
- (b) In all cases, the projected length of taper l shall be not less than $3y$.
- (c) The shell plate center line may be on either side of the head plate center line.



GENERAL NOTES [sketches (c) and (d)]:

- (a) In all cases l shall be not less than 3 times y when t_h exceeds $1.25t_s$; minimum length of skirt is $3t_h$, but need not exceed 1-1/2 in. except when necessary to provide required length of taper.
- (b) When t_h is equal to or less than $1.25t_s$, length of skirt shall be sufficient for any required taper.
- (c) Length of required taper l may include the width of the weld.
- (d) The shell plate center line may be on either side of the head plate center line.

FIG. NE-3358.1(a)-1 HEADS ATTACHED TO SHELLS

FIG. NE-3358.1(a)-1 HEADS ATTACHED TO SHELLS

(b) For flange rings of bolted flanged connections, and for flat heads with a projection having holes for a bolted connection, the sum of a and b shall not be less than three times the nominal wall thickness of the abutting pressure part.

(c) For other components, the sum of a and b shall not be less than two times the nominal wall thickness of the abutting pressure part. Examples of such components are flat heads without a projection having holes for a bolted connection and the side plates of a rectangular vessel.

(d) Other dimensions at the joint shall be in accordance with details as shown in Fig. NE-4243-1 and Fig. NE-4243-2 where:

In Fig. NE-4243-1:

sketch (a)

$a + b$ not less than $2t_s$

($b=0$)

t_w not less than t_s

t_s =actual thickness of shell

sketch (b)

$a + b$ not less than $2t_s$

t_w not less than t_s

t_p not less than t_s

t_s =actual thickness of shell, in.

sketch (c)

$a + b$ not less than $2t_s$

a not less than t_s

t_p not less than t_s

t_s =actual thickness of shell, in.

sketch (d)

$a + b$ not less than $2t_s$

a not less than t_s

t_p not less than t_s

t_s =actual thickness of shell, in.

sketch (e)

$a + b$ not less than $2t_s$

($b=0$)

t_s =actual thickness of shell

sketch (f)

$a + b$ not less than $2t_s$

t

t_s = actual thickness of shell

sketch (g)

$a + b$ not less than $2t_s$

a_1 not less than $0.5a_2$ nor greater than $2a_2$

$a_1 + a_2 = a$

t_s = actual thickness of shell

sketch (h)

a not less than $3t_n$

$(b=0)$

c not less than t_n or t_D ¹⁷ whichever is less

sketch (i)

$a + b$ not less than $3t_n$

c not less than t_n or t_D ¹⁷ whichever is less

In Fig. NE-4243-2:

For forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle not greater than 45 deg measured from the face:

t_c	= $0.7t_n$ or $1/4$ in., whichever is less
t_w	= the lesser of $t_n/2$ or $t/4$
t, t_n	= nominal thickness of welded parts, in.

For all other material forms and for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle greater than 45 deg measured from the face:

t_n	= $0.7t_n$ or $1/4$ in., whichever is less
t_w	= the lesser of t_n or $t/2$ or
t, t_n	= nominal thicknesses of welded parts, in.

(e) Joint details that have a dimension through the joint less than the thickness of the shell, head, or other pressure part, or that provide attachment eccentric thereto, are not permissible [Fig. NE-4243-1 sketches (j), (k), and (l)].

NE-3358.4 Flat Heads With Hubs.

Hubs for butt welding as shown in Fig. NE-4243.1-1 shall have the following minimum dimensions:

sketch (a)

r not less than $1.5t_s$

sketch (b)

r not less than $1.5t_s$

e not less than t_s

sketch (c)

h not less than $1.5t_s$

sketch (d)

t_f not less than $2t_s$

r not less than $3t_f$

sketch (e)

t_f not less than $2t_s$

r not less than $3t_f$

e not less than t_f

NE-3359 Design Requirements for Nozzle Attachment Welds

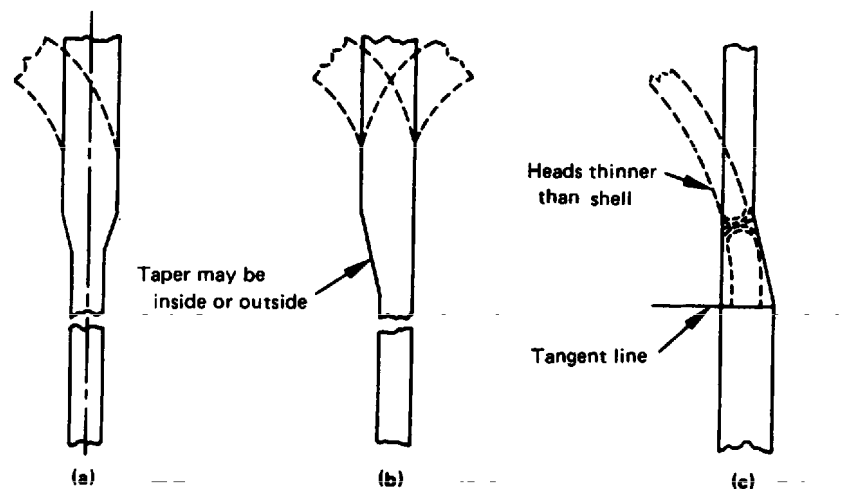
In addition to the requirements of NE-3352.4, the minimum design requirements for nozzle attachment welds shall be as stipulated in (a) and (b) below.

$17t_d$ is defined in XI-3130.

(a) *Required Weld Strength.* Sufficient welding shall be provided on either side of the line through the center of the opening parallel to the longitudinal axis

Page 108

of the shell to develop the strength of the reinforcing parts as prescribed in NE-3336, through shear or tension in the weld, whichever is applicable. The strength of groove welds shall be based on the area subjected to shear or to tension. The strength of fillet welds shall be based on the area subjected to shear computed on the minimum leg dimension. The inside diameter of a fillet weld shall be used in figuring its length. Calculations are not required for full penetration welds.



GENERAL NOTE: Length of taper may include the width of the weld.

FIG. NE-3361-1 CATEGORY A AND B JOINTS BETWEEN SECTIONS OF UNEQUAL THICKNESS

FIG. NE-3361-1 CATEGORY A AND B JOINTS BETWEEN SECTIONS OF UNEQUAL THICKNESS

(b) *Allowable Stress Values for Welds.* The allowable stress values for groove and fillet welds and for shear in nozzles, in

percentage of stress values for the vessel material, are as follows:

Nozzle wall shear	70%
Groove weld tension	74%
Groove weld shear	60%
Fillet weld shear	49%

NE-3360 SPECIAL VESSEL REQUIREMENTS

NE-3361 Tapered Transitions

A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections (Fig. NE-3361-1) shall be provided at joints between sections that differ in thickness by more than one-fourth the thickness of the thinner section or by more than $\frac{1}{8}$ in. (3.2 mm), whichever is less. The transition may be formed by any process that will provide a uniform taper. The weld may be partly or entirely in the tapered section or adjacent to it.

NE-3362 Bolted Flange and Studded Connections

(a) It is recommended that the dimensional requirements of bolted flange connections to external piping conform to ANSI B16.5, Steel Pipe Flanges and Flanged Fittings, ANSI B16.24, Brass or Bronze Flanges and Flanged Fittings, 150 and 300 lb, MSS SP-42, 150 lb Corrosion Resistant Cast Flanged Valves, or to API 605, Large Diameter Carbon Steel Flanges. Such flanges and flanged fittings may be used for the pressure-temperature ratings given in the appropriate standard. Flanges and flanged fittings in accordance with other standards are acceptable, provided they have been designed in accordance with the rules of Appendix XI for the vessel Design Loadings and are used within the pressure-temperature ratings so determined.

(b) Where tapped holes are provided for studs, the threads shall be full and clean, and shall engage the stud for a length not less than the larger of d_s or:

$$0.75d_s \times \frac{\text{Maximum allowable stress value of stud material at Design Temperature}}{\text{Maximum allowable stress value of tapped material at Design Temperature}}$$

in which d_s is the diameter of the stud. The thread engagement need not exceed $1\frac{1}{2}d_s$.

NE-3363 Access Openings

Access openings, where provided, shall consist of handhole or manhole openings having removable covers. These may be located on either the inside or outside of the shell or head openings and may be attached by studs or bolts in

combination with gaskets or welded membrane seals or strength welds. Plugs using pipe threads are not permitted.

NE-3364 Attachments

Attachments used to transmit support loads shall meet the requirements of NE-3135.

NE-3365 Supports

All vessels shall be so supported and the supporting members shall be so arranged and attached to the vessel wall as to provide for the maximum imposed loadings. The stresses produced in the vessel by such loadings and by steady state and transient thermal conditions shall be limited to the stress limits of this Subsection. For design of supports, see Subsection NF.

NE-3366 Bellows Expansion Joints

NE-3366.1 General Requirements.¹⁸

Expansion or bellows-type joints may be used to provide flexibility for containment systems. Expansion joints in piping portions of the containment system shall meet the requirements for Class 2 piping. The expansion joints which are constructed as a part or appurtenance of the vessel shall conform to this Subsection and shall conform with the requirements of (a) through (h) below.

(a) Bellows may be used to absorb axial movement, lateral deflection, angular rotation, or any combination of these movements. They are not normally designed for absorbing torsion. The layout, anchorage, guiding, and support shall be such as to avoid the imposition of motions or forces on the bellows other than those for which they have been designed.

¹⁸ For general information, see standards of the Expansion Joint Manufacturers Association, Inc., 25 N. Broadway, Tarrytown, NY 10591.

(b) In all systems containing bellows, the hydrostatic end force caused either by pressure or the bellows spring force or both must be resisted by rigid anchors, cross connections of the expansion joint ends, or other means.

(c) The expansion joint shall be installed in such locations as to be accessible for scheduled inspection, where applicable.

(d) The joints shall be provided with bars or other suitable members for maintaining the proper face-to-face dimension during shipment and installation. Bellows shall not be extended or compressed to make up deficiencies in length or offset to accommodate connecting parts which are not properly aligned unless such movements have been specified by the system designer or can be justified by the expansion joint manufacturer.

(e) The expansion joints shall be marked to show the direction of flow, if applicable, and shall be installed in accordance with this marking.

(f) Internal sleeves shall be provided for expansion joints over 6 in. (152 mm) in diameter when flow velocities exceed the following values:

(1) air, steam, and other gases - 25 ft/sec (7.6 m/s)

(2) water and other liquids - 10 ft/sec (3.0 m/s)

(g) Pressure retaining materials shall conform to the requirements of NE-2000. Convolutions or toroids of a bellows expansion joint shall be fabricated from material in the annealed condition.

(h) All welded joints in the expansion joint shall comply with the requirements of NE-4400 and NE-4800.

NE-3366.2 Design Requirements.

Bellows may be of the unreinforced or reinforced convoluted type or the toroidal type. The design shall conform to NE-3000 except as stipulated in (a) through (j) below.

(a) The circumferential membrane stresses in both the bellows and the reinforcing member, due to pressure, shall not exceed 1.1 times the allowable stress value given in Section II, Part D, Subpart 1, Tables 1A and 1B for the material at

the design temperature.

(b) The sum of the bellows meridional membrane and bending stresses due to internal pressure shall not exceed a value which results in a permanent decrease in the measured space between adjacent convolutions of 7% after the pressure test required by NE-6230.

(c) The ratio of the internal pressure at which the bellows will become unstable (squirm) to the equivalent cold service pressure shall exceed 2.25. By definition, squirm shall be considered to have occurred if under internal pressure an initially symmetrical bellows deforms, resulting in a lack of parallelism or uneven spacing of adjacent convolutions at any point on the circumference. Unless otherwise specified, this deformation shall be construed as unacceptable squirm when

Page 110

the ratio of the maximum convolution pitch under internal pressure exceeds 1.15 for unreinforced and 1.20 for reinforced bellows. In the case of universal expansion joints, which consist of two bellows joined by a cylindrical section, compliance with these criteria shall be satisfied by the entire assembly. No external restraints on the bellows shall be employed during squirm testing other than those which will exist after installation.

(1) For single joints used in axial or lateral motion, the squirm test may be performed with the bellows fixed in the straight position at the maximum length expected in service; for rotation and universal joints, the bellows shall be held at the maximum design rotation angle or offset movement. In the case of single joints subjected to rotation movement, or of universal joints subjected to lateral offset movement, an instability condition as previously defined may or may not appear. Instead, movement of the convolutions may occur due to the superposition of the lateral internal pressure component on the applied rotation. In such cases, that portion of the bellows deformation due to the design rotation angle or offset movement shall not be included in the deformation used to define squirm.

(2) In the case of squirm tests, the equivalent cold service pressure is defined as the Design Pressure multiplied by the ratio E_c/E_h , where E_c and E_h are defined as the modulus of elasticity of the bellows material at room temperature and normal service temperature, respectively.

(d) The combination of meridional membrane and bending stresses S in the bellows due to internal pressure and deflection, multiplied by a stress factor K_s ,¹⁹ shall not exceed the value defined by the following equation:

$$K_s \times S = S_f$$

where

K_s	= $K_{sc} \times K_{ss}$, but never less than 1.25
K_{sc}	= factor for differences in design fatigue curves at temperatures greater than 100°F, and is equal to:

$$\frac{2S_c}{S_c + S_h}$$

K_{ss}	= factor for the statistical variation in test results = $1.470 - 0.044$ times the number of replicate tests
----------	--

S	= total combined meridional membrane and bending stress, psi, due to pressure and deflection (the calculation of the individual stress components and their combination shall be determined by the same method as used for determining S_f); in the case of single joints subjected to rotation movement and universal joints subjected to lateral offset movement, the increase in deflection stress caused by the lateral internal pressure component shall be included in determining the combined stress, psi
S_f	= total combined stress to failure at design cyclic life, psi, (number of cycles to failure) obtained from plots of stress versus cyclic life based on data from fatigue tests of a series of bellows at a given temperature (usually room temperature) evaluated by a best-fit continuous curve or series of curves; the S_f plot shall be parallel to the best-fit curve and shall lie below all of the data points
S_c	= basic material allowable stress value at room temperature from Section II, Part D, Subpart 1, Tables 1A and 1B, psi, times 1.1
S_h	= basic material allowable stress value at normal service temperature from Section II, Part D, Subpart 1, Tables 1A and 1B, psi, times 1.1

(e) Compliance with (a), (b), (c), and (d) above shall be demonstrated by any one of the procedures of (1) through (3) below.

(1) Calculation of the individual stresses, whose combination and relation to fatigue life may be performed by any analytical method based on elastic shell theory. The resulting equations shall be substantiated by correlation with actual tests of a consistent series of bellows of the same basic design (unreinforced, reinforced, and toroidal bellows are considered as separate designs) by each bellows manufacturer in order to demonstrate predictability of rupture pressure, meridional yielding, squirm, and cyclic life. A minimum of five burst tests on bellows of varying sizes, with not less than three convolutions, shall be conducted to verify that the analytical method will adequately satisfy (a) and (b) above. No specimen shall rupture at less than four times its equivalent cold pressure rating. A minimum of ten squirm tests on bellows of varying diameters and number of convolutions shall be conducted to verify that the analytical method will adequately satisfy (c) above. Since column instability is most likely to occur in bellows less than 20 in. in diameter when the convoluted bellows length is greater than its diameter, the test specimens shall reflect these considerations. In the case of universal expansion joints, two additional tests shall be conducted to verify that the analytical method will adequately satisfy (c) above. The cyclic life plot (versus the combined stress) used

Page 111

in evaluating NE-3365.1(d) shall be obtained from the results of at least 25 fatigue tests on bellows of varying diameters, thicknesses, and convolution profiles. These curves may be used for diameter and convolution profiles other than those tested, provided that a variation in these dimensions has been included in the correlation with test data. Each group of five such tests on varying bellows may be considered the equivalent of one replicate test in determining K_s .

(2) Individual expansion joint designs may be shown to comply by the testing of duplicate bellows. At least two test specimens are required, one to demonstrate pressure capacity in accordance with (a), (b), and (c) above, and the second to demonstrate fatigue life in accordance with (d) above. In the case of rupture and fatigue tests, the specimens need not possess a duplicate number of convolutions provided that the number of convolutions is not less than three and the diameter, thickness, depth, and pitch of the specimen is identical to the part to be furnished. Squirm test specimens shall possess the total number of convolutions. The pressure test required by NE-6230 shall satisfy the instability test

requirements for bellows larger than 50 in. in diameter.

(a) The test of (e)(1) or (e)(2) above may be conducted at room temperature provided that cold service pressure is defined as the Design Pressure multiplied by the ratio of S_c/S_h for rupture specimens and E_c/E_h for squirm specimens.

(b) The fatigue life of the test specimen shall exceed $K_s^{4.3}$ times the number of design cycles specified for the most significant cyclic movements. This test shall include the effect of internal pressure. If lateral and rotation movements are specified, these may be converted to equivalent axial motion for cyclic testing; the convolution deflection produced by the lateral component of the internal pressure force during the squirm test (for single rotation joints and universal joints) shall be added to the mechanical deflections in determining fatigue life. Where accelerated fatigue testing is employed, the deflection and number of cycles required shall be in accordance with Appendix II. Cumulative fatigue requirements can be satisfied in accordance with NE-3365.1(g) without additional testing by assuming that the slope of the fatigue curve is 4.3 (on a log-log plot) and that the curve passes through the test point.

(3) An individual design may be shown to comply by a design analysis in accordance with NE-3200. The stresses at every point in the bellows shall be determined by either elastic shell theory or by a plastic analysis, where applicable. Where an elastic analysis is employed, stress intensity Tables 2A, 2B, and 4 in Section II, Part D, Subpart 1 and fatigue curves of Appendix I may be used to evaluate the design. The stability requirements of (c) above may be demonstrated by either (3)(a) or (3)(b) below:

(a) elastic stability calculations, provided that the ratio of the internal pressure at which the bellows is predicted to become unstable to the equivalent cold operating pressure exceeds 10; or

(b) the pressure test of NE-6230, provided that the test is conducted at 2.25 times the equivalent cold design pressure, and single rotation and universal joints are held at their design rotation angle or offset movement during the test and the requirements of NE-3365.1(b) are not exceeded by such a test. (The pressure test required by NE-6230 shall satisfy the instability test requirements for bellows larger than 50 in. in diameter.)

(f) The bellows manufacturer's design report shall state which of the above procedures was utilized to verify the design.

(g) If there are two or more types of stress cycles which produce significant stresses, their cumulative effect shall be evaluated as stipulated in NE-3221.5(e)(5).

(h) Where necessary to carry the pressure, the cylindrical ends of the bellows may be reinforced by suitable collars; the design method used to assure that the stresses generated will not cause premature failure of the bellows material or weldment shall include the attachment weld between the bellows and end connections.

(i) If reinforcing rings are used, they shall have the same radius as the root of the convolution.

(j) The Design Specifications shall state the maximum allowable force that can be imposed on the connecting parts or shall request the bellows manufacturer to determine the force necessary to deflect the bellows a given distance, preferably the maximum movement to be absorbed.

NE-3367 Closures on Small Penetrations

Closures on penetrations of 2 in. pipe size (DN 50) or less may be made by the use of closure fittings such as blind flanges, welded plugs, or caps manufactured in accordance with standards listed in Table NE-3132-1.

NE-3700 ELECTRICAL AND MECHANICAL PENETRATION ASSEMBLIES

NE-3720 DESIGN RULES

(a) The design of the pressure retaining portion of the electrical and mechanical penetration assemblies shall be the same as for vessels (NE-3300).

Page 112

(b) For closing seams in electrical and mechanical penetrations meeting the requirements of NE-4730(c), the closure head shall meet the requirements of NE-3325 using a factor $C=0.30$. The fillet weld shall be designed using an allowable stress of

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NE-4000

ARTICLE NE-4000 FABRICATION AND INSTALLATION

Page 113

NE-4100 GENERAL REQUIREMENTS

NE-4110 INTRODUCTION

Containment vessels, penetration assemblies, and appurtenances shall be fabricated and installed in accordance with the requirements of this Article, and shall be manufactured from materials which meet the requirements of NE-2000.

NE-4120 CERTIFICATION OF MATERIAL AND FABRICATION BY COMPONENT CERTIFICATE HOLDER

NE-4121 Means of Certification

The Certificate Holder for an item for a containment vessel shall certify by application of the appropriate Code Symbol and completion of the appropriate Data Report in accordance with NCA-8000 that the materials used comply with the requirements of NE-2000, and that the fabrication complies with the requirements this Article.

NE-4121.1 Certification of Treatments, Tests, and Examinations.

If the Certificate Holder or Subcontractor performs treatments, tests, repairs, or examinations required by other Articles of this Subsection, the Certificate Holder shall certify that this requirement has been fulfilled (NCA-3862). Reports of all required treatments and the results of all required tests, repairs, and examinations performed shall be available to the Inspector.

NE-4121.2 Repetition of Tensile or Impact Tests.

If during the fabrication of the vessel the material is subjected to heat treatment that has not been covered by treatment of the test coupons (NE-2200) and that may reduce either the tensile or impact properties below the required values, the tensile and impact tests shall be repeated by the Certificate Holder on test specimens taken from test coupons which have been taken and treated in accordance with the requirements of NE-2000.

NE-4122 Material Identification

(a) Material for pressure retaining parts shall carry identification markings which will remain distinguishable until the component is assembled or installed. If the original identification markings are cut off or the material is divided, the marks shall be either transferred to the parts cut or a coded marking shall be used to assure identification of each piece of material during subsequent fabrication or installation. In either case, an as-built sketch or a tabulation of materials shall be made identifying each piece of material with the Certified Material Test Report, where applicable, and the coded marking. For studs, bolts, and nuts, it is permissible to identify the Certified Material Test Reports for material in each component in lieu of identifying each piece of material with the Certified Material Test Report and the coded marking. Material supplied with a Certificate of Compliance and welding materials shall be identified and controlled so that they can be traced to the vessel, or else a control procedure shall be employed which ensures that the specified material is used.

(b) Material from which the identification marking is lost shall be treated as nonconforming material until appropriate tests or other verifications are made and documented to assure material identification. Testing is required unless positive identification can be made by other documented evidence. The material may then be remarked, upon establishing positive identification.

NE-4122.1 Marking Material.

Material shall be marked in accordance with NCA-3866.6.

NE-4123 Examinations

Visual examination activities that are not referenced for examination by other specific Code paragraphs, and are performed solely to verify compliance with

Page 118

requirements of NE-4000, may be performed by the persons who perform or supervise the work. These visual examinations are not required to be performed by personnel and procedures qualified to NE-5500 and NE-5100, respectively, unless so specified.

NE-4125 Testing of Welding Material

All welding material shall meet the requirements of NE-2400.

NE-4130 REPAIR OF MATERIAL

NE-4131 Elimination and Repair of Defects

Material originally accepted on delivery in which defects exceeding the limits of NE-2500 are known or discovered during the process of fabrication or installation is unacceptable. The material may be used provided the condition is corrected in accordance with the requirements of NE-2500 for the applicable product form, except:

- (a) the limitation on the depth of the weld repair does not apply;
- (b) the time of examination of the weld repairs to weld edge preparations shall be in accordance with NE-5130; and
- (c) radiographic examination is not required for weld repairs to seal membrane material when the material thickness is $\frac{1}{4}$ in. (6 mm) or less.

NE-4200 FORMING, FITTING, AND ALIGNING

NE-4210 CUTTING, FORMING, AND BENDING

NE-4211 Cutting

Plates, edges of heads, and other parts may be cut to shape and size by mechanical means such as machining, shearing, grinding, or by oxygen or arc cutting. After oxygen cutting, the edges to be welded shall be uniform and smooth and shall be free of all loose scale and slag accumulations before welding.

NE-4211.1 Preheating Before Thermal Cutting.

When thermal cutting is performed to prepare weld joints or edges, to remove attachments or defective material, or for any other purpose, consideration shall be given to preheating the material using preheat schedules such as suggested in Appendix D.

NE-4212 Forming and Bending Processes

Any process may be used to hot or cold form or bend pressure retaining material, including weld metal, provided the required dimensions are attained (see NE-4214 and NE-4220), and provided the impact properties of the material, when required, are not reduced below the minimum specified values or they are effectively restored by heat treatment following the forming operation. *Hot forming* is defined as forming with the material temperature higher than 100°F (56°C) below the lower transformation temperature of the material. When required, the process shall be qualified for impact properties as outlined in NE-4213.

NE-4212.1 Required Postweld Heat Treatment.

Vessel shell sections and heads of P-No.1 material fabricated by cold forming shall be postweld heat treated when the resulting maximum extreme fiber elongation is more than 5%.

NE-4213 Qualification of Forming Processes for Impact Property Requirements

A procedure qualification test shall be conducted using specimens taken from material of the same specification, grade or class, heat treatment, and with similar impact properties as required for the material in the vessel. These specimens shall be subjected to the equivalent forming or bending process and heat treatment as the material in the vessel. Applicable tests shall be conducted to determine that the required impact properties of NE-2300 are met after straining.

NE-4213.1 Exemptions.

Procedure qualification tests are not required for material listed in (a) through (f) below:

- (a) hot formed material, such as forgings, in which the hot forming is completed by the Material Organization prior to removal of the impact test specimens;
- (b) hot formed material represented by test coupons required in either NE-2211 or NE-4121.2 which have been subjected to heat treatment representing the hot forming procedure and the heat treatments to be applied to the parts;
- (c) material which does not require impact tests in accordance with NE-2300;
- (d) material which has final strain less than 0.5%;
- (e) material where the final strain is less than that of a previously qualified procedure for that material;
- (f) material from which the impact testing required by NE-2300 is performed on each heat and lot, as applicable, after forming.

Page 119

NE-4213.2 Procedure Qualification Test.

The procedure qualification test shall be performed in the manner stipulated in (a) through (f) below.

- (a) The tests shall be performed on three different heats of material both before and after straining to establish the effects of the forming and subsequent heat treatment operations.
- (b) Specimens shall be taken in accordance with the requirements of NE-2000 and shall be taken from the tension side of the strained material.
- (c) The percent strain shall be established by the following formulas.

For cylinders:

$$\% \text{ strain} = \frac{50t}{R_f} \left(1 - \frac{R_f}{R_o} \right)$$

For spherical or dished surfaces:

$$\% \text{ strain} = \frac{75t}{R_f} \left(1 - \frac{R_f}{R_o} \right)$$

For pipe:

$$\% \text{ strain} = \frac{100r}{R}$$

where

t	= nominal thickness, in.
R_f	= final radius to center line of shell, in.
R_o	= original radius (equal to infinity for a flat part), in.
R	= nominal bending radius to the center line of the pipe, in.
r	= nominal radius of the pipe, in.

(d) The procedure qualification shall simulate the maximum percent surface strain, employing a bending process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient C_v test specimens shall be taken from each of the three heats of material to establish a transition curve showing both the upper and lower shelves. On each of the three heats, tests consisting of three impact specimens shall be conducted at a minimum of five different temperatures distributed throughout the transition region. The upper and lower shelves may be established by the use of one test specimen for each shelf. Depending on the product form, it may be necessary to plot the transition curves using both lateral expansion and energy level data (NE-2300). In addition, drop weight tests shall be made when required by NE-2300.

(f) Using the results of the impact test data from each of three heats taken both before and after straining, determine either:

(1) the maximum change in NDT temperature along with:

(a) the maximum change of lateral expansion and energy at the temperature under consideration; or

(b) the maximum change of temperature at the lateral expansion and energy levels under consideration; or

(2) when lateral expansion is the acceptance criterion (NE-2300), either the maximum change in temperature or the maximum change in lateral expansion.

NE-4213.3 Acceptance Criteria for Formed Material.

To be acceptable, the formed material used in the vessel shall have impact properties before forming sufficient to compensate for the maximum loss of impact properties due to the qualified forming procedure used.

NE-4213.4 Requalification.

A new procedure qualification test is required when any of the following changes are made:

(a) the actual postweld heat treatment time at temperature is greater than previously qualified, considering NE-2211:

(1) if the material is not postweld heat treated, the procedure shall be qualified without postweld heat treatment;

(b) the maximum calculated strain of the material exceeds the previously qualified strain by more than 0.5%;

(c) where preheat over 250°F (121°C) is used in the forming or bending operation but not followed by a subsequent postweld heat treatment.

NE-4214 Minimum Thickness of Fabricated Material

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of NE-3000, the material may be repaired in accordance with NE-4130.

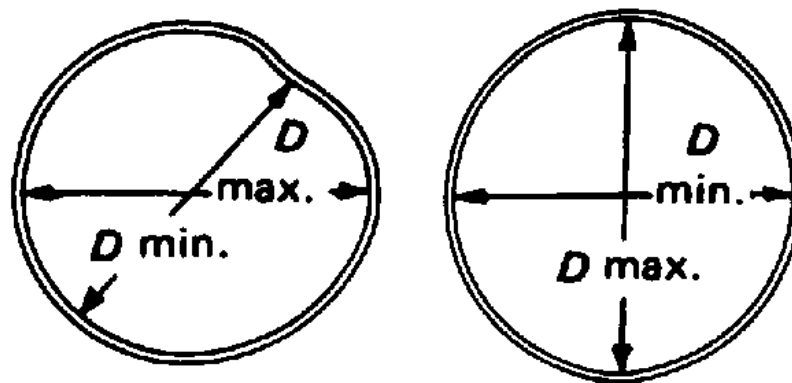
NE-4220 FORMING TOLERANCES

NE-4221 Tolerance for Vessel Shells

Cylindrical, conical, or spherical shells of a completed vessel, except for formed heads covered by NE-4222, shall meet the requirements of the following subparagraphs at all cross sections. If the plates are to be rolled, the adjoining edges of longitudinal joints of cylindrical vessels shall first be shaped to the proper

Page 120

curvature by preliminary rolling or forming in order to avoid having objectional flat spots along the completed joints.



**FIG. NE-4221.1-1 MAXIMUM DIFFERENCE
IN CROSS-SECTIONAL DIAMETERS**

FIG. NE-4221.1-1 MAXIMUM DIFFERENCE IN CROSS-SECTIONAL DIAMETERS

NE-4221.1 Maximum Difference in Cross-Sectional Diameters.

The difference between the maximum and minimum inside diameters at any cross section shall not exceed 1% of the nominal diameter at the cross section under consideration. The diameters may be measured on the inside or outside of the vessel. If measured on the outside, the diameters shall be corrected for the plate thickness at the cross section under consideration (Fig. NE-4221.1-1). When the cross section passes through an opening, the permissible difference in inside diameters given above may be increased by 2% of the inside diameter of the opening.

NE-4221.2 Maximum Deviation From True Theoretical Form for External Pressure.

Vessels designed for external pressure shall meet the following tolerances.

(a) The maximum plus-or-minus deviation from the true circular form of cylinders or the theoretical form of other shapes, measured radially on the outside or inside of the component, shall not exceed the maximum permissible deviation obtained from Fig. NE-4221.2-1. Measurements shall be made from a segmental circular template having the design inside or outside radius (depending on where the measurements are taken) and a chord length equal to twice the arc length obtained from Fig. NE-4221.2-2. For Fig. NE-4221.2-1, the maximum permissible deviation e need not be less than $0.3t$. For Fig. NE-4221.2-2, the arc length need not be greater than $0.30D_o$. Measurements shall not be taken on welds or other raised parts.

(b) The value of t in inches at any cross section is the nominal plate thickness less corrosion allowance for sections of constant thickness and the nominal thickness of the thinnest plate less corrosion allowance for sections having plates of more than one thickness.

(c) The value of L in Fig. NE-4221.2-1 and Fig. NE-4221.2-2 is determined as follows.

(1) For cylinders, L is as given in NE-3133.2.

(2) For cones, L is the axial length of the conical section if no stiffener rings are used or, if stiffener rings are used, the axial length from the head bend line at the large end of the cone to the first stiffener ring, with D_o taken as the outside diameter in inches of the cylinder at the large end of the cone.

(3) For spheres, L is one-half of the outside diameter D_o , in.

NE-4221.3 Deviations From Tolerances.

Deviations from the tolerance requirements stipulated in NE-4221.1 and NE-4221.2 are permitted, provided the drawings are modified and reconciled with the Design Report and provided the modifications are certified by a Registered Professional Engineer in an addendum to the Design Report.

NE-4221.4 Tolerance Deviations for Vessel Parts Fabricated From Pipe.

Vessel parts subjected to either internal or external pressure and fabricated from pipe, meeting all other requirements of this Subsection, may have variations of diameter and deviations from circularity permitted by the specification for such pipe.

NE-4221.5 Localized Thin Areas.

Localized thin areas are permitted if the adjacent areas surrounding each has sufficient thickness to provide the necessary reinforcement according to the rules for reinforcement in NE-3330.

NE-4222 Tolerances for Formed Vessel Heads

The tolerance for formed vessel heads shall be as set forth in the following subparagraphs.

NE-4222.1 Maximum Difference in Cross-Sectional Diameters.

The skirt or cylindrical end of a formed head shall be circular to the extent that the difference in inches between the maximum and minimum diameters does not exceed the lesser of $(D + 50)/200$ or $(D + 12)/100$, where D is the nominal inside diameter in inches and shall match the cylindrical edge of the adjoining part within the alignment tolerance

specified in NE-4232.

NE-4222.2 Deviation From Specified Shape

(a) The inner surface of a torispherical or ellipsoidal head shall not deviate outside the specified shape by more than $1\frac{1}{4}\%$ of D , or inside the specified shape by more than $\frac{5}{8}\%$ of D , where D is the nominal inside diameter of the vessel. Such deviations shall be measured perpendicular to the specified shape and shall

Page 121

not be abrupt. The knuckle radius shall not be less than specified. For 2:1 ellipsoidal heads, the knuckle radius may be considered to be 17% of the diameter of the vessel.

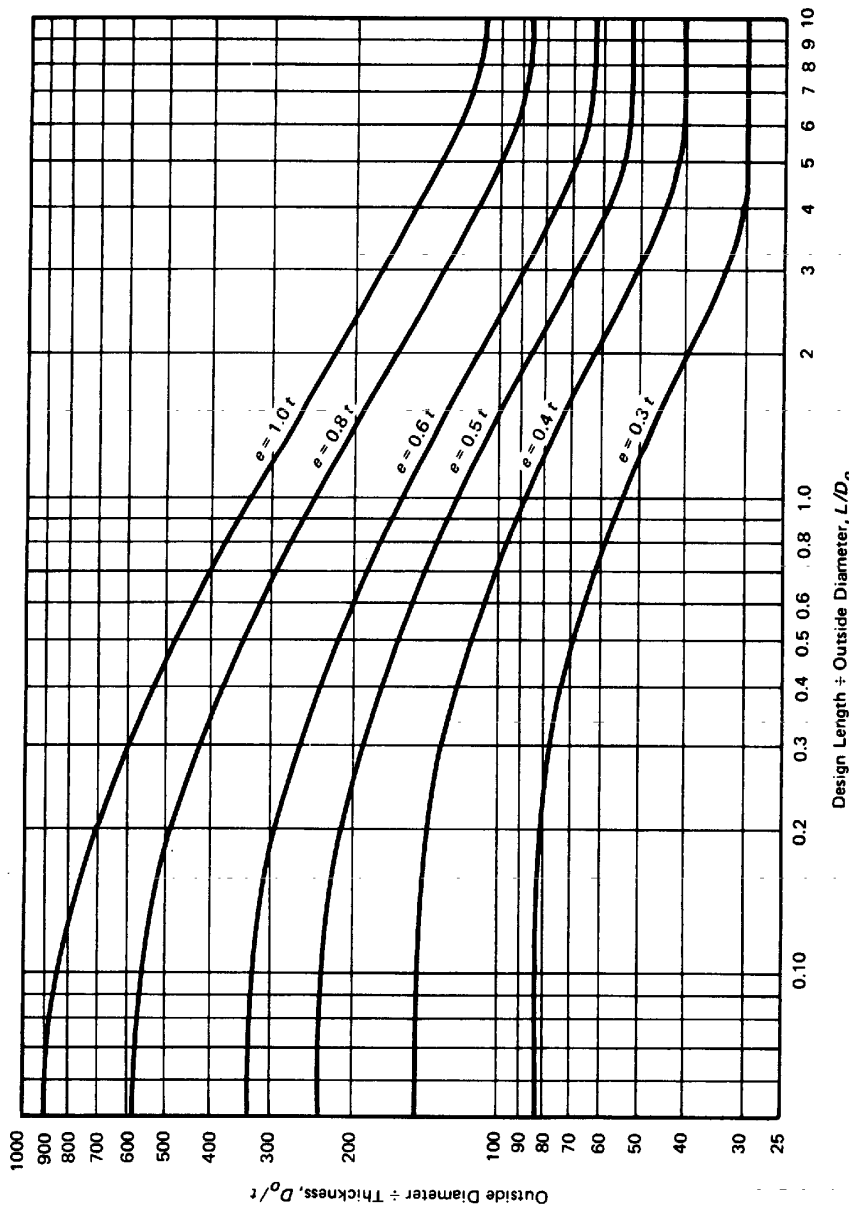


FIG. NE-4221.2-1 MAXIMUM PERMISSIBLE DEVIATION e FROM A TRUE CIRCULAR FORM

FIG. NE-4221.2-1 MAXIMUM PERMISSIBLE DEVIATION e FROM A TRUE CIRCULAR FORM

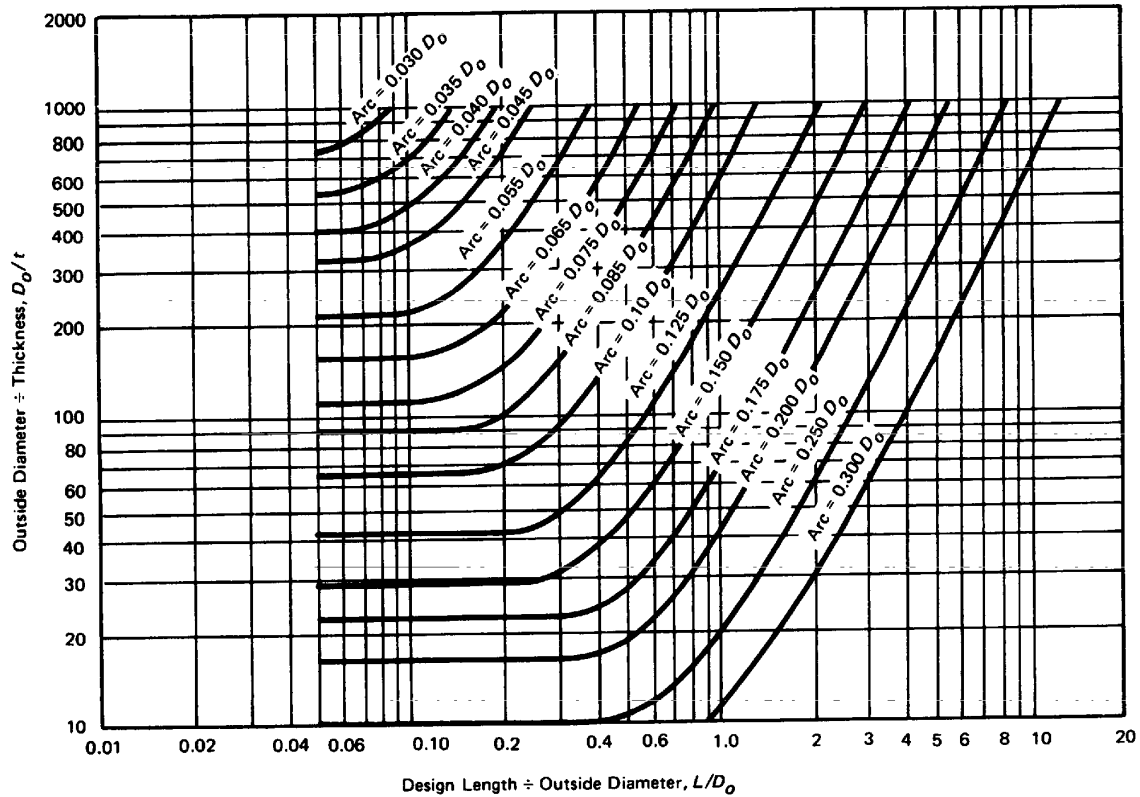


FIG. NE-4221.2-2 MAXIMUM ARC LENGTH FOR DETERMINING PLUS OR MINUS DEVIATION

FIG. NE-4221.2-2 MAXIMUM ARC LENGTH FOR DETERMINING PLUS OR MINUS DEVIATION

TABLE NE-4232-1
MAXIMUM ALLOWABLE OFFSET IN
FINAL WELDED JOINTS

Section Thickness, in.	Longitudinal	Circumferential
Up to $\frac{1}{2}$, incl.	$\frac{1}{4} t$	$\frac{1}{4} t$
Over $\frac{1}{2}$ to $\frac{3}{4}$, incl.	$\frac{1}{8}$ in.	$\frac{1}{4} t$
Over $\frac{3}{4}$ to $1\frac{1}{2}$, incl.	$\frac{1}{8}$ in.	$\frac{3}{16}$ in.
Over $1\frac{1}{2}$ to 2, incl.	$\frac{1}{8}$ in.	$\frac{1}{8} t$
Over 2	Lesser of $\frac{1}{16} t$ and $\frac{3}{8}$ in.	Lesser of $\frac{1}{8} t$ and $\frac{3}{4}$ in.

TABLE NE-4232-1 MAXIMUM ALLOWABLE OFFSET IN FINAL WELDED JOINTS

(b) Hemispherical heads and any spherical portion of a formed head shall meet the local tolerances for spheres as given in NE-4221.2, using L as the outside spherical radius in inches and D_o as two times L .

(c) Deviation measurements shall be taken on the surface of the base material and not on welds.

NE-4230 FITTING AND ALIGNING

NE-4231 Fitting and Aligning Methods

Parts that are to be joined by welding may be fitted, aligned, and retained in position during the welding operation by the use of bars, jacks, clamps, tack welds, or temporary attachments.

NE-4231.1 Tack Welds.

Tack welds used to secure alignment shall be either removed completely, when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified welders using qualified welding procedures. When tack welds are to become part of the finished weld, they shall be visually examined and defective tack welds removed.

NE-4232 Maximum Offset of Aligned Sections

(a) Alignment of sections shall be such that the maximum offset of the finished weld will not be greater than the applicable amount listed in Table NE-4232-1, where t is the nominal thickness of the thinner section at the joint.

(b) Joints in spherical vessels, joints within heads, and joints between cylindrical shells and hemispherical heads shall meet the requirements in Table NE-4232-1 for longitudinal joints.

NE-4232.1 Fairing of Offsets.

Any offset within the allowable tolerance provided above shall be faired to at least a 3:1 taper over the width of the finished weld, or, if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld. In addition, offsets greater than those stated in Table NE-4232-1 are acceptable provided the requirements of NE-3200 are met.

NE-4240 REQUIREMENTS FOR WELD JOINTS

NE-4241 Category A Weld Joints

Category A weld joints shall be full penetration butt welded joints. Joints that have been welded from one side with backing that has been removed, and those welded from one side without backing, are acceptable as full penetration welds provided the weld root side of the joints meet the requirements of NE-4424.

NE-4242 Category B Weld Joints

Category B weld joints shall be full penetration butt welded joints, except that NPS 2 (DN 50) and smaller pipe sizes may be socket welded. Joints made with consumable inserts or gas backup, or with metal backing rings or strips which are later removed, are acceptable as full penetration joints. When used, backing strips shall be continuous in cross section. Joints prepared with opposing lips to form an integral backing strip and joints with backing strips which are not later removed are acceptable.

NE-4243 Category C Weld Joints

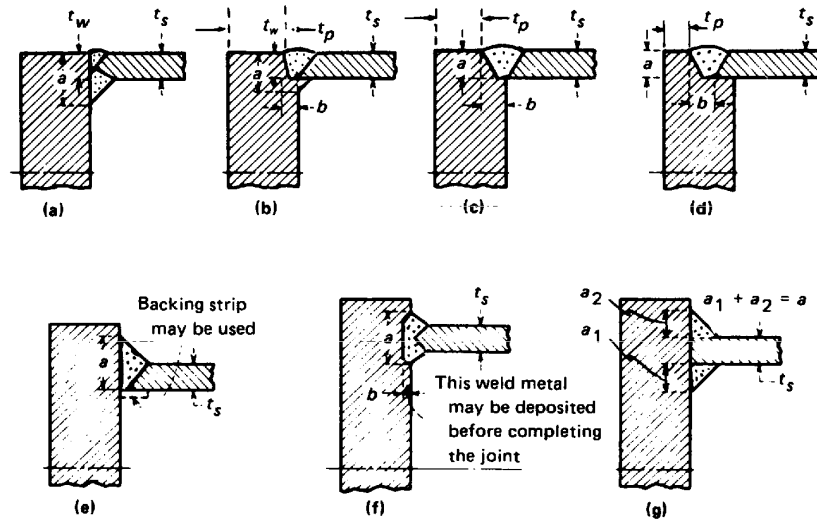
Category C weld joints shall be full penetration joints, as shown in Fig. NE-4243-1 and Fig. NE-4243-2, except that socket welded flanges of NPS 2 (DN 50) and less and slip-on flanges may be used.

NE-4243.1 Flat Heads and Tubesheets With Hubs.

Hubs for butt welding to the adjacent shell, head, or other pressure part, as in Fig. NE-4243.1-1, shall not be machined from rolled plate. The component having the hub shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material, in a direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension test specimen, subsize if necessary, taken in this direction and as close to the

Page 124

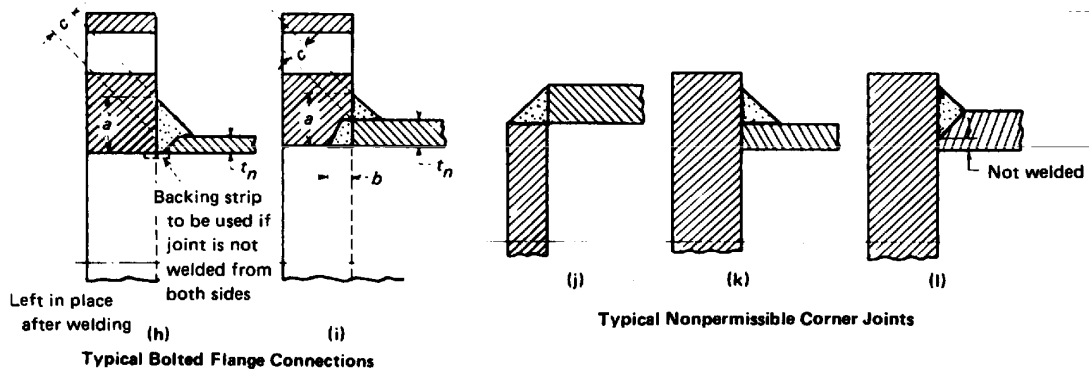
hub as is practical. In no case shall the height of the hub be less than 1.5 times the thickness of the pressure part to which it is welded.



Typical Unstayed Flat Heads and Side Plates of Rectangular Vessels

GENERAL NOTES [sketches (a) through (g)]:

- (1) For unstayed flat heads, see NE-3325; t_s , t_p , and t_w are as defined in NE-3325.1.
- (2) For definitions of a and b , see NE-3358.3.



Typical Bolted Flange Connections

Typical Nonpermissible Corner Joints

GENERAL NOTES [sketches (h) and (i)]:

- (1) c and t_n are as defined in XI-3130.
- (2) For definitions of a and b , see NE-3358.3.

FIG. NE-4243-1 ATTACHMENT OF PRESSURE PARTS TO PLATES TO FORM A CORNER JOINT

FIG. NE-4243-1 ATTACHMENT OF PRESSURE PARTS TO PLATES TO FORM A CORNER JOINT

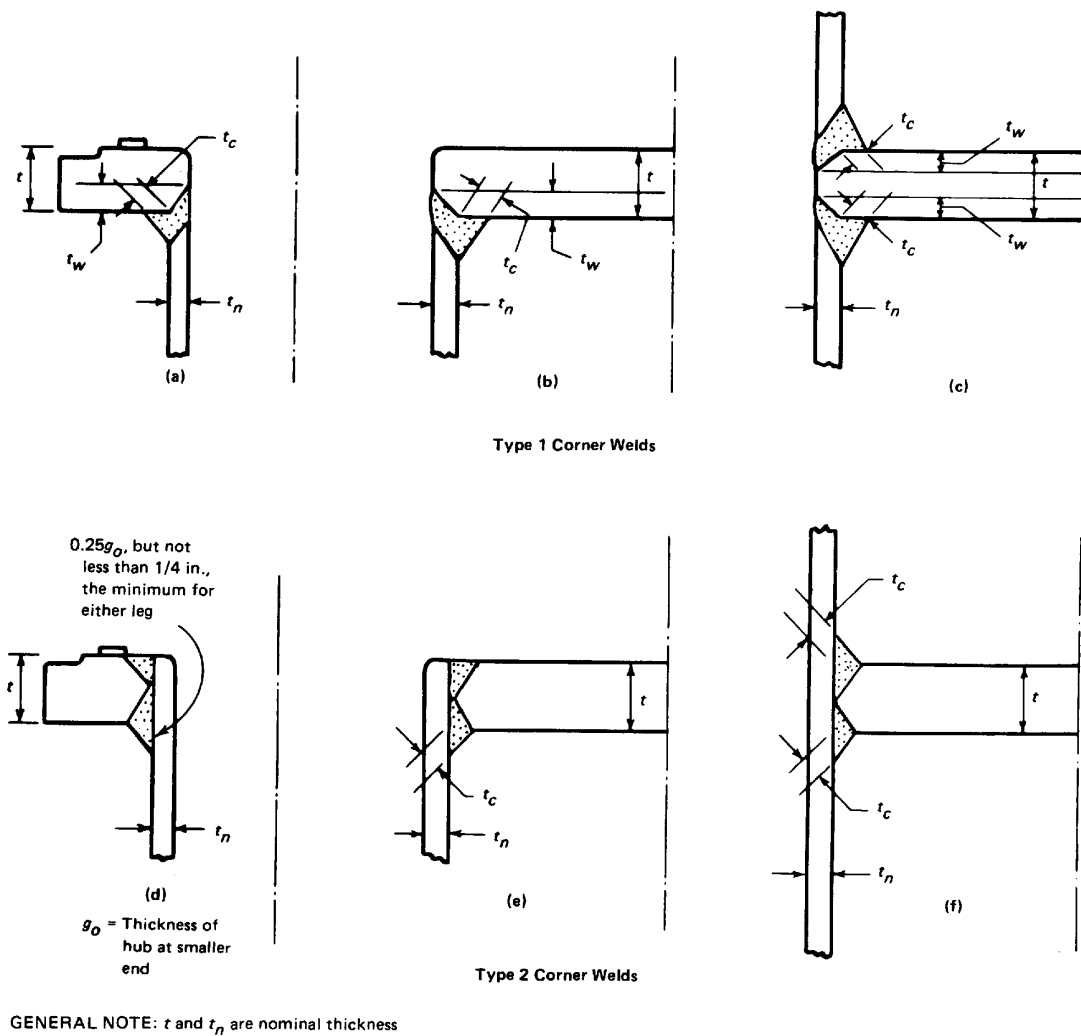
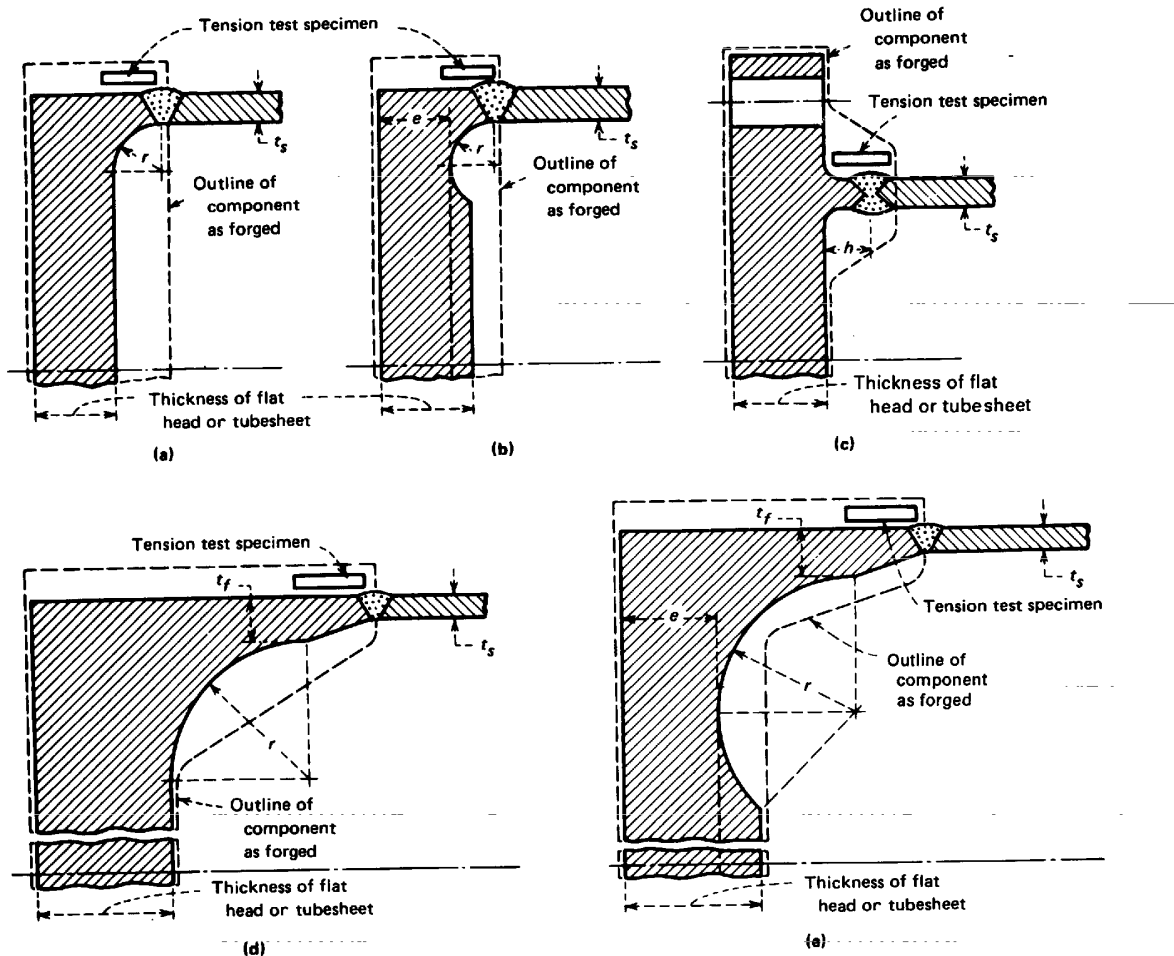


FIG. NE-4243-2 ACCEPTABLE TYPES OF FULL PENETRATION WELD DETAILS FOR CATEGORY C JOINTS

FIG. NE-4243-2 ACCEPTABLE TYPES OF FULL PENETRATION WELD DETAILS FOR CATEGORY C JOINTS



GENERAL NOTE:

Not permissible if machined from rolled plate. The tension test specimen may be located, when possible, inside the forged hub, instead of outside, as shown.

FIG. NE-4243.1-1 TYPICAL FLAT HEADS

FIG. NE-4243.1-1 TYPICAL FLAT HEADS

NE-4244 Category D Weld Joints

Category D and similar weld joints shall be welded using one of the details of (a) through (g) below.

(a) *Butt Welded Nozzles.* Nozzles shall be attached by full penetration butt welds through either the vessel or the nozzle wall, as shown in Fig. NE-4244(a)-1. Backing strips, if used, may be left in place.

(b) *Full Penetration Corner Welded Nozzles.* Nozzles shall be attached by full penetration welds through the wall of the vessel or nozzle similar to those shown in Fig. NE-4244(b)-1. When complete joint penetration cannot be verified by

visual examination or other means permitted, backing strips or equivalent shall be used with full penetration welds deposited from only one side. Backing strips, if used, may be left in place.

(c) *Use of Deposited Weld Metal for Opening and Nozzles.* Nozzles shall be joined to the vessel by full penetration weld to built-up weld deposits which may be applied to either the vessel or nozzle wall as shown in Fig. NE-4244(c)-1. Backing strips, if used, may be left in place. Fillet welds shall be used in the attachment of nozzles only to provide a transition between the parts joined or to provide a seal. The fillet welds, when used, shall be finished by grinding to provide a smooth surface having a transition radius at its intersection with either part being joined.

(d) *Attachment of Nozzles Using Partial Penetration Welds.* Partial penetration welds shall meet the requirements of NE-3352.4(d) and NE-3359. Nozzles shall be attached as shown in Fig. NE-4244(d)-1, Fig. NE-4244(d)-2, or Fig. NE-4244(d)-3.

(e) *Attachment of Fittings With Internal Threads.* Internally threaded fittings shall be attached by a full penetration groove weld, or for NPS 2 (DN 50) and less by two fillet or partial penetration welds, one on each face of the vessel wall, or by a fillet groove weld from the outside only as shown in Fig. NE-4244(e)-1 sketch (c-3). Internally threaded fitting and bolting pads not exceeding 3 in. pipe size (DN 80), as shown in Fig. NE-4244(e)-2, may be attached to vessels having a wall thickness not greater than $\frac{3}{8}$ in. (10 mm) by a fillet weld, deposited from the outside only. The design requirements of NE-3352.4(e) shall be met for all vessels.

(f) *Tubed Connections.* Nozzles or tubes recessed into thick walled components or parts may be welded from only one side provided the requirements of NE-3352.4(f) are met. Typical connections are shown in Fig. NE-4244(f)-1.

(g) *Reinforcing Plates.* Reinforcing plates of nozzles attached to the outside of a vessel shall be provided with at least one telltale hole (maximum size $\frac{1}{4}$ in. pipe tap) that may be tapped for a preliminary compressed air and soapsuds test for tightness of welds. These telltale holes may be left open or may be plugged when the vessel is in service. If the holes are plugged, the plugging material used shall not be capable of sustaining pressure between the reinforcing plate and the vessel wall.

NE-4300 WELDING QUALIFICATIONS

NE-4310 GENERAL REQUIREMENTS

NE-4311 Types of Processes Permitted

Only those welding processes which are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Subsection may be used for welding pressure retaining material or attachments thereto. Any process used shall be such that the records required by NE-4320 can be prepared, except that records for stud welds shall be traceable to the welders and welding operators and not necessarily to each specific weld.

NE-4311.1 Stud Welding Restrictions.

Stud welding is acceptable only for nonstructural and temporary attachments (NE-4435). Studs shall be limited to 1 in. (25 mm) maximum diameter for round studs and an equivalent cross-sectional area for studs of other shapes when welding in the flat position and $\frac{3}{4}$ in. (19 mm) diameter for all other welding positions. Postweld heat treatment shall comply with NE-4600, except that time at temperature need not exceed $\frac{1}{2}$ hr, regardless of base material thickness. Welding procedure and performance qualification shall comply with the requirements of Section IX.

NE-4311.2 Capacitor Discharge Welding.

Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments provided:

(a) temporary attachments are removed in accordance with the provisions of NE-4435(b); and

(b) the energy output for permanent nonstructural attachments such as strain gages and thermocouples is limited to 125 W-sec and the minimum thickness of the material to which the attachment is made is greater than 0.09 in. (2.3 mm); and

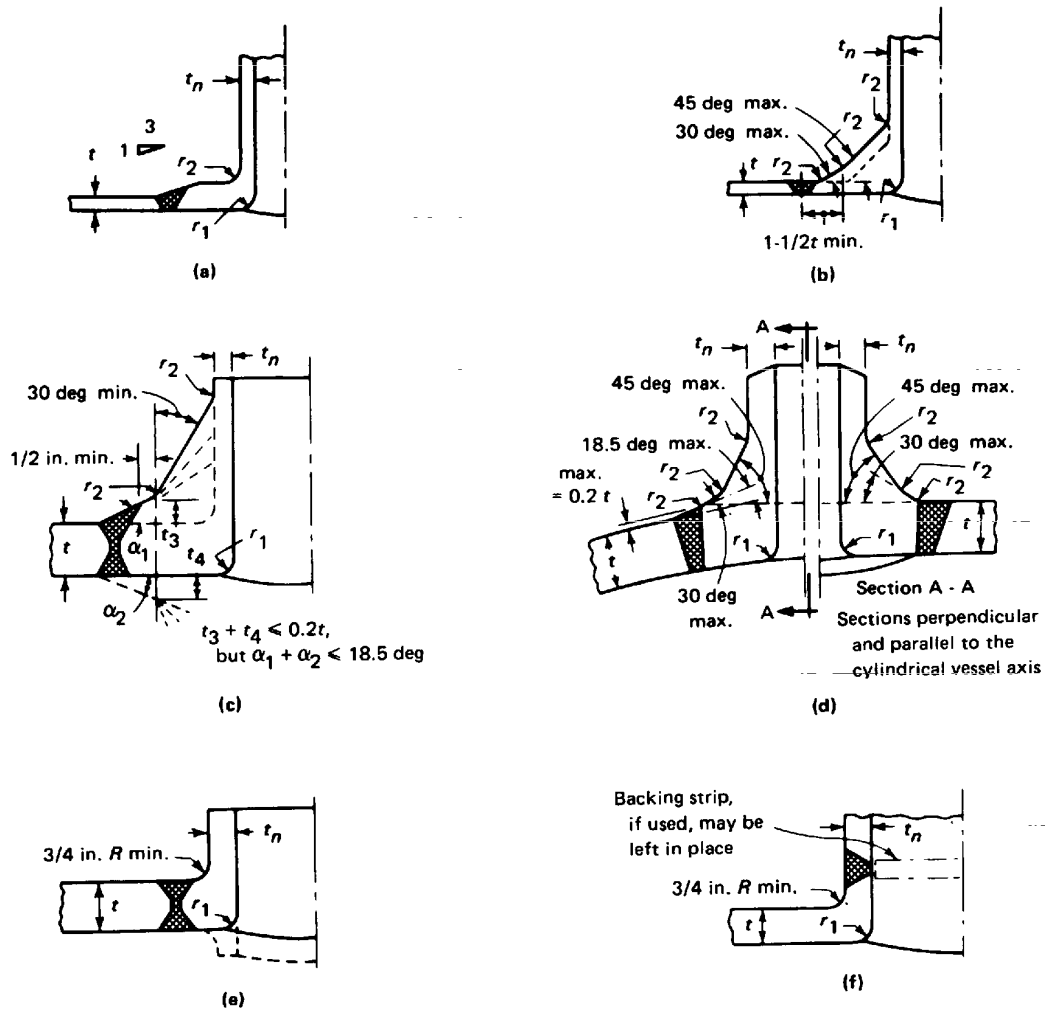


FIG. NE-4244(a)-1 NOZZLES ATTACHED BY FULL PENETRATION BUTT WELDS
For Definition of Symbols, See NE-3352.4(a).

FIG. NE-4244(a)-1 NOZZLES ATTACHED BY FULL PENETRATION BUTT WELDS

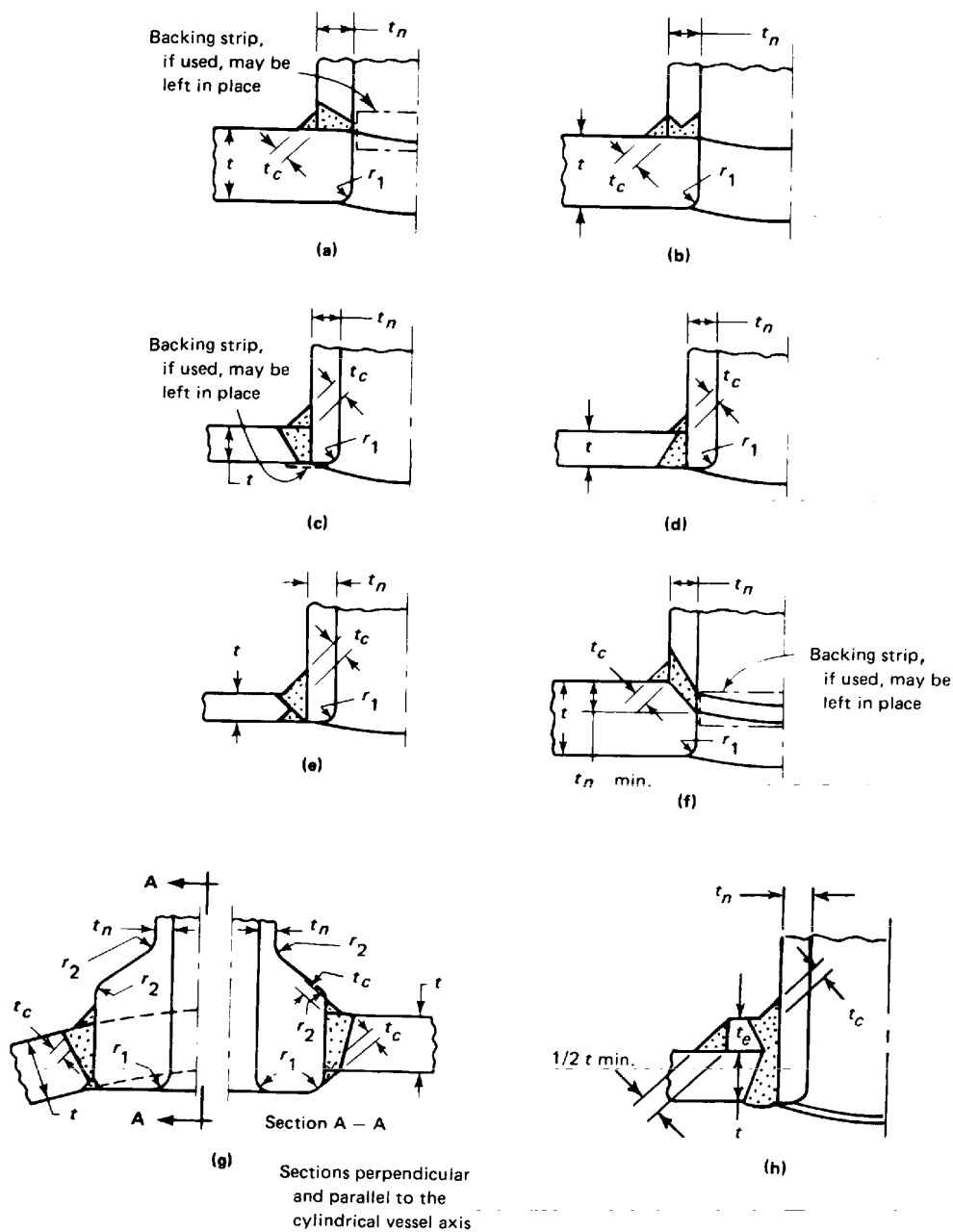


FIG. NE-4244(b)-1 NOZZLES ATTACHED BY FULL PENETRATION CORNER WELDS
For Definition of Symbols, See NE-3352.4(b).

FIG. NE-4244(b)-1 NOZZLES ATTACHED BY FULL PENETRATION CORNER WELDS

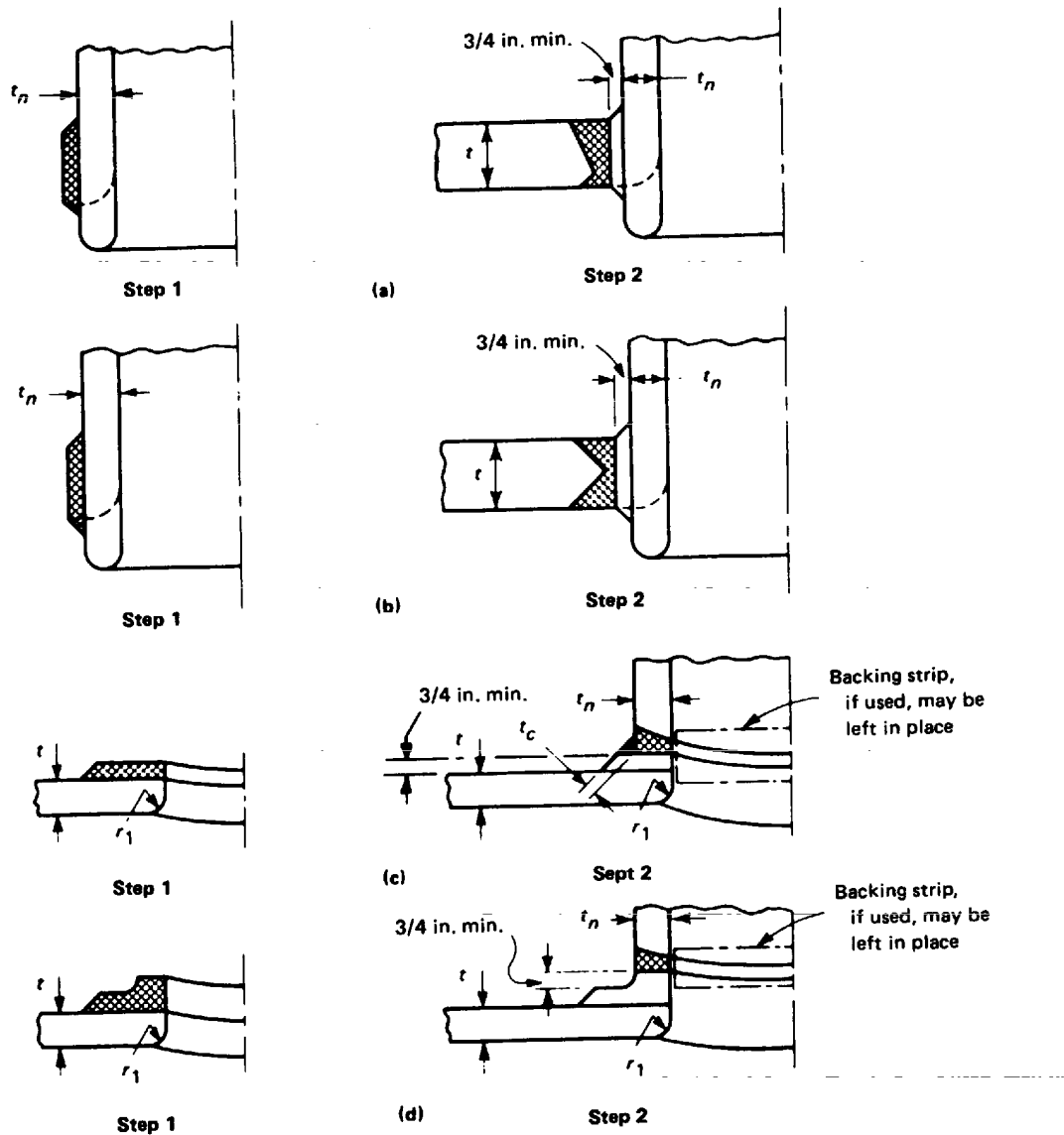


FIG. NE-4244(c)-1 DEPOSITED WELD METAL FOR OPENINGS AND NOZZLES
For Definition of Symbols, See NE-3352.4(c).

FIG. NE-4244(c)-1 DEPOSITED WELD METAL FOR OPENINGS AND NOZZLES

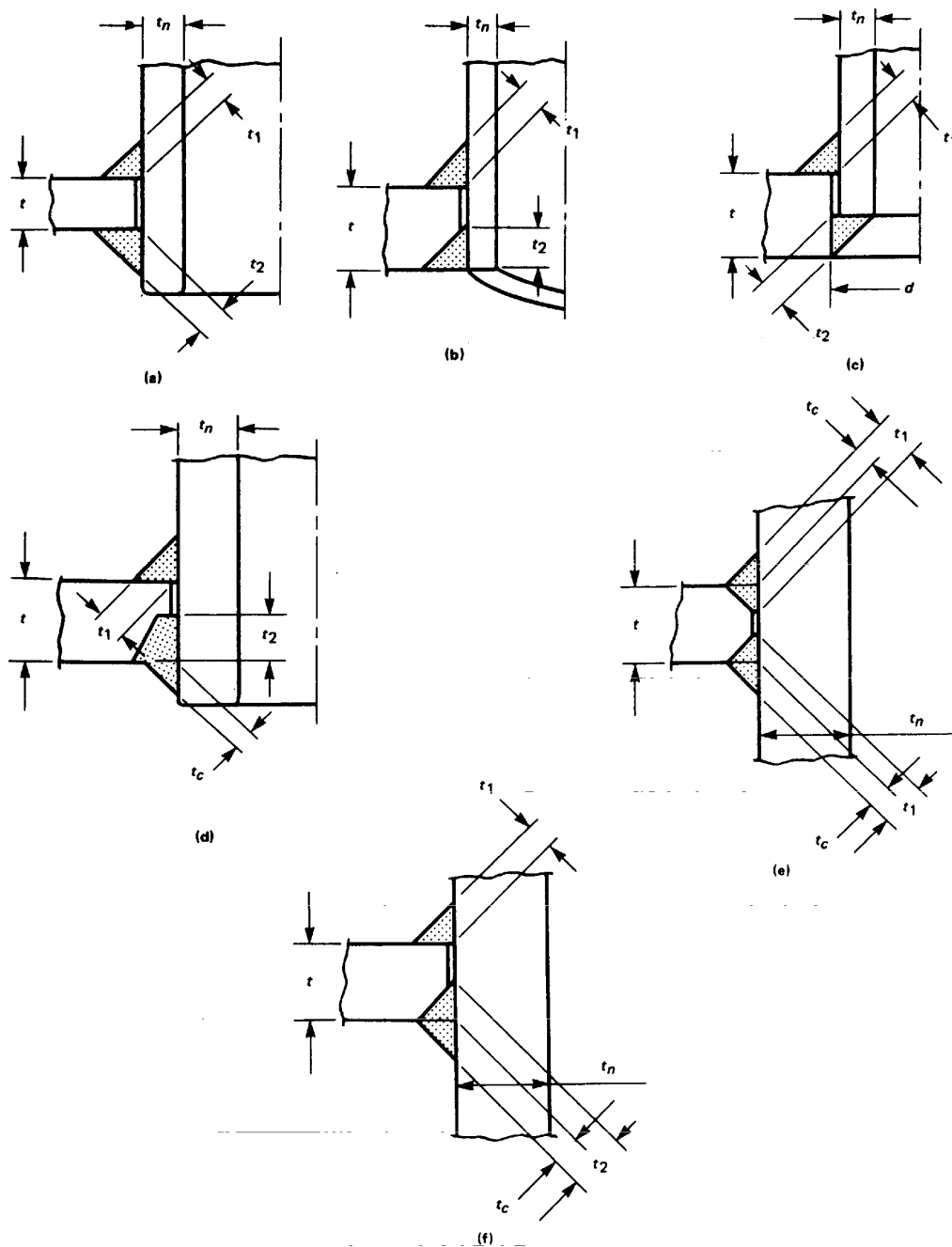
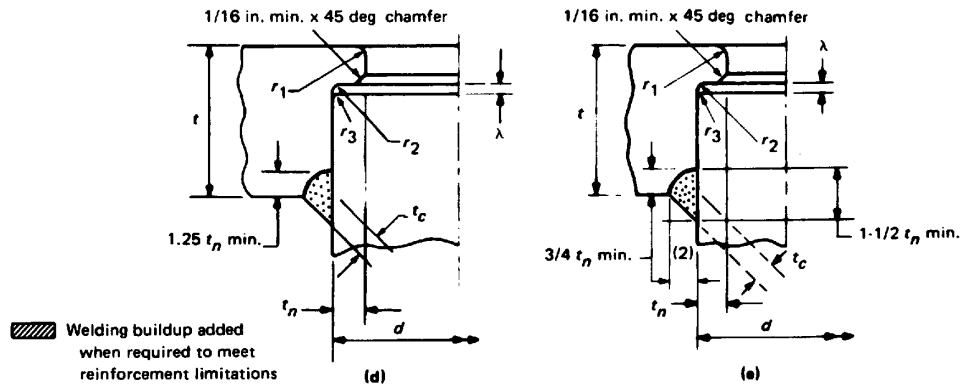
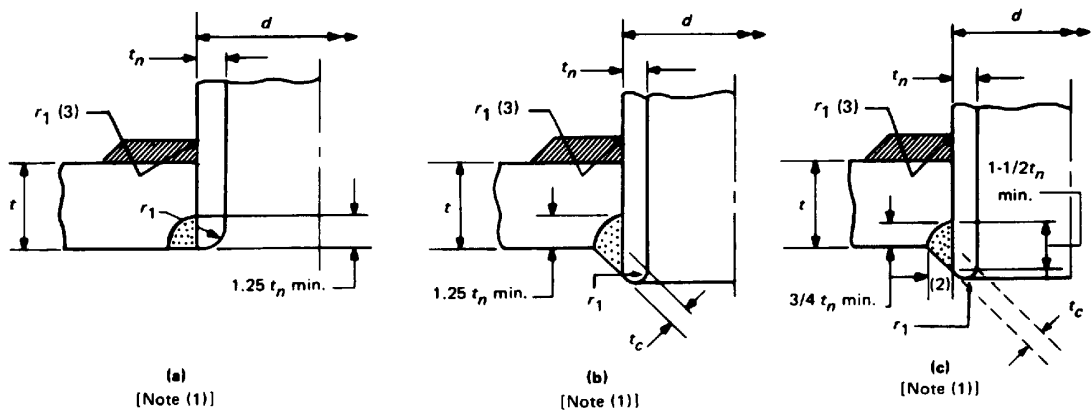


FIG. NE-4244(d)-1 ACCEPTABLE TYPES OF WELDED NOZZLES USING PARTIAL PENETRATION WELDS
For Definition of Symbols, See NE-3352.4(d).

FIG. NE-4244(d)-1 ACCEPTABLE TYPES OF WELDED NOZZLES USING PARTIAL PENETRATION WELDS



NOTES:

- (1) Weld deposit, if used, shall be examined as required by NE-5243.
- (2) The $3/4 t_n$ minimum dimension applies to the fillet leg and groove depth.
- (3) If weld deposit reinforcement is not used, r_1 shall apply to the base material instead of the weld buildup.

FIG. NE-4244(d)-2 PARTIAL PENETRATION WELD CONNECTIONS
For Definition of Symbols, See NE-3352.4(d).

FIG. NE-4244(d)-2 PARTIAL PENETRATION WELD CONNECTIONS

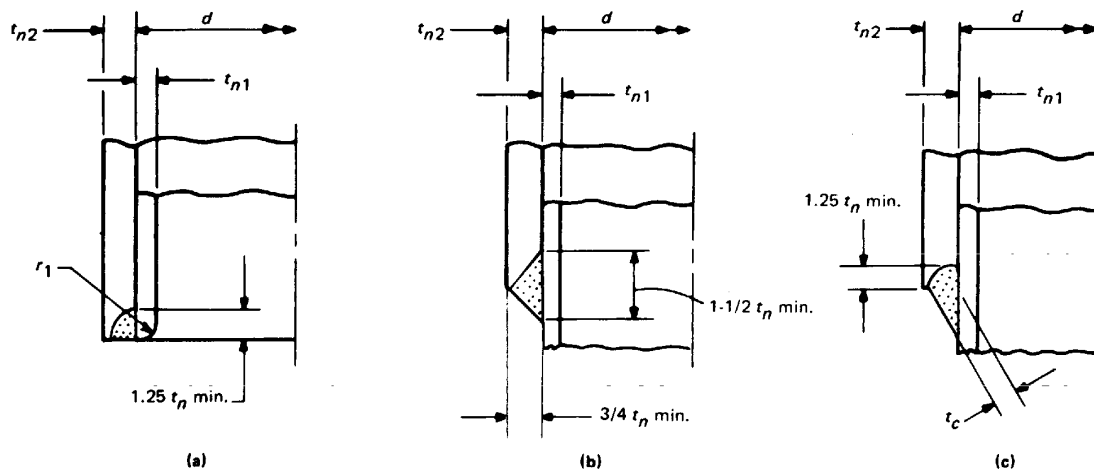


FIG. NE-4244(d)-3 PARTIAL PENETRATION WELD CONNECTIONS FOR COAXIAL CYLINDERS
For Definition of Symbols, See NE-3352.4(d).

FIG. NE-4244(d)-3 PARTIAL PENETRATION WELD CONNECTIONS FOR COAXIAL CYLINDERS

Page 134

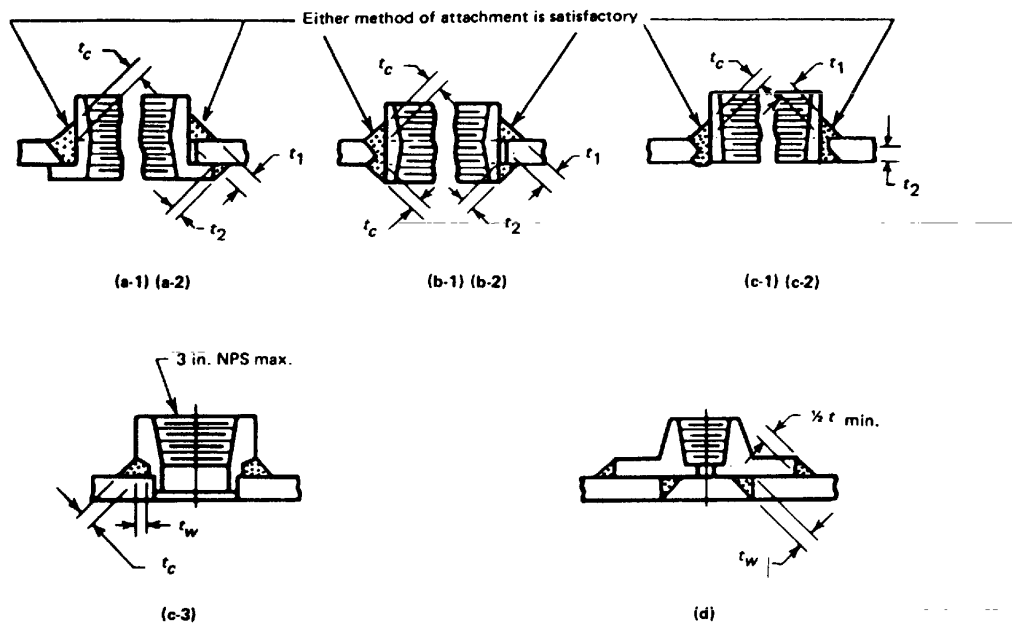


FIG. NE-4244(e)-1 ACCEPTABLE TYPES OF FITTINGS WITH INTERNAL THREADS
For Definition of Symbols, See NE-3352.4(e).

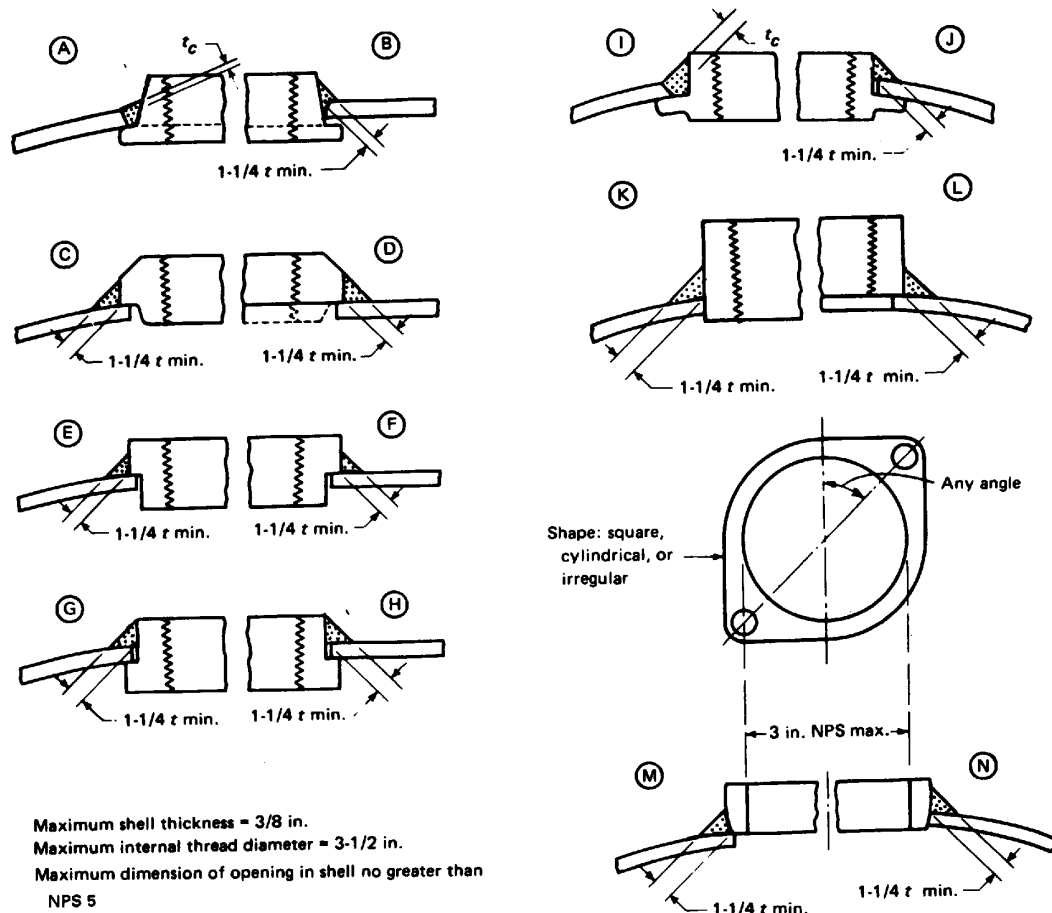


FIG. NE-4244(e)-2 ACCEPTABLE TYPES OF SMALL FITTINGS

FIG. NE-4244(e)-2 ACCEPTABLE TYPES OF SMALL FITTINGS

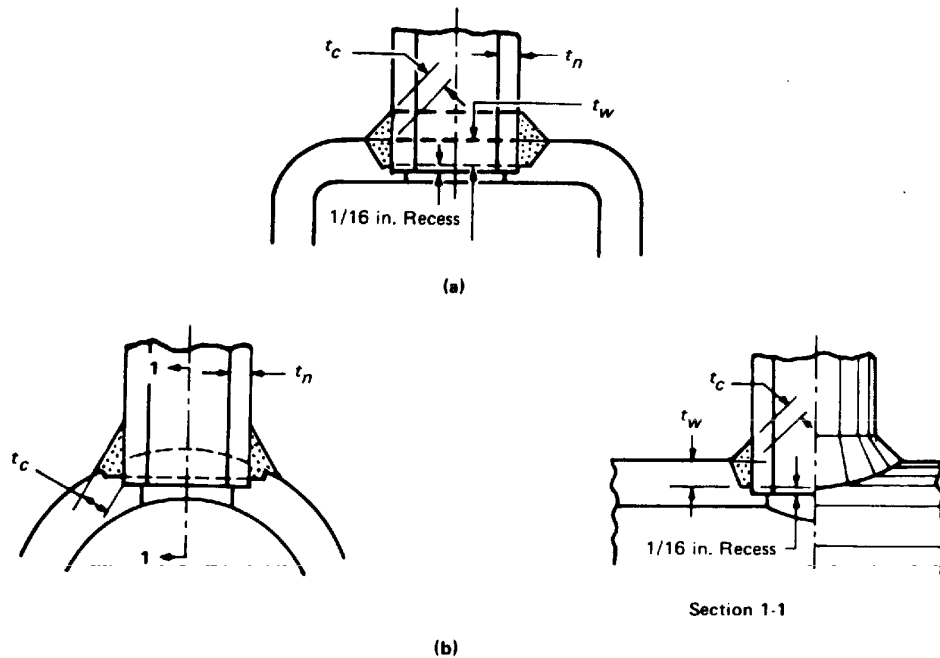


FIG. NE-4244(f)-1 TUBE CONNECTIONS

FIG. NE-4244(f)-1 TUBE CONNECTIONS

(c) a Welding Procedure Specification is prepared describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required.

NE-4311.4 Inertia and Continuous Drive Friction Welding.

Inertia and continuous drive friction welding shall not be used in the fabrication of containment vessels.

NE-4320 WELDING QUALIFICATIONS, RECORDS, AND IDENTIFYING STAMPS

NE-4321 Required Qualifications

(a) Each Certificate Holder is responsible for the welding done by his organization, and he shall establish the procedure and conduct the tests required by this Article and by Section IX in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures.

(b) Procedures, welders, and welding operators used to join permanent or temporary attachments to pressure parts and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Article.

(c) When making procedure test plates for butt welds, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. This applies particularly to material and weld metal of 80.0 ksi (552 MPa) tensile strength or higher and heavy sections of both low and high tensile strength material. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

NE-4322 Maintenance and Certification of Records

The Certificate Holder shall maintain a record of his qualified welding procedures and of the welders and welding operators qualified by him, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and signed by any authorized individual assigned by the Certificate Holder, and they shall be accessible to the Owner and to the Inspector.

Page 136

NE-4322.1 Identification of Joints by Welder or Welding Operator

(a) Each welder or welding operator shall apply the identification mark assigned to him by the Certificate Holder on or adjacent to all permanent welded joints or series of joints on which he welds. The marking shall be at intervals of 3 ft (0.9 m) or less and shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps. As an alternative, the Certificate Holder shall keep a record of permanent welded joints in each item, and of the welders and welding operators used in making each of the joints.

(b) When a multiple number of permanent structural attachment welds, nonstructural welds, fillet welds, socket welds, welds of specially designed seals, weld metal cladding, hard surfacing and tube-to-tubesheet welds, are made on an item, the Certificate Holder need not identify the welder or welding operator who welded each individual joint, provided:

(1) the Certificate Holder maintains a system that will identify the welders or welding operators who made such welds on each item so that the Inspector can verify that the welders or welding operators were all properly qualified;

(2) the welds in each category are all of the same type and configuration and are welded with the same welding procedure specification.

(c) The identification of welder or welding operator is not required for tack welds.

NE-4323 Welding Prior to Qualifications

No welding shall be undertaken until after the welding procedures which are to be used have been qualified. Only welders and welding operators who are qualified in accordance with NE-4320 and Section IX shall be used.

NE-4324 Transferring Qualifications

The welding procedure qualifications and the performance qualification tests for welders and welding operators conducted by one Certificate Holder shall not qualify welding procedures and shall not qualify welders or welding operators to weld for any other Certificate Holder, except as provided in Section IX, QW-201 and QW-300.2.

NE-4330 GENERAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION TESTS

NE-4331 Conformance to Section IX Requirements

All welding procedure qualification tests shall be in accordance with the requirements of Section IX as supplemented by the requirements of this Article.

NE-4333 Heat Treatment of Qualification Welds of Ferritic Material

Postweld heat treatment of procedure qualification welds shall conform to the applicable requirements of NE-4600 and Section IX. The postweld heat treatment time at temperature shall be at least 80% of the maximum time to be applied to the weld material. The postweld heat treatment total time may be applied in one heating cycle.

NE-4334 Preparation of Test Coupons and Specimens

(a) Removal of test coupons from the test weld and the dimensions of specimens made from them shall conform to the requirements of Section IX, except that the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with (b) below.

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test specimens. When each process cannot be included in the full-size impact test specimen at the $1/4t$ location required by this

Section, additional full-size specimens shall be obtained from locations in the test weld that will ensure that at least a portion of each process has been included in full-size test specimens. As an alternative, additional test welds can be made with each process so that full-size specimens can be tested for each process.

NE-4334.1 Coupons Representing the Weld Deposits.

Impact specimen and testing methods shall conform to NE-2321. The impact specimen shall be located so that the longitudinal axis of the specimen is at least $\frac{1}{4}t$, and where the thickness of the test assembly permits, not less than $\frac{3}{8}$ in. (10 mm) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified in NE-4620, and the test assembly is cooled at an accelerated rate, the longitudinal axis of the specimen shall be a minimum of t from

Page 137

the edge of the test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the weld. The length of the notch of the Charpy V-notch specimen shall be normal to the surface of the weld. Where drop weight specimens are required, the tension surface of the specimen shall be oriented parallel to the surface of the test weld assembly.

NE-4334.2 Coupons Representing the Heat Affected Zone.

Where impact tests of the heat affected zone are required by NE-4335.2, specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through (c) below.

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented either parallel or perpendicular to the principal direction of rolling or forging.

(b) The heat affected zone impact test specimens and testing methods shall conform to the requirements of NE-2321.2. The specimens shall be removed from a location as near as practical to a depth midway between the surface and center thickness. The coupons for heat affected zone impact specimens shall be taken transverse to the axis of the weld and etched to define the heat affected zone. The notch of the Charpy V- notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much heat affected zone as possible in the resulting fracture. Where the material thickness permits, the axis of a specimen may be inclined to allow the root of the notch to align parallel to the fusion line. When a grain refining heat treatment is not performed on welds made by the electroslag or electrogas welding process, the notch for the impact specimens shall be located in the grain coarsened region.

(c) For the comparison of heat affected zone values with base material values [NE-4335.2(b)], Charpy V-notch specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the heat affected zone specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the heat affected zone specimens, and the axis of the notch shall be normal to the surface of the base material.

NE-4335 Impact Test Requirements

When materials are required to be impact tested per NE-2300, impact tests of the weld metal and heat affected zone shall be performed in accordance with the following subparagraphs. Exemption from impact testing under NE-2311(a)(8) does not apply for weld metal unless the specific weld metal used is included in Table NE-2311(a)-1. Exemption from impact testing of the heat affected zone of those base materials exempted by NE-2311(a)(8) is not permitted. The weld procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of NE-2330 and NE-4334. Retests in accordance with the provisions of NE-2350 are permitted.

NE-4335.1 Impact Tests of Weld Metal

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding $\frac{5}{8}$ in. (16 mm) in thickness when the weld is made on the surface or penetrates the base material that requires impact testing in accordance with NE-2310. In addition, such testing of the weld metal is required for the welding procedure qualification tests for any weld repair to base material that requires impact testing in accordance with NE-2310, regardless of the depth of the repair. Exemption from impact testing under NE-2311(a)(8) does not apply for weld metal of welding procedure qualification tests for either production weld joints or base material repairs, unless the

specific weld metal used is included in Table NE-2311(a)-1.

(b) The impact test requirements and acceptance standards for welding procedure qualification weld metal shall be the same as specified in NE-2330 for the base material to be welded or repaired. Where two materials which have different fracture toughness requirements are to be joined by welding, the test requirements and acceptance standards of either material may be used for the weld metal, except where otherwise specified by NCA-1230 or other parts of this Section.

(c) A Welding Procedure Specification qualified to the impact testing requirements of Subsection NB or Subsection NC may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection.

NE-4335.2 Impact Tests of Heat Affected Zone

(a) Charpy V-notch tests of the heat affected zone of the welding procedure qualification test assembly are required whenever the thickness of the weld exceeds $\frac{5}{8}$ in. (16 mm) and either of the base materials requires impact testing in accordance with the rules of NE-2310.

The only exceptions to the requirements are the following:

(1) the qualification for welds in P-No. 1 materials that are postweld heat treated and made by any process other than electroslog, electrogas, or thermit;

(2) the qualification for weld deposit cladding or hard-facing on any base material.

Page 138

(b) Impact testing of the procedure qualification test heat affected zone, where required by NE-4335, shall be conducted in accordance with (b)(1) through (b)(3) or (b)(4) through (b)(6), and (c) below, if applicable.

(1) For tests of welding procedure qualifications for materials that require tests in accordance with NE-2332.1 and NE-2333.1, when applicable, three Charpy V-notch heat affected zone and three Charpy V-notch unaffected base material specimens shall be tested at a temperature in accordance with NE-2331(a)(1). The Charpy V-notch impact test of the unaffected base material shall meet the requirements of Table NE-2332.1-1 or Table NE-2332.1-2, and Table NE-2333.1-1, if applicable. If the average toughness value of the three heat affected zone specimens is equal to or greater than the average value of the unaffected base material Charpy V-notch specimens, the qualification test shall be considered acceptable, the values and testing temperatures shall be recorded on the Welding Procedure Qualification Record, and the production base material impact tests may be conducted at temperatures in accordance with NE-2331.

(2) If the heat affected zone Charpy V-notch average toughness value of (b)(1) above is less than the unaffected base material value and the qualification test meets the other criteria of acceptance, the Charpy V-notch test results may be recorded on the Welding Procedure Qualification Record. In this case, either production base material impact tests shall be conducted 30°F lower than required by NE-2331 or data which will provide a testing temperature reduction for the production base material below that of NE-2331, or an increase in the lowest service temperature for the base material for which the welding procedure is being qualified shall be obtained in accordance with (b)(3) below and included. Alternatively, the welding procedure qualification may be rewelded and retested.

(3) The data for use in (b)(2) above shall be developed by performing additional Charpy V-notch tests on either the welding procedure qualification test heat affected zone or the unaffected base material or both at temperatures which provide toughness values that meet or exceed those required for the thickness or thickness-strength combination of the material to be welded in production. The average toughness values for the heat affected zone and unaffected base material shall be plotted on a property-temperature chart. The temperature at which these two sets of data exhibit a common acceptable value of toughness for the production thickness or thickness-strength combination involved shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the heat affected zone. This difference, if a positive number, shall be used in (b)(2) above as the adjustment temperature. The welding procedure adjustment temperature shall be added to the highest lowest service temperature established by the tests of NE-2332.1 for all of the base material to be welded by this procedure in production. If the temperature difference is zero or a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by the tests for NE-2332.1 will still apply as stated in (b)(1) above. Where the actual lowest service temperature is not required for the production material to be

welded (for example, where a testing temperature is established by the Design Specification to determine that the material has adequate toughness to meet the requirements at the specified test temperature), the adjustment temperature determined by the curves shall be used to establish a reduction in the specified testing temperature for the production material. The adjustment temperature shall be used to lower the specified testing temperature for any production material upon which the procedure will be used.

(4) For tests of welding procedure qualifications for materials that require tests in accordance with NE-2332.2, three Charpy V-notch heat affected zone specimens and three Charpy V-notch unaffected base material specimens shall be tested at a temperature lower than or equal to the lowest service temperature. The Charpy V-notch impact tests of the unaffected base material shall meet or exceed the applicable Over $2\frac{1}{2}$ in. (64 mm) thickness requirements of Table NE-2332.1-1 or Table NE-2332.1-2, and Table NE-2333.1-1, if applicable. If the average toughness value of the three heat affected zone specimens is equal to or greater than the average value for the unaffected base material Charpy V-notch specimens, the qualification test shall be considered acceptable. The values and testing temperature shall be recorded on the Welding Procedure Qualification Record.

(5) If the heat affected zone Charpy V-notch average toughness value of (b)(4) above is less than the unaffected base material value, and the qualification test meets the other criteria of acceptance, the Charpy V-notch test results may be recorded on the Welding Procedure Qualification Record. In this case, either production base material impact tests shall be conducted 30°F (17°C) lower than required by NE-2331 or data which will provide a testing temperature reduction for the production base material below that of NE-2331, or an increase in the lowest service temperature for the base material for which the welding procedure is being qualified shall be obtained in accordance with

Page 139

(b)(6) below and included. Alternatively, the welding procedure qualification may be rewelded and retested.

(6) The data for use in (b)(5) above shall be developed by performing additional Charpy V-notch tests on either or both of the welding procedure qualification heat affected zone and unaffected base material at temperatures which provide values equal to or greater than the applicable Over $2\frac{1}{2}$ in. (64 mm) thickness requirements of Table NE-2332.1-1 or Table NE-2332.1-2, and Table NE-2333.1-1, if applicable. The average toughness values for the heat affected zone and the unaffected base material shall be plotted on a property-temperature chart. The temperature at which these two sets of data exhibit a common toughness value equal to or greater than the applicable Over $2\frac{1}{2}$ in. (64 mm) thickness requirements of Table NE-2332.1-1 or Table NE-2332.1-2, and Table NE-2333.1-1, if applicable, shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the heat affected zone. This difference, if a positive number, shall be used in (b)(5) above as the adjustment temperature. The adjustment temperature shall be added to the highest T_{NDT} established by the tests of NE-2332.2 for all of the base materials to be welded by this procedure in production. If the temperature difference is zero or a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by the tests for NE-2332.2 will still apply as stated in (b)(4) above.

Where the actual T_{NDT} is not required for the production material to be welded (for example, where a testing temperature is established by the Design Specification to determine that the T_{NDT} is at or below the specified temperature), the adjustment temperature determined by the curves shall be used to establish a reduction in the specified testing temperature for the production material. The adjustment temperature shall be used to lower the specified testing temperature for any production material upon which the procedure will be used.

(c) Should the unaffected base material Charpy V-notch impact test results fail to meet the applicable requirements referenced in (b)(1) or (b)(4) above, additional unaffected base material Charpy V-notch impact tests shall be tested at higher temperatures until the applicable requirements are met. Charpy V-notch impact tests of the heat affected zone shall be tested at the same temperature at which acceptable unaffected base material properties were achieved. The rules governing the average toughness of the heat affected zone relative to the average toughness of the unaffected base material shall be followed as in (b)(1) through (3), or (b)(4) through (6), as applicable, to determine the data which are to be recorded on the Welding Procedure Qualification Record.

(d) A Welding Procedure Specification qualified to the impact testing requirements of Subsection NB or Subsection NC may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection.

NE-4336 Qualification Requirements for

Built-Up Weld Deposits

Built-up weld deposits for base metal reinforcement shall be qualified in accordance with the requirements of NE-4331 through NE-4335.

NE-4340 PERFORMANCE QUALIFICATION OF WELDERS FOR CLAD MATERIAL

NE-4341 General Requirements

A welder who has passed a test on composite welds in clad plate, as provided in NE-4341.1, or as part of a procedure qualification test, as provided in NE-4429.1(a), is qualified for welding base metal and lining or cladding material separately. Likewise, a welder who has qualified on base metal and lining or cladding material separately is qualified to make composite welds. Qualification on both base plate and lining or cladding material is required only of welders who weld both materials.

NE-4341.1 Requirements for Composite Materials.

Performance qualification tests shall be made in accordance with Section IX by preparing test plates from clad material having the same P-Numbers in QW-442 as that of the base plate and cladding material to be used in construction, and having the same F-Number in QW-432 as the filler metal that will be used in construction. When the cladding material is not listed in QW-442, qualification shall be made on the same grade as used in the vessel. Heat treatment is not required but is permitted if the welder's work or construction is to be heat treated.

NE-4341.2 Requirements for Corrosion Resistant Welds.

Performance qualification tests for welding corrosion resistant materials shall be the same as the procedure qualification tests described in NE-4331.

Page 140

NE-4400 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS

NE-4410 PRECAUTIONS TO BE TAKEN BEFORE WELDING

NE-4411 Identification, Storage, and Handling of Welding Materials

Each Certificate Holder is responsible for control of the welding electrodes and other material which is used in the fabrication and installation of components (NE-4120). Suitable identification, storage, and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by electrodes and flux.

NE-4412 Cleanliness and Protection of Welding Surfaces

The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

NE-4420 RULES FOR MAKING WELDED JOINTS

NE-4421 Backing Rings

Backing rings shall conform to the requirements of NE-4240. The material for backing rings, when used, shall be compatible with the base metal. Permanent backing rings, when permitted by NE-4240, shall be continuous, and any splices shall be made by full penetration welds. Spacer pins shall not be incorporated into the welds.

NE-4422

NE-4422 Peening

Controlled peening may be performed to minimize distortion. Peening shall not be used on the initial layer root of the weld metal, nor on the final layer, unless the weld is postweld heat treated in accordance with NE-4600.

NE-4423 Miscellaneous Welding Requirements

(a) Before applying weld metal on the second side to be welded, the root of full penetration double welded joints shall be prepared by suitable methods such as chipping, grinding, or thermal gouging, except for those processes of welding by which proper fusion and penetration are otherwise obtained and demonstrated to be satisfactory by welding procedure qualification.

(b) If the welding is stopped for any reason, extra care shall be taken in restarting to get the required penetration and fusion. For submerged arc welding, chipping out a groove in the crater is recommended.

(c) Where single welded joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joint for its full length.

NE-4424 Surfaces of Welds

As-welded surfaces are permitted. However, the surface of welds shall be sufficiently free from coarse ripples, grooves, overlaps, abrupt ridges, and valleys to meet (a) through (e) below.

(a) The surface condition of the finished weld shall be suitable for the proper interpretation of radiographic and other required nondestructive examinations of the welds. In those cases where there is a question regarding the surface condition on the interpretation of a radiographic film, the film shall be compared to the actual weld surface for interpretation and determination of acceptability.

(b) Reinforcements are permitted in accordance with NE-4426.

(c) Undercuts shall not exceed $\frac{1}{32}$ in. (0.8 mm) and shall not encroach on the required section thickness.

(d) Concavity on the root side of a single welded circumferential butt weld is permitted when the resulting thickness of the weld meets the requirements of NE-3000.

(e) If the surface of the weld requires grinding to meet the above criteria, care shall be taken to avoid reducing the weld or base material below the required thickness.

NE-4425 Welding Components of Different Diameters

When components of different diameters are welded together, there shall be a gradual transition between the two surfaces in accordance with NE-3361. The length of the transition may include the weld.

Page 141

NE-4426 Reinforcement of Welds

The surface of the reinforcement of all butt welded joints in vessels may be flush with the base material or may have uniform crowns. The height of reinforcement on each face of the weld shall not exceed the following thickness:

Nominal Thickness, in.	Maximum Reinforcement, in.
Up to 1, incl.	$\frac{3}{32}$
Over 1 through 2, incl.	$\frac{1}{8}$
Over 2 through 3, incl.	$\frac{5}{32}$
Over 3 through 4, incl.	$\frac{7}{32}$
Over 4 through 5, incl.	$\frac{1}{4}$
Over 5	$\frac{5}{16}$

NE-4427 Shape and Size of Fillet Welds

Fillet welds may vary from convex to concave. The shape and size of the weld shall be in accordance with the requirements of Fig. NE-4427-1. A fillet weld in any single continuous weld may be less than the specified fillet weld dimension by not more than $\frac{1}{16}$ in. (1.6 mm), provided that the total undersize portion of the weld does not exceed 10% of the length of the weld. Individual undersize weld portions shall not exceed 2 in. (51 mm) in length. In making socket welds, a gap as shown in Fig. NE-4427-1 shall be provided prior to welding. The gap need not be present nor be verified after welding.

NE-4428 Seal Welds of Threaded Joints

Where seal welding of threaded pipe joints is performed, the exposed threads shall be either removed entirely or covered with weld metal.

NE-4429 Welding of Clad Parts¹

The joint types and welding procedures used for cladding shall be such as to prevent the formation of brittle weld composition.

NE-4429.1 Groove Welds in Clad Plate

(a) The requirements in Section IX for procedure qualification shall be modified as follows for groove welds in clad plate.

¹ Welds that are exposed to corrosive action should have a resistance to corrosion that is not substantially less than that of the cladding. The use of filler metal that will deposit weld metal which is similar to the composition of the cladding material is recommended. If weld metal of different composition is used, it should have properties compatible with the application.

(1) The requirements in QW-403 and QW-404 shall apply separately to the base plate and to the cladding.

(2) The thicknesses specified in Table QW-451 shall apply to the total thickness of clad plate.

(3) For material not included in Table QW-422, the material used in the test plate shall be within the range of chemical composition of that to be used in construction.

(b) The welding procedure for groove welds in integrally clad plate shall be qualified as provided in (a) above when any part of the cladding thickness of the clad plate is included in the design calculations in accordance with NE-3122.4 (b). When the cladding thickness is not included in the design calculations, the procedure for groove welds may be qualified as in (a) above or the weld in the base plate joint may be qualified by itself in accordance with the rules in Section IX and the weld in the cladding joint by itself in accordance with NE-4429.3.

NE-4429.2 Alloy Welds in Base Metal.

Groove joints in base-metal plates and parts may be made with corrosion resistant alloy-steel filler metal, or groove joints may be made between corrosion resistant alloy steel and carbon or low alloy steel, provided the welding procedure and the welders have been qualified in accordance with the requirements of Section IX for the combination of materials used. Some applications of this rule are base metal welded with alloy-steel electrodes and alloy nozzles welded to shells.

NE-4429.3 Corrosion Resistant Weld Deposits.

Construction in which deposits of corrosion resistant alloy weld metal are applied as a protective covering on the surface of base metal plates and parts and over welded base metal joints, whether adjacent or not to the edges of lining sheets or cladding material, shall be qualified in accordance with the rules given in (a) through (f) below.

(a) The qualification test plate shall consist of a base plate not less than 6 in. (152 mm) long, 3 in. (76 mm) wide, and $\frac{1}{4}$ in. (6 mm) thick, to which are clamped or bonded two strips of lining or cladding material separated by a gap left in the lining or a groove cut in the cladding. The gap or groove shall run lengthwise of the test plate, approximately midway of the plate width. The nominal thickness of the lining or cladding shall be within 20% plus or minus of the thickness to be used in construction.

(b) The requirements of Section IX, QW-403 and QW-404, shall apply separately to the base plate and the lining or cladding. For material not included in Table QW-422, the material used in the test plate shall

Page 142

be within the range of chemical composition of that to be used in construction.

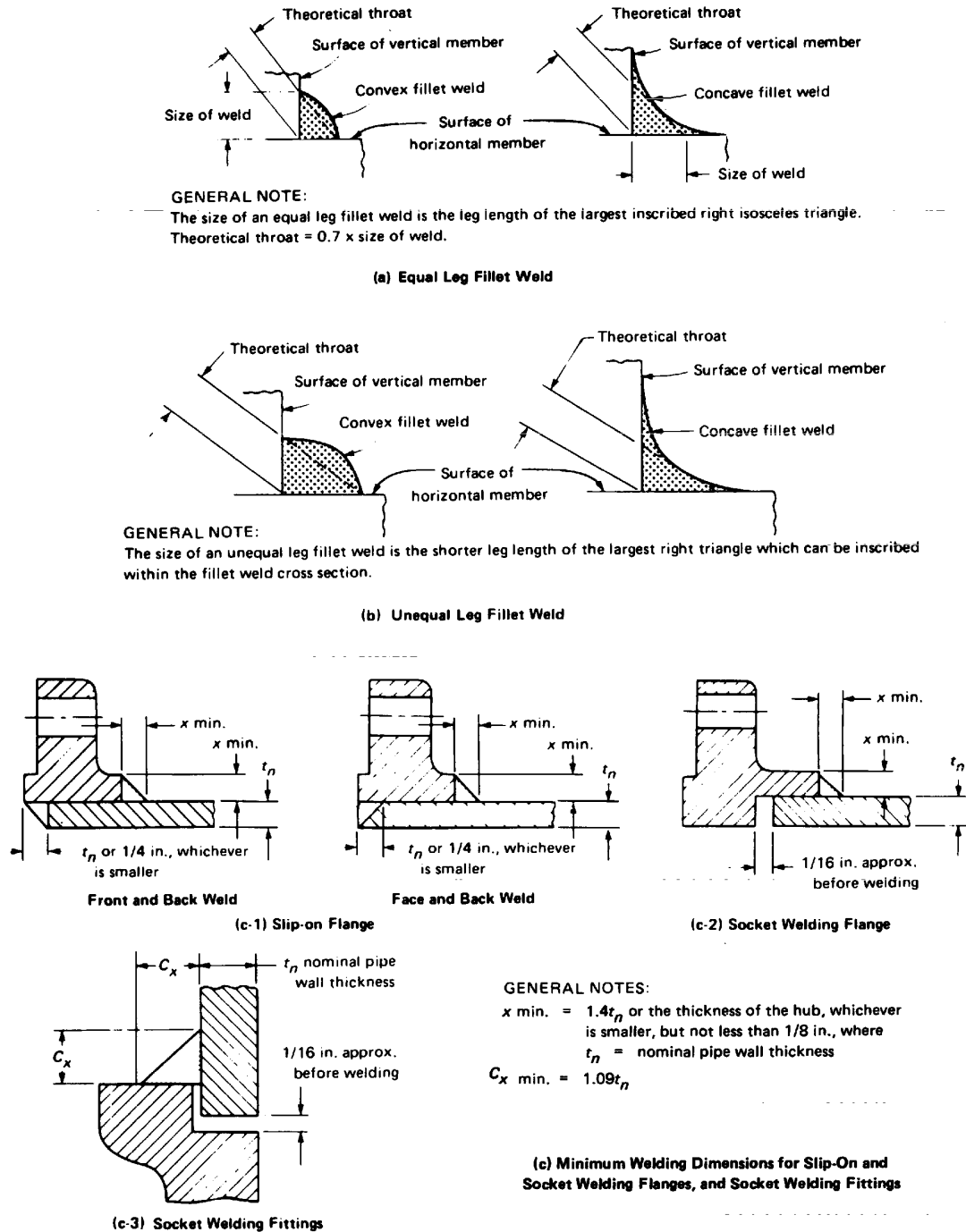


FIG. NE-4427-1 FILLET AND SOCKET WELD DETAILS AND DIMENSIONS

FIG. NE-4427-1 FILLET AND SOCKET WELD DETAILS AND DIMENSIONS

(c) The width of gap shall be not less than twice the nominal thickness of the lining or cladding and not less than the maximum gap to be used in construction, but need not be greater than $\frac{3}{4}$ in. (19 mm) in order to qualify welding procedures in which corrosion resistant weld metal is deposited in contact with base metal and adjacent lining or cladding material on two sides of a gap, as in welding the joints in linear sheets or clad plates.

(d) The width of a gap shall be not less than $\frac{3}{4}$ in. (19 mm) in order to qualify welding procedures in which corrosion resistant weld metal is deposited in contact with base metal with lining or cladding material on one side only, as in layering corrosion resistant weld metal on flange facings or in making fillet welds.

(e) The weld joint shall be made between the edges of the lining or cladding material by the procedure to be used in construction. The cooling of the test plate and any subsequent heat treatment shall follow the procedure to be used in construction.

(f) The tests to qualify the welding procedure shall be performed on two longitudinal bend test specimens that conform to the dimensions and other requirements of Section IX, QW-161 and QW-462.3(b). The specimens shall be tested in accordance with, and meet the requirements of, QW-162 and QW-163.

NE-4429.4 Fillet Welds.

Fillet welds of corrosion resistant metal deposited in contact with two materials of dissimilar composition may be used for connection attachments under the limitations of NE-3359. The qualification of the welding procedures and welders to be used on fillet welds for a given combination of materials and alloy weld metal shall be made in accordance with NE-4429.3 or, alternatively, by the rules prescribed in Section IX.

NE-4430 WELDING OF ATTACHMENTS

NE-4431 Materials for Attachments

Nonpressure-retaining attachments (NE-1132.1) welded to the containment vessel shall be of materials which meet the requirements of NE-2190. Materials for pressure retaining attachments shall meet the requirements of NE-2120.

NE-4432 Welding of Structural Attachments

The rules of NE-4321 governing welding qualifications shall apply to the welding of structural attachments to pressure retaining material.

NE-4433 Structural Attachments

Structural attachments shall conform reasonably to the curvature of the shell or surface to which they are attached, and may be attached by either full penetration, fillet, or partial penetration continuous or intermittent welds.

NE-4434 Welding of Internal Structural Supports to Clad Components

Internal structural supports on cladding surfaces shall be welded to the base metal and not to the cladding, except for weld overlay cladding.

NE-4435 Welding of Nonstructural and Temporary Attachments and Their Removal

(a) Nonstructural attachments (NE-1132.1) welded to the pressure retaining portion of the containment vessel need not comply with NE-2000 and may be welded with continuous or intermittent fillet or partial penetration welds, provided the requirements of (1) through (4) below are met:

- (1) the welding procedure and the welders have been qualified in accordance with NE-4321;
- (2) the material is identified and is compatible with the material to which it is attached;
- (3) the welding material is identified and compatible with the materials joined;

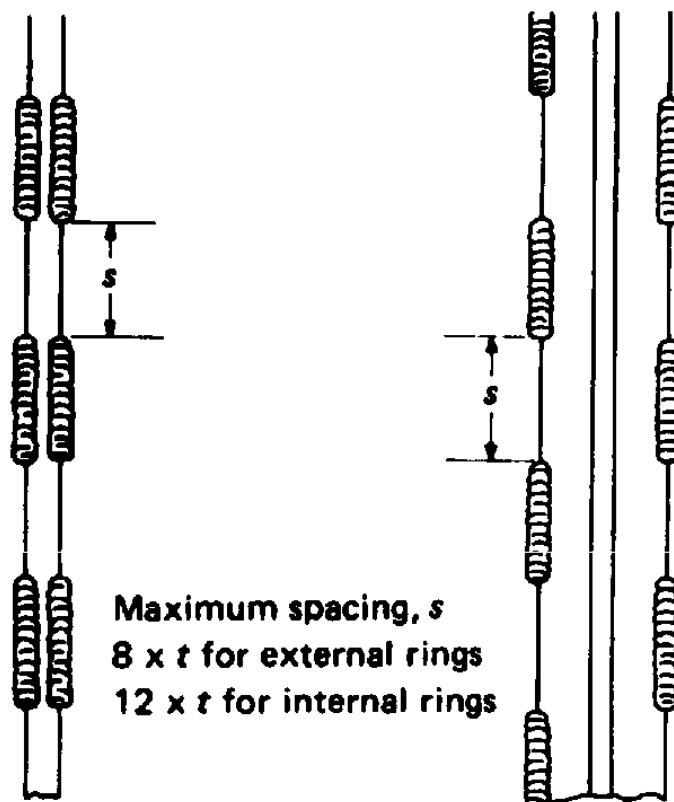
- (4) the welds are postweld heat treated when required by NE-4620.
- (b) Removal of temporary attachments shall be accomplished as follows:
- (1) The temporary attachment is completely removed in accordance with the procedures of NE-4211.
- (2) As an alternative to (a)(4) above, postweld heat treatment may be deferred until after removal of the attachment.

NE-4437 Attachment of Stiffening Rings to Shell

(a) Stiffening rings, when used, may be placed on the inside or outside of a vessel and shall be attached

Page 144

to the shell by welding or bolting. The ring shall be in contact with the shell.



**FIG. NE-4437(b)-1 ATTACHMENT
OF STIFFENING
RINGS TO SHELL**

FIG. NE-4437(b)-1 ATTACHMENT OF STIFFENING RINGS TO SHELL

(b) Stiffening rings may be attached to the shell either by continuous or intermittent welding. The total length of the intermittent welding on each side of the stiffening ring shall be:

(1) not less than one-half the outside circumference of the vessel for rings on the outside; and

(2) not less than one-third of the circumference of the vessel for rings on the inside. Acceptable arrangements and spacing of intermittent welds are shown in Fig. NE-4437(b)-1. Welds on opposite sides of the stiffener may be either staggered or in-line as indicated.

(c) All welding of stiffening rings shall comply with the requirements of this Subsection. In areas where a corrosion allowance is specified in the Design Specification, stiffening rings shall be attached to the shell with a continuous fillet, seal, or full penetration weld.

NE-4450 REPAIR OF WELD METAL DEFECTS

NE-4451 General Requirements

Defects in weld metal detected by the examinations required by NE-5000, or by the tests of NE-6000, shall be eliminated and when necessary repaired.

NE-4452 Elimination of Surface Defects

Weld metal surface defects may be removed by grinding or machining and not repaired by welding provided that the requirements of (a) through (c) below are met:

(a) the remaining thickness of the section is not reduced below that required by NE-3000;

(b) the depression, after defect elimination, is blended uniformly into the surrounding surface;

(c) the area is examined by a magnetic particle or liquid penetrant method in accordance with NE-5110 after blending and meets the acceptance standards of NE-5300 to ensure that the defect has been removed or the indication reduced to an acceptable limit. Defects detected by the visual or volumetric method and located on an interior surface need only be reexamined by the method which initially detected the defect when the interior surface is inaccessible for surface examination.

NE-4453 Requirements for Making Repairs to Welds

Excavations in weld metal, when repaired by welding, shall meet the requirements of the following subparagraphs.

NE-4453.1 Defect Removal.

Defects may be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined by a liquid penetrant or magnetic particle method in accordance with NE-5110 and meet the acceptance standards of NE-5340 or NE-5350. This examination is not required where defect elimination removes the full thickness of the weld and where the backside of the weld joint is not accessible for removal of examination materials.

NE-4453.2 Requirements for Welding Material, Procedures, and Welders.

The weld repair shall be made using welding material, welders, and welding procedures qualified in accordance with NE-4125 and NE-4300.

NE-4453.3 Blending of Repaired Areas.

After repair the surface shall be blended uniformly into the surrounding surface.

NE-4453.4 Examination of Repair Welds.

The examination of a weld repair shall be repeated as required for the original weld, except that it need only be reexamined by the liquid penetrant or magnetic particle method when the unacceptable indication was originally detected by the liquid penetrant or magnetic particle

Page 145

method and when the repair cavity does not exceed the following:

- (a) $\frac{1}{3}t$ for $t \leq \frac{3}{4}$ in. (19 mm)
- (b) $\frac{1}{4}$ in. for $\frac{3}{4}$ in. (19 mm) $< t \leq 2\frac{1}{2}$ in. (64 mm)
- (c) the lesser of $\frac{3}{8}$ in. (10 mm) or 10% t for $t > 2\frac{1}{2}$ in. (64 mm)

where t equals the thickness of the weld.

NE-4453.5 Heat Treatment of Repaired Areas.

The area shall be heat treated in accordance with NE-4620.

NE-4454 Inserted Strips in Clad Material

The thickness of inserted strips used to restore cladding at joints shall be equal to that of the nominal minimum thickness of cladding specified for the plates backed, if necessary, with corrosion resistant weld metal deposited in the groove to bring the insert flush with the surface of the adjacent cladding.

NE-4600 HEAT TREATMENT

NE-4610 WELDING PREHEAT REQUIREMENTS

NE-4611 When Preheat Is Necessary

The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, elevated temperature, physical properties, and material thicknesses. Some practices used for preheating are given in Appendix D as a general guide for the materials listed by P-Numbers of Section IX. It is cautioned that preheating suggested in Appendix D does not necessarily ensure satisfactory completion of the welded joint and that the preheating requirements for individual materials within the P-Number listing may be more or less restrictive. The Welding Procedure Specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.

NE-4612 Preheating Methods

Preheat for welding or thermal cutting, when employed, may be applied by any method which does not harm the base material or any weld metal already applied, or which does not introduce deleterious material into the welding area which is harmful to the weld.

NE-4613 Interpass Temperature

Consideration shall be given to the limitations of interpass temperatures for quenched and tempered material to avoid detrimental effects on the mechanical properties.

NE-4620 POSTWELD HEAT TREATMENT

NE-4621 Heating and Cooling Methods

Postweld heat treatment (PWHT) may be accomplished by any suitable methods of heating and cooling, provided the required heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control are maintained.

NE-4622 PWHT Time and Temperature Requirements

NE-4622.1 General Requirements.²

The requirements for postweld heat treatment are given in (a), (b), and (c) below.

(a) Except as otherwise permitted in NE-4622.7, all welds, including repair welds, shall be postweld heat treated. During postweld heat treatment, the metal temperatures shall be maintained with the temperature ranges and for the minimum holding times specified in Table NE-4622.1-1, except as otherwise permitted in NE-4622.4(c). P-Number groups in Table NE-4622.1-1 are in accordance with Section IX, QW-420. Except as provided in NE-4624.3, PWHT shall be performed in temperature-surveyed and -calibrated furnaces, or PWHT shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material.

(b) Unless exempted in Table NE-4622.7(b)-1, all doors, nozzles, opening frames, and similar welded construction shall be welded into a portion of the shell plate or plates, and the welded subassembly shall be postweld heat treated prior to welding into the shell.

(c) The requirements of the following subparagraphs shall also apply.

2 Any postweld heat treatment time which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

NE-4622.2 Time-Temperature Recordings.

Time-temperature recordings of all postweld heat treatments shall be made available for review by the Authorized Inspector. Identification on the time-temperature recording shall be to the weld, part, or vessel. A summary

Page 146

of the time-temperature recording may be provided for permanent records in accordance with NCA-4134.17.

TABLE NE-4622.1-1
MANDATORY REQUIREMENTS FOR POSTWELD HEAT TREATMENT (PWHT) OF WELDS¹

P-Number (Sect. IX, QW-420)	Holding Temperature Range, °F [Note (2)]	Minimum Holding Time at Temperature For Weld Thickness (Nominal)		
		½ in. or less	Over ½ in. to 2 in.	Over 2 in.
1	1100–1250	30 min	1 hr/in.	2 hr plus 15 min each additional inch over 2 in.
----- 8, 34, 42, 43, 45	PWHT neither required nor prohibited			

NOTES:

(1) Exemption to the mandatory requirements of this Table are defined in NE-4622.7.

(2) All temperatures are metal temperatures.

TABLE NE-4622.1-1 MANDATORY REQUIREMENTS FOR POSTWELD HEAT TREATMENT (PWHT) OF WELDS¹

NE-4622.3 Definition of Nominal Thickness Governing PWHT.

Nominal thickness in Table NE-4622.7(b)-1 is the thickness of the weld, the pressure retaining material for structural attachment welds or the thinner of the pressure retaining materials being joined, whichever is least. It is not intended that nominal thickness include material provided for forming allowance, thinning, or mill overrun when the excess material does not exceed $\frac{1}{8}$ in. (3.2 mm). For fillet welds the nominal thickness is the throat thickness, and for partial penetration and material repair welds the nominal thickness is the depth of the weld groove or penetration.

NE-4622.4 Holding Times at Temperature

(a) The holding time at temperature as specified in Table NE-4622.1-1 shall be based on the nominal thickness of the weld. The holding time need not be continuous. It may be an accumulation of the times of multiple postweld heat treatment cycles.

(b) Holding time at temperature in excess of the minimum requirements of Table NE-4622.1-1 may be used, provided that specimens so heat treated are tested in accordance with NE-2200, NE-2400, and NE-4300.

(c) Alternatively, when it is impractical to postweld heat treat at the temperature range specified in Table NE-4622.1-1, it is permissible to perform the postweld heat treatment of certain materials at lower temperatures for longer periods of time in accordance with Table NE-4622.4(c)-1 and (1) below.

(1) Base materials certified in accordance with NE-2200 may be postweld heat treated at these lower minimum temperatures and increased minimum holding times without recertification. Postweld heat treatment at these lower minimum temperatures and increased minimum holding times may also be the tempering operation, provided a higher tempering temperature is not required by the material specification.

**TABLE 4622.4(c)-1
ALTERNATIVE HOLDING TEMPERATURES
AND TIMES¹**

Material P-Numbers	Alternative Holding Temperature Range, °F	Alternative Minimum¹ Holding Times
1	1050	2 hr/in. thick
1	1000	4 hr/in. thick

NOTE:

(1) All other requirements of NE-4622 shall apply.

TABLE NE-4622.4(c)-1 ALTERNATIVE HOLDING TEMPERATURES AND TIMES¹

NE-4622.5 PWHT Requirements When Different P-Number Materials Are Joined.

Postweld heat treatment is not required when joining P-No. 1 material 1½ in. (38 mm) or less in thickness to P-No. 8, P-No. 42, P-No. 43, or P-No. 45 materials with electrodes that produce austenitic or non-air-hardening nickel-chromium-iron deposits.

NE-4622.6 PWHT Requirements for Nonpressure-Retaining Parts.

When nonpressure-retaining material is welded to pressure retaining material, the postweld heat treatment temperature range of the pressure retaining material shall control.

NE-4622.7 Exemptions to Mandatory Requirements.

Postweld heat treatment in accordance with this Subarticle is not required for:

(a) nonferrous materials;

(b) welds exempted in Table NE-4622.7(b)-1;

Page 147

Page 148

TABLE NE-4622.7(b)-1
EXEMPTIONS TO MANDATORY PWHT¹

98

P-Number, (Sec. IX, QW-20)	Type of Weld [Note (6)]	Nominal Thickness (NE-4622.3)	Max. Reported Carbon, % [Note (7)]	Min. Preheat Required, °F
1	All welds where the materials being joined are 1½ in. and less, exclusive of welds joining nozzles or penetrations with an I.D. greater than 2 in. to the vessel shell	1¼ in. or less Over 1¼ in. to 1½ in. ¾ in. or less Over ¾ in. to 1½ in.	0.30 or less 0.30 or less Over 0.30 Over 0.30	... 200 ... 200
	All welds joining nozzles and penetrations with an I.D. greater than 2 in. to the vessel shell provided all of the following are satisfied: (1) the shell thickness does not exceed 1½ in., (2) the size does not exceed NPS 12, (3) the ratio of major to minor diameter of non-circular openings does not exceed 1.15, and (4) the weld is at least 1.0 (R) ^{1/2} from any other non-postweld heat treated weld in the vessel shell.	1¼ in. or less Over 1¼ in. to 1½ in. ¾ in. or less Over ¾ in. to 1½ in.	0.30 or less 0.30 or less Over 0.30 Over 0.30	... 200 ... 200
	All welds in material over 1½ in., exclusive of welds joining nozzles or penetrations to the vessel shell	¾ in. or less	...	200
	All welds, including repair welds in material greater than 1½ in., but equal to or less than 1¾ in. exclusive of welds joining nozzles or penetrations to the vessel shell [Note (2)]	1¾ in. or less	0.24	200
	All welds joining nozzles or penetrations with a nominal I.D. of 2 in. and less	¾ in. or less	...	200
	Repairs to welds in subassemblies postweld heat treated as required by NE-4622.1(b) with the total accumulated repair length of any weld not exceeding 25% of the original weld length	¾ in. or less	...	200
1 Gr. 1 or Gr. 2	Cladding or repair of cladding [Note (3)] with A-No. 8 or F-No. 43 filler metal in base material of: 1½ in. or less over 1½ in. to 3 in. over 3 in.	...	0.30	100
		...	0.30	200
		...	0.30	250
				[Note (4)] [Note (5)]

NOTES:

- (1) The exemptions noted in this Table do not apply to electron beam welds in ferritic materials over ¼ in. in thickness.
- (2) This exemption is limited to SA-299, SA-516, SA-537, and SA-738 materials, under the following conditions:
 - (a) The exemption from impact testing as provided in NE-2311(a)(8) is not permitted.
 - (b) For Charpy V Notch Testing per NE-2331(a)(1), the testing criteria are as described in either of the following:
 - (1) The testing temperature is 10°F below the Lowest Service Metal Temperature, and the C_v energy values are as shown in Table NE-2332.1-2.
 - (2) The testing temperature is the Lowest Service Metal Temperature, and the C_v energy values are increased by 5 ft.-lb. over those shown in Table NE-2332.1-2.
 - (c) For Drop Weight Testing permitted by NE-2331(a)(2), the difference between Lowest Service Metal Temperature and the nil ductility transition temperature, (LSMT - T_{NDT}), is equal to or greater than (10°F + A), in which the value of A is determined in accordance with Appendix R.
- (3) Maximum process heat input = 150,000 J/in. The maximum resulting hardness of the heat affected zone in the procedure qualification test plate shall not exceed 35 Rc.
- (4) Intermediate postweld soak at not less than 200°F for 2 hr minimum.
- (5) Intermediate postweld soak at not less than 300°F for 2 hr minimum.
- (6) Where the thickness of material is identified in the Type of Weld column, it is the thickness of the base material at the welded joint.
- (7) Carbon level of the pressure retaining materials being joined.

[98]

TABLE NE-4622.7(b)-1 EXEMPTIONS TO MANDATORY PWHT¹

(c) welds subjected to temperatures above the PWHT temperature range specified in Table NE-4622.1-1, provided the Welding Procedure Specification is qualified in accordance with Section IX and the base material and the deposited weld material have been heat treated at the higher temperature;

(d) extensions and the welds joining these extensions to nozzles, opening frames, and similar construction, provided all other requirements of NE-4620 are met and the weld is located at least $0.5\sqrt{rt}$ from the surface of the vessel, where r is the mean radius of the nozzle or opening and t is the nominal thickness of the nozzle or opening;

(e) nonpressure parts attached to pressure parts which have been previously postweld heat treated, provided the attachment welds meet the requirements of Table NE-4622.7(b)-1.

NE-4623 PWHT Heating and Cooling Rate Requirements

Above 800°F (427°C) the rate of heating and cooling in any hourly interval shall not exceed 400°F (222°C) divided by the maximum thickness in inches of the material being heat treated, but shall not exceed 400°F (222°C) and need not be less than 100°F (56°C) in any hourly interval. During the heating and cooling period there shall not be a greater variation in temperature than 250°F (139°C) within any 15 ft (4.6 m) interval of weld length.

NE-4624 Methods of Postweld Heat Treatment

The postweld heat treatment shall be performed in accordance with the requirements of one of the following subparagraphs.

NE-4624.1 Furnace Heating - One Heat.

Heating the vessel or item in a closed furnace in one heat is the preferred procedure and should be used whenever practical. The furnace atmosphere shall be controlled so as to avoid excessive oxidation, and direct impingement of flame on the vessel or item is prohibited.

NE-4624.2 Furnace Heating - More Than One Heat.

The vessel or item may be heated in more than one heat in a furnace, provided the furnace atmosphere control requirements of NE-4624.1 apply and overlap of the heated sections of the vessel or item is at least 5 ft. When this procedure is used, the portion of the vessel or item outside the furnace shall be shielded so that the temperature gradient is not harmful. The cross section where the vessel or item projects from the furnace shall not intersect a nozzle or other structural discontinuity.

NE-4624.3 Local Heating.

Welds may be locally postweld heat treated when it is not practical to heat treat the entire vessel or item. Local postweld heat treatment shall consist of heating a circumferential band around the vessel or item at temperatures within the ranges specified in this Subarticle. The minimum width of the controlled band at each side of the weld, on the face of the greatest weld width, shall be the thickness of the weld or 2 in. (51 mm), whichever is less. The temperature of the vessel or item from the edge of the controlled band outward shall be gradually diminished so as to avoid harmful thermal gradients. This procedure may also be used for postweld heat treatment after repairs.

NE-4624.4 Heating Vessels Internally.

The vessel or item may be heated internally by any appropriate means and with adequate indicating and recording temperature devices to aid in the control and maintenance of a uniform distribution of temperature in the vessel or item. Prior to this operation, the vessel or item shall be fully enclosed with insulating material.

NE-4630 INTERMEDIATE POSTWELD HEAT TREATMENT

The temperature, time-at-temperature, and heating and cooling rate requirements of NE-4620 are not mandatory for

intermediate heat treatments.

NE-4660 HEAT TREATMENT OF ELECTROSLAG WELDS

Electroslag welds in ferritic material over $1\frac{1}{2}$ in. (38 mm) in thickness at the joints shall be given a grain refining heat treatment.

NE-4700 MECHANICAL JOINTS AND PENETRATION ASSEMBLIES

NE-4710 BOLTING AND THREADING

NE-4711 Thread Engagement

The threads of all bolts or studs shall be engaged in accordance with the design.

Page 149

NE-4712 Thread Lubricants

Any lubricant or compound used in threaded joints shall be suitable for the service conditions and shall not react unfavorably with either the service fluid or any material in the system.

NE-4713 Removal of Thread Lubricants

All threading lubricants or compounds shall be removed from surfaces which are to be seal welded.

NE-4714 Stud Threading

Studs shall be threaded full length or shall be machined down to the root diameter of the thread in the unthreaded portion.

NE-4720 BOLTING FLANGED JOINTS

In bolting gasketed flanged joints, the contact faces of the flanges shall bear uniformly on the gasket and the gasket shall be properly compressed in accordance with the design principles applicable to the type of gasket used. All flanged joints shall be made up with relatively uniform bolt stress.

NE-4730 ELECTRICAL AND MECHANICAL PENETRATION ASSEMBLIES

(a) Electrical and mechanical penetration assemblies, except for those portions performing an electrical conducting or insulating function, shall be constructed in accordance with the rules for containment vessels.

(b) Tubes or pipe of NPS 2 (DN 50) and less may be joined to a penetration assembly in accordance with the rules of NE-4740.

(c) The closing seam for the penetration assembly may be made with a multipass single lap fillet weld as shown in Fig.2 NE-4730-1, provided the requirements of (1) through (5) below are met:

(1) one of the heads on the penetration assembly meets the requirements of NE-3352.1;

(2) the penetration assembly shall not exceed 18 in. O.D;

(3) the design pressure of the penetration assembly shall not exceed 100 psi (690 kPa) and the design temperature shall not exceed 400°F (204°C);

(4) examination of the fillet weld shall be by the liquid penetrant method in accordance with NE-5350;

(5) the fillet weld and closure head shall meet the requirements of NE-3720(b).

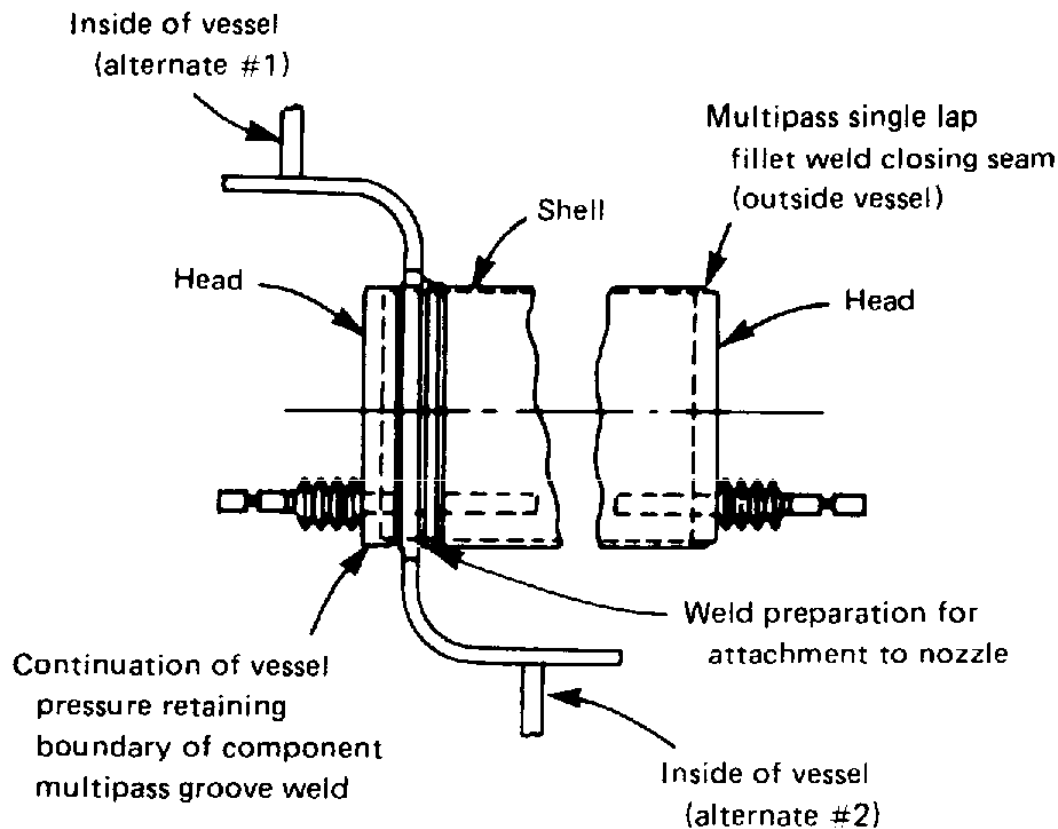


FIG. NE-4730-1 PENETRATION ASSEMBLY

FIG. NE-4730-1 PENETRATION ASSEMBLY

NE-4740 SPECIAL QUALIFICATION REQUIREMENTS FOR ELECTRICAL AND MECHANICAL PENETRATION ASSEMBLIES

NE-4741 General Requirements

These rules are applicable only for the attachment of pipes and tubes of NPS 2 (DN 50) and less to electrical and mechanical penetration assemblies as permitted in NE-4730. The welding procedure shall be qualified as a new procedure specification and shall be completely requalified when any of the changes listed below are made in the procedure. Changes other than those so given may be made in a procedure without the necessity for requalification, provided the procedure specification is amended to show these changes.

NE-4742 Essential Variables for All Welding Processes

Essential variables for all welding processes shall be as listed in (a) through (k) below:

- (a) a change from one welding process to any other welding process or combination of welding processes;
- (b) a change in the P-Number classification of pipe or tube material in Section IX, QW-442 and QW-422; a separate qualification is required for each pipe or tube material which is not included under any P-Number;
- (c) a change in the P-Number of the penetration assembly;

Page 150

(l) the base material may be a homogeneous material or a cladding material of wrought-type or weld-overlay-type; if welding is performed between the pipe or tube and cladding, the cladding shall be considered the base material; a separate qualification is required for welding pipes or tubes to base material or cladding material which is not included under any P-Number;

(d) changes in the weld metal analysis of the deposited weld metal as given in (1) and (2) below:

(1) a change from any A-Number in Section IX, QW-442, to any other A-Number or to any F-Number in QW-432 or to any analysis not listed in the tables, except that each AISI type similar to A-No. 7 or A-No. 8 of QW-442 shall require separate qualifications;

(2) a change from any F-Number in QW-432 to any other F-Number or to any A-Number in QW-442 or to any analysis not listed in the tables;

(e) for pipes or tubes of specified wall thickness of 0.100 in. or less, an increase or decrease of 10% of specified wall thickness or specified diameter;

(f) for specified wall thicknesses greater than 0.100 in. (2.54 mm), only one qualification test is required;

(g) a decrease of 10% or more in the specified width of the ligament between holes when the specified width of the ligament is less than the greater of $\frac{3}{8}$ in. (10 mm) or three times the specified pipe or tube wall thickness;

(h) the addition of other welding positions than those already qualified (Section IX, QW-461.1);

(i) a change in the specified preheating temperature range;

(j) a change in the specified postweld heat treating temperature;

(k) a change from multiple pass to single pass or vice versa.

NE-4743 Essential Variables for Shielded Metal-Arc Welding

Additional essential variables for shielded metal-arc welding are as given in (a) and (b) below:

(a) an increase in electrode diameter;

(b) a change from one F-Number in Section IX, QW-422 or QW-432, to any other F-Number (Notes 2 and 3 in QW-432 shall apply).

NE-4744 Essential Variables for Gas Tungsten-Arc and Gas Metal-Arc Welding

Additional essential variables for gas tungsten-arc and gas metal-arc welding are as given in (a) through (f) below:

(a) a change in the configuration of the penetration assembly at the hole edges, including the addition or omission of preplaced metal inserts;

(b) a change in the size or shape of preplaced metal inserts;

(c) a change from one shielding gas to another shielding gas or to a mixture of shielding gases;

(d) when using mixed shielding gas, a change of $\pm 25\%$ or 5 cu ft/hr (0.14 m³/hr), whichever is the larger, in the rate of flow of the minor gas constituent;

- (e) for gas tungsten-arc welding process, the addition or omission of filler metal;
- (f) a change in the nominal diameter of the filler metal.

NE-4745 Test Assembly

The procedure qualification shall be made on a test assembly which simulates the conditions to be used in production with respect to the hole pattern and the essential variables listed in NE-4741. In addition, the thickness of the test assembly at the holes shall be as thick as the production penetration assembly at the holes, except that it need not exceed 2 in. (51 mm). The minimum required number of weld joints shall be ten.

NE-4746 Examination of Test Assembly

The test assembly shall be examined by a liquid penetrant method in accordance with the requirements of NE-5110 and shall meet the acceptance standards of NE-5350. Following this, the test assembly shall be sectioned longitudinally through each pipe or tube. The thickness of the test assembly may be reduced to $\frac{1}{2}$ in. (13 mm) prior to this sectioning. The four faces of each pipe or tube exposed by sectioning shall be polished and etched with a suitable etchant and shall be visually examined for cracks. The weld throat, minimum leakage path, shall be not less than two-thirds of the specified pipe or tube wall thickness, and the weld shall be free from cracks on visual examination with $\times 10$ magnification.

NE-4747 Performance Qualification Test

The requirements for the performance qualification test for welders and welding operators shall be the same as those for the procedure qualification, except that the minimum required number of tubes in the test assembly shall be six. Any welder or welding operator who makes a procedure test that passes satisfactorily is thereby qualified.

Page 151

NE-4800 EXPANSION JOINTS

NE-4810 BELLOWS-TYPE EXPANSION JOINTS

For bellows-type expansion joints the requirements of (a) through (e) below shall be met.

- (a) All welded joints shall comply with the requirements of NE-4400.
- (b) The longitudinal weld in the bellows shall be a butt-type full penetration weld.
- (c) The bellows element of the expansion joint shall be attached to the welding ends or flange by circumferential welds of a butt-type having full penetration weld through the thickness of the bellows portion, as shown in Fig. NE-4810(c)-1.
- (d) Other than the attachment welds, no circumferential welds are permitted in the bellows elements.
- (e) Weld repairs shall not be permitted on parent material of bellows elements.

Page 152

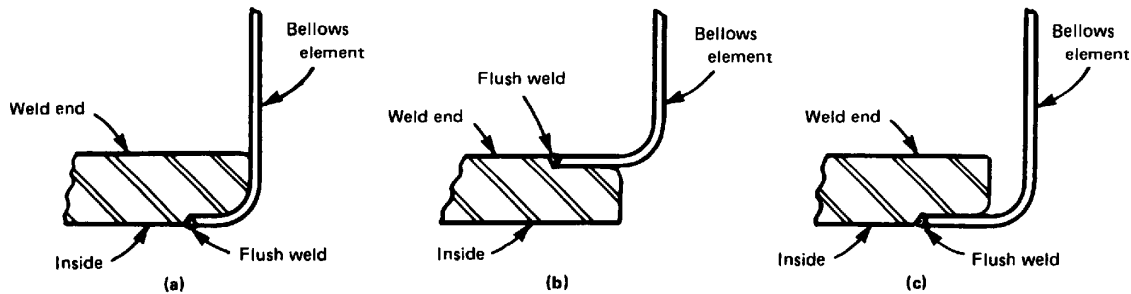


FIG. NE-4810(c)-1 BELLOWS ATTACHMENT WELDS

FIG. NE-4810(c)-1 BELLOWS ATTACHMENT WELDS

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NE-5000

ARTICLE NE-5000 EXAMINATION

Page 153

NE-5100 GENERAL REQUIREMENTS FOR EXAMINATION OF VESSELS

NE-5110 PROCEDURES, QUALIFICATIONS, AND EVALUATION

NE-5111 General Requirements

Nondestructive examinations shall be conducted in accordance with the examination methods of Section V, except as they may be modified by the requirements of this Article. Radiographic examination shall be in accordance with Section V, Article 2, except that the geometric unsharpness shall not exceed the limits of T-285. Ultrasonic examination shall be in accordance with Section V, Article 5; magnetic particle examination shall be in accordance with Section V, Article 7; and liquid penetrant examination shall be in accordance with Section V, Article 6. The examinations required by this Article or by reference to this Article shall be performed by personnel who have been qualified as required by this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards of this Article.

NE-5112 Nondestructive Examination Procedures

All nondestructive examinations required by this Article shall be performed in accordance with detailed written procedures which have been proven by actual demonstration to the satisfaction of the Inspector. The procedures shall comply with the appropriate Article of Section V for the particular examination method. The digitization of radiographic film and radiosopic images shall meet the requirements of Section V, Article 2, Mandatory Appendix III, "Digital Image Acquisition, Display, and Storage for Radiography and Radioscopy." Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Inspector on request. At least one copy of the procedure shall be readily available to all applicable nondestructive examination personnel for reference and use.

NE-5113 Post-Examination Cleaning

Following any nondestructive examination in which examination materials are applied to the piece, the piece shall be thoroughly cleaned in accordance with applicable material or procedure specifications.

NE-5120 TIME OF EXAMINATION OF WELDS

Acceptance examination of welds required by NE-5200 shall be performed at the times stipulated in (a), (b), and (c) below.

(a) Radiographic examination of all welds in vessels may be performed prior to any required postweld heat treatment.

(b) Magnetic particle or liquid penetrant examinations shall be performed after any required postweld heat treatment, except that welds in P-No. 1 material may be examined either before or after postweld heat treatment.

(c) All dissimilar metal weld joints, such as in austenitic or high nickel to ferritic material or using austenitic or high nickel alloy filler metal to join ferritic materials, which penetrate the vessel wall shall be examined after final postweld heat treatment.

(d) Ultrasonic examination of electroslog welds in ferritic materials shall be performed after a grain refining heat treatment, when performed, or after final postweld heat treatment.

NE-5130 EXAMINATION OF WELD EDGE PREPARATION SURFACES

All full penetration weld edge preparation surfaces for joint Categories A, B, C, D, and similar joints in material 2 in. or more in thickness shall be examined

Page 156

by the magnetic particle or liquid penetrant method. Indications shall be evaluated in accordance with the acceptance standards of (a), (b), and (c) below.

(a) Only indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Laminar-type imperfections are acceptable without repair if they do not exceed 1 in. (25 mm) in length. The extent of all laminar-type imperfections exceeding 1 in. (25 mm) in length shall be determined by ultrasonic examination. Imperfections exceeding 1 in. (25 mm) in length shall be repaired by welding to a depth of $\frac{3}{8}$ in. (10 mm) or the depth of the imperfection, whichever is less, unless the ultrasonic examination reveals that additional depth of repair is required to meet the ultrasonic examination requirement for the product form.

(c) Indications of nonlaminar imperfections of (1) through (3) below are unacceptable:

(1) any linear indications greater than $\frac{3}{16}$ in. (4.8 mm) long;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);

(3) four or more indications, in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less, edge to edge.

(d) Weld repairs made to weld edge preparations for Category A, B, C, D, or similar type welds shall be examined by the magnetic particle or liquid penetrant method before the surfaces become inaccessible. The examination may be performed before or after postweld heat treatment.

NE-5200 REQUIRED EXAMINATION OF WELDS

NE-5210 CATEGORY A WELDED JOINTS

NE-5211 Butt Welded Joints

Category A welded joints shall be fully radiographed.

NE-5220 CATEGORY B WELDED JOINTS

[98]

NE-5221 Butt Welds

Circumferential welds as defined in NE-3351.2 shall be radiographed. The provision of NE-5280 is applicable.

[98]

NE-5230 CATEGORY C WELDED JOINTS

NE-5231 Butt Welds

Category C butt welds shall be radiographed.

NE-5232 Nonbutt-Welded Joints

(a) If other than a butt welded joint detail is used, it shall be examined by the ultrasonic method, magnetic particle method, or liquid penetrant method.

(b) When a pressure retaining part is to be welded to a plate thicker than $\frac{1}{2}$ in. (13 mm) to form a corner joint as shown in Fig. NE-4243-1 and Fig. NE-4243-2 sketches (a), (b), and (c), the plate shall be examined before welding on all cut edges adjacent to the weld, including those for weld joint preparation, by magnetic particle or liquid penetrant examination. After welding, all such edges that remain exposed shall be reexamined. Where the material is nonmagnetic, only the liquid penetrant method shall be used.

NE-5240 CATEGORY D WELDED JOINTS

NE-5241 Butt Welds

Category D butt welds shall be radiographed.

NE-5242 Nonbutt-Welded Joints

If other than a butt welded joint detail is used, it shall be examined by an ultrasonic method, a magnetic particle method, or a liquid penetrant method. Welds on reinforcing plates attached to the outside of the vessel shall be solution film tested with a pressure of at least 15 psi (103 kPa) under the reinforcing plate.

NE-5244 Weld Buildup Deposits for Openings and Nozzles

When weld buildup deposits are made to a surface as shown in Step 1 of Fig. NE-4244(c)-1, the weld buildup deposit, the fusion zone, and the parent metal beneath the weld buildup deposit shall be ultrasonically examined to assure freedom from lack of fusion and laminar defects. Opening structures or nozzles may then be attached by a full penetration weld as shown in Step 2 of Fig. NE-4244(c)-1. The full penetration weld shall be examined in accordance with NE-5241.

Page 157

NE-5260 ATTACHMENTS

NE-5261 Butt Welded Joints

All butt welded joints in pressure retaining parts not included in Categories A, B, C, and D, such as those on doors, opening frames, permanent attachments, and similar construction, shall be radiographed. Butt welds in nonpressure-retaining structural parts attached to pressure retaining parts shall be fully radiographed for a minimum distance of $16t$, where t is the thickness of the structural part.

NE-5262 Nonbutt-Welded Joints

If other than a butt welded joint detail is used on pressure retaining parts, it shall be examined by an ultrasonic method, a magnetic particle method, or a liquid penetrant method, all in accordance with NE-5110. For nonpressure-retaining structural parts attached to pressure retaining parts in which nonbutt-welds are used, the portion of the attachment within

the limit of $16t$ shall be examined in the same manner.

NE-5270 SPECIAL WELDS

Weld metal cladding shall be examined by the liquid penetrant method.

NE-5278 Electroslag Welds

In addition to the requirements for the type of weld being examined, all complete penetration welds made by the electroslag welding process in ferritic materials shall be ultrasonically examined.

[98]

NE-5280 SPECIAL EXCEPTIONS FOR RADIOGRAPHY

(a) When the joint detail does not permit radiographic examination, ultrasonic examination plus liquid penetrant or magnetic particle examination of the completed weld may be substituted for:

- (1) joints attaching penetration assemblies, which are fabricated as appurtenances to a vessel;
- (2) the closing seam within an electrical penetration assembly, not necessarily fabricated as an appurtenance; or
- (3) the closing seam in a piping assembly which performs a containment function and which provides for the process piping to penetrate the containment vessel.

(b) The absence of suitable radiographic equipment shall not be justification for such a substitution. The substitution of ultrasonic examination can be made, provided the examination is performed using a detailed written procedure which has been proved by actual demonstration to the satisfaction of the Authorized Inspector as being capable of detecting and locating continuities. The nondestructive examination shall be in accordance with NE-5110 and shall meet the acceptance standards of NE-5330 for the ultrasonic examination, NE-5340 for the magnetic particle examination, and NE-5350 for the liquid penetrant examination.

[98]

NE-5300 ACCEPTANCE STANDARDS

NE-5320 RADIOGRAPHIC ACCEPTANCE STANDARDS

Indications shown on the radiographs of welds and characterized as imperfections are unacceptable under the following conditions:

- (a) any indication characterized as a crack or zone of incomplete fusion or penetration;
- (b) any other elongated indication which has a length greater than:
 - (1) $\frac{1}{4}$ in. for t up to $\frac{3}{4}$ in., inclusive
 - (2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. to $2\frac{1}{4}$ in., inclusive
 - (3) $\frac{3}{4}$ in. for t over $2\frac{1}{4}$ in.

where t is the thickness of the thinner portion of the weld;

(c) internal root weld conditions are acceptable when the density change as indicated in the radiograph is not abrupt; elongated indications on the radiograph at either edge of such conditions shall be unacceptable, as provided in (b) above;

(d) any group of aligned indications having an aggregate length greater than t in a length of $12t$ unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication;

(e) rounded indications in excess of that shown as acceptable in Appendix VI.

NE-5330 ULTRASONIC ACCEPTANCE STANDARDS

All imperfections which produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and evaluate them in terms of the acceptance standards as given in (a) and (b) below.

Page 158

(a) Imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths exceeding:

- (1) $\frac{1}{4}$ in. for t up to $\frac{3}{4}$ in., inclusive
- (2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. to $2\frac{1}{4}$ in., inclusive
- (3) $\frac{3}{4}$ in. for t over $2\frac{1}{4}$ in.

where t is the thickness of the weld being examined; if a weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses.

(b) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

NE-5340 MAGNETIC PARTICLE ACCEPTANCE STANDARDS

NE-5341 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication which is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. After an indication has been verified to be nonrelevant, it is not necessary to reinvestigate repetitive nonrelevant indications of the same type. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NE-5342 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

- (1) any cracks or linear indications;
- (2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);
- (3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;
- (4) ten or more rounded indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) with the area taken in the most unfavorable location relative to the indications being evaluated.

NE-5350 LIQUID PENETRANT ACCEPTANCE STANDARDS

NE-5351 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities such as may occur from machining marks or surface conditions may produce similar indications which are nonrelevant.

(b) Any indication which is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are

present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NE-5352 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks or linear indications;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);

(3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) with the area taken in the most unfavorable location relative to the indications being evaluated.

Page 159

NE-5500 QUALIFICATIONS AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

NE-5510 GENERAL REQUIREMENTS

Organizations performing Code required nondestructive examinations shall use personnel competent and knowledgeable to the degree specified by NE-5520. When these services are subcontracted by the Certificate Holder or Quality System Certificate Holder, he shall verify the qualification of personnel to the requirements of NE-5520. All nondestructive examinations required by this Subsection shall be performed by and the results evaluated by qualified nondestructive examination personnel.

NE-5520 PERSONNEL QUALIFICATION, CERTIFICATION, AND VERIFICATION

NE-5521 Qualification Procedure

(a) Personnel performing nondestructive examinations shall be qualified in accordance with the recommended guidelines of SNT-TC-1A.^{1,2} The Employer's³ written practice required by paragraph 5 of SNT-TC-1A shall identify his requirements relative to the recommended guidelines. The recommended guidelines of SNT-TC-1A shall be considered minimum requirements, except as modified in (1) through (5) below.

(1) Qualification of Level III nondestructive examination personnel shall be by examination.

(a) The basic and method examinations, paragraphs 8.8(1) and 8.8(2) of SNT-TC-1A, may be prepared and administered by the Employer, ASNT, or an outside agency.

1 SNT-TC-1A is a Recommended Practice for Nondestructive Testing Personnel Qualification and Certification published by the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, Ohio 43228-0518. SNT-TC-1A-1992 is the applicable edition.

2 Personnel qualified by examination and certified to previous editions of SNT-TC-1A are considered to be qualified to the 1992 edition when the recertification is based on continuing satisfactory performance. All reexaminations and new examinations shall be in accordance with the 1992 edition.

3 Employer as used in this Article shall include: N Certificate Holders; Quality System Certificate Holders; Material Organizations who are qualified in accordance with NCA-3862(a)(1); and organizations who provide subcontracted nondestructive examination services to organizations described above.

(b) The specific examination, paragraph 8.8(3) of SNT-TC-1A, shall be prepared and administered by the Employer or an outside agency. The Employer or outside agency administering the specific examination shall identify the

minimum grade requirement in the written program when the basic and method examinations have been administered by ASNT, which issues grades on a pass/fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(2) The written practice identified in paragraph 5 of SNT-TC-1A and the procedures used for examination of personnel shall be referenced in the Employer's Quality Program.

(3) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform nondestructive examination of limited scope, may be less than that recommended in Table 6.3.1 of SNT-TC-1A. The training and experience times shall be described in the written practice, and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate.

(a) The minimum classroom training times identified in Table 6.3.1 of SNT-TC-1A may be reduced from 8 and 16 hr to 4 and 8 hr respectively for visual examination personnel.

(4) For visual examination, the Jaeger Number 1 letters shall be used in lieu of the Jaeger Number 2 letters specified in paragraph 8.2(1) of SNT-TC-1A. The use of equivalent type and size letters is permitted.

(5) A Level I individual shall be qualified to perform specific setups, calibrations, and tests, and to record and evaluate data by comparison with specific acceptance criteria defined in written instructions. The Level I individual shall implement these written NDE instructions under the guidance of a Level II or III individual. A Level I individual may independently accept the results of nondestructive examinations when the specific acceptance criteria are defined in the written instructions.

(b) For nondestructive examination methods not covered by SNT-TC-1A documents, personnel shall be qualified to comparable levels of competency by subjection to comparable examinations on the particular method involved.

(c) The emphasis shall be on the individual's ability to perform the nondestructive examination in accordance with the applicable procedure for the intended application.

(d) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use personnel qualified to perform one or more operations. As an example, one person may be used who is qualified to conduct radiographic examination and another may be used who is qualified to interpret and evaluate the radiographic film.

Page 160

NE-5522 Certification of Personnel

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of Levels I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations [NE-5521(a)(2)], the Employer may use a letter from ASNT as evidence on which to base the certification.

(c) When an outside agency is the examining agent for Level III qualification of the Employer's personnel, the examination results shall be included with the Employer's record.

NE-5523 Verification of Nondestructive Examination Personnel Certification

The Certificate Holder has the responsibility to verify the qualification and certification of nondestructive examination personnel employed by Material Organizations qualified by them in accordance with NCA-3820 and subcontractors who provide nondestructive examination services to them.

NE-5530 RECORDS

Personnel qualification records identified in paragraph 9.4 of SNT-TC-1A shall be retained by the Employer.

NE-5700 EXAMINATION REQUIREMENTS FOR EXPANSION JOINTS

NE-5710 BELLOWS EXPANSION JOINTS

The examinations stipulated in (a) through (f) below are required to verify the integrity of bellows expansion joints for installation in nuclear containment systems.

(a) The formed bellows shall be determined by visual examination to be free of defects, such as notches, crevices, material buildup or upsetting, and weld spatter which may serve as points of local stress concentration. Suspect surface areas shall be further examined by liquid penetrant examination in accordance with NE-5110.

(b) The longitudinal welds in the bellows shall be examined by the liquid penetrant method in accordance with NE-5111. When the individual ply thickness exceeds $\frac{1}{8}$ in. (3.2 mm), the weld shall also be radiographed in accordance with NE-5111. These examinations may be performed either before or after the bellows is formed.

(c) The circumferential attachment weld between the bellows and weld ends or flanges shall be liquid penetrant examined in accordance with NE-5110 when the total bellows thickness is $\frac{1}{4}$ in. (6 mm) or less. When the total thickness exceeds this limit, the weld shall be radiographed in accordance with NE-5110 except where radiography is not meaningful, i.e., when the weld thickness constitutes less than 20% of the total thickness being radiographed, liquid penetrant examination may be substituted.

(d) In the case of liquid penetrant examination of bellows weld joints, imperfections producing the following indications are unacceptable:

- (1) cracks or linear indications;
- (2) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;
- (3) five or more randomly distributed rounded indications in a weld length of 6 in. (152 mm);
- (4) any rounded indication exceeding the lesser of one-half the bellows thickness or $\frac{1}{16}$ in. (1.6 mm) in diameter.

(e) The examination of all other welds in the expansion joint shall comply with NE-5000.

(f) The variation of the cylindrical end thickness of the formed bellows from the nominal or specified thickness shall not exceed the values given in Table 2 of SA-480. Thinning of the bellows material during forming shall be considered in the design and selection of material thickness but need not be limited to values specified in Table 2 of SA-480.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NE-6000

ARTICLE NE-6000 TESTING

Page 161

NE-6100 GENERAL REQUIREMENTS

NE-6110 PRESSURE TESTING OF VESSELS AND APPURTENANCES

NE-6111 Scope of Pressure Testing

All pressure retaining vessels and appurtenances (hereafter reference is to vessels only) shall be pressure tested. Bolts, studs, nuts, washers, and gaskets are exempted from the pressure test.

NE-6112 Pneumatic Testing

A pneumatic test in accordance with NE-6300 may be substituted for the hydrostatic test when permitted by NE-6112.1 (a).

NE-6112.1 Pneumatic Test Limitations

(a) A pneumatic test may be used in lieu of a hydrostatic test only when any of the following conditions exists:

(1) when the vessels are so designed or supported that they cannot be safely filled with liquid;¹

(2) when the vessels, which are not readily dried, are to be used in services where traces of the testing medium cannot be tolerated.

(b) A pneumatic test at a pressure not to exceed 10% of the test pressure may be applied prior to either a hydrostatic or a pneumatic test as a means of locating leaks.

NE-6112.2 Precautions to Be Employed in Pneumatic Testing.

Compressed gaseous fluid is hazardous when used as a testing medium. It is therefore recommended that special precautions for protection of personnel be taken when a gaseous fluid under pressure is used as a test medium.

1 These tests may be made with the item being tested partially filled with liquid, if desired.

NE-6113 Witnessing of Pressure Tests

Pressure testing required by this Article shall be performed in the presence of the Inspector.

NE-6120 PREPARATION FOR TESTING

NE-6121 Exposure of Joints

All joints, including welded joints, shall be left uninsulated and exposed for examination during the test, except as permitted in NE-6225.

NE-6122 Addition of Temporary Supports

Vessels designed to contain vapor or gas may be provided with additional temporary supports, if necessary, to support the weight of the test liquid.

NE-6123 Restraint or Isolation of Expansion Joints

Expansion joints shall be provided with temporary restraints, if required, for the additional pressure load under test.

NE-6124 Isolation of Equipment Not Subjected to Pressure Test

Equipment that is not to be subjected to the pressure test shall be either disconnected from the vessel or isolated during the test by a blind flange or similar means. Valves may be used if the valves with their closures are suitable for the proposed test pressure.

NE-6125 Treatment of Flanged Joints Containing Blanks

Flanged joints at which blanks are inserted to isolate other equipment during the test need not be retested.

Page 164

NE-6126 Precautions Against Test Medium Expansion

If a pressure test is to be maintained for a period of time and the test medium in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure.

NE-6127 Check of Test Equipment Before Applying Pressure

The test equipment shall be examined before pressure is applied to ensure that it is tight and that all low pressure filling lines and other items that should not be subjected to the test have been disconnected or isolated.

NE-6200 HYDROSTATIC TESTS

NE-6210 HYDROSTATIC TEST PROCEDURE

NE-6211 Venting During Fill Operation

The vessel in which the test is to be conducted shall be vented during the filling operation to minimize air pocketing.

NE-6212 Test Medium and Test Temperature

(a) Water or an alternative liquid, as permitted by the Design Specification, shall be used for the hydrostatic test.

(b) It is recommended that the test be made at a temperature that will minimize the possibility of brittle fracture. The test pressure shall not be applied until the vessel and the pressurizing fluid are at approximately the same temperature.

NE-6220 HYDROSTATIC TEST PRESSURE REQUIREMENTS

NE-6221 Minimum Hydrostatic Test Pressure

The vessel shall be hydrostatically tested at not less than 1.35 times the Design Pressure.

NE-6222 Maximum Permissible Test Pressure

The stress limits specified in NE-3226 shall be used in determining the maximum permissible test pressure. In multichamber components, pressure may be simultaneously applied to the appropriate adjacent chamber to satisfy these stress limits.

NE-6223 Hydrostatic Test Pressure Holding Time

The hydrostatic test pressure shall be maintained a minimum of 10 min prior to initiation of the examination for leakage required by NE-6224.

NE-6224 Examination for Leakage After Application of Pressure

Following the application of the hydrostatic test pressure for the required time (NE-6223), all joints, connections, and regions of high stress, such as regions around openings and thickness transition sections, shall be examined for leakage, except as provided in NE-6225. This examination shall be made at a pressure equal to the greater of the Design Pressure or three-fourths of the test pressure, and it shall be witnessed by the Inspector. Leakage of temporary gaskets and seals, installed for the purpose of conducting the hydrostatic test and which will be replaced later, may be permitted unless the leakage exceeds the capacity to maintain system test pressure for the required amount of time. Other leaks, such as those from permanent seals, seats, and gasketed joints in components, may be permitted when specifically allowed by the Design Specification. Leakage from temporary seals or leakage permitted by the Design Specification shall be directed away from the surface of the component to avoid masking leaks from other joints.

NE-6225 Examination of Inaccessible Welds

Examination of inaccessible pressure retaining welds of containment vessels during the pressure test is waived where such joints are covered by concrete or otherwise made inaccessible during construction of the vessel, provided that:

(a) no openings or penetrations are embedded in the concrete;

(b) the nozzle is integrally reinforced and is attached to the shell by a full penetration weld;

(c) prior to being covered or made inaccessible, the welds are examined by the radiographic or ultrasonic method;

(d) prior to being covered or made inaccessible, the welded joint is tested for leak tightness using a gas medium test such as the Halide Leak Detection Test or Vacuum Box Test.

NE-6230 BELLOWS EXPANSION JOINTS

The hydrostatic test requirements for bellows expansion joints shall be as required in (a) through (c) below.

(a) The completed expansion joint shall be subjected to a hydrostatic test in accordance with the applicable provisions of this Article as supplemented by the Design Specification.

(b) This test may be performed with the bellows fixed in the straight position, at its neutral length, when the design has been shown to comply with NE-3365.2(e)(1) or NE-3365.2(e)(2). If the design is to comply with NE-3365.2(e)(3), this test shall be performed with the bellows fixed at the maximum design rotation angle or offset movement.

(c) In addition to inspecting the expansion joint for leaks and general structural integrity during the test, the Inspector shall also visually inspect the bellows for evidence of meridional yielding as defined in NE-3365.2(b), and for evidence of squirm as defined in NE-3365.2(c). If the design is to comply with NE-3365.2(e)(3), actual measurements shall be made before, during, and after the pressure test in accordance with NE-3365.2(b) and NE-3365.2(c).

NE-6300 PNEUMATIC TESTS

NE-6310 PNEUMATIC TESTING PROCEDURES

NE-6311 General Requirements

When a pneumatic test is performed, it shall be conducted in accordance with the requirements of this Subarticle and NE-6100. In some cases it is desirable to test vessels when partly filled with liquids. For such vessels, a combined hydrostatic and pneumatic test may be used as an alternative to the pneumatic test of this paragraph provided the liquid level is set so that the stress intensities of NE-3226 are not exceeded. After setting the liquid level to meet this condition, the test shall be conducted as prescribed in this Subarticle.

NE-6312 Test Medium and Test Temperature

(a) The gas used as the test medium shall be nonflammable.

(b) Testing temperature shall be in accordance with NE-6212(b).

NE-6313 Procedure for Applying Pressure

The pressure in the system shall be gradually increased to not more than one-half of the test pressure, after which the pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached.

NE-6320 PNEUMATIC TEST PRESSURE REQUIREMENTS

NE-6321 Minimum Required Pneumatic Test Pressure

The pneumatic test pressure for vessels shall not be less than 1.1 times the Design Pressure of the vessel.

NE-6322 Maximum Permissible Test Pressure

The maximum test pressure shall be limited as defined in NE-6222.

NE-6323 Test Pressure Holding Time

The test pressure of NE-6321 shall be maintained for a minimum total time of 10 min.

NE-6324 Examination for Leakage After Application of Pressure

Following the application of pressure for the time specified in NE-6323, the test pressure shall be reduced to a value equal to the greater of the Design Pressure or three-fourths of the test pressure and held for a sufficient time to permit

examination as defined in NE-6224.

NE-6400 PRESSURE TEST GAGES

NE-6410 REQUIREMENTS FOR PRESSURE TEST GAGES

NE-6411 Types of Gages to Be Used and Their Location

Pressure test gages used in pressure testing shall be indicating pressure gages and shall be connected directly to the vessel. If the indicating gage is not readily visible to the operator controlling the pressure applied, an additional indicating gage shall be provided where it will be visible to the operator for the duration of the test. For vessels with a large volumetric content,

Page 166

it is recommended that a recording gage be used in addition to the indicating gages.

NE-6412 Range of Indicating Pressure Gages

(a) Analog-type indicating pressure gages used in testing shall be graduated over a range not less than $1\frac{1}{2}$ times nor more than 4 times the test pressure.

(b) Digital-type pressure gages may be used without range restriction provided the combined error due to calibration and readability does not exceed 1% of the test pressure.

NE-6413 Calibration of Pressure Test Gages

All test gages shall be calibrated against a standard dead weight tester or a calibrated master gage. The test gages shall be calibrated before each test or series of tests. A series of tests is that group of tests using the same pressure test gage or gages which is conducted within a period not exceeding 2 weeks.

NE-6700 CONTAINMENT PENETRATION

NE-6710 PRESSURE TESTS

NE-6711 Electrical and Mechanical Penetration Assemblies

Electrical and mechanical penetration assemblies shall be tested in accordance with the requirements of this Article, except that when electrical and mechanical penetrations are made following the containment vessel pressure test, the test pressure of the welds connecting the electrical or mechanical penetration to the containment vessel may be less than the required containment test pressure but shall be not less than the design pressure of the containment vessel.

NE-6712 Piping Penetrations

Piping penetration assemblies shall be tested in accordance with the requirements of this Article, except that when piping penetrations are made following the containment vessel pressure test, the test pressure of the welds connecting the piping to the containment vessel may be less than the required containment test pressure but shall be not less than the design pressure of the containment vessel. The provisions of NB-6111 or NC-6111, as appropriate, apply to the process piping portion of the penetration assembly. The N-5 Data Report Form shall identify the test pressure used for each of the above pipe penetration weld connections.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NE-7000

ARTICLE NE-7000 OVERPRESSURE PROTECTION

Page 167

NE-7100 GENERAL REQUIREMENTS

NE-7110 SCOPE

(a) A containment vessel shall be protected from the consequence arising from the application of conditions of pressure and coincident temperature that would cause the Service or Test Limits specified in the Design Specification to be exceeded. Pressure relief or vacuum relief devices are not required where the Service or Test Limits specified in the Design Specification are not exceeded.

(b) Pressure relief devices not permanently installed in accordance with NE-7141 shall be removed from the containment vessel before placing the vessel in service.

(c) It is recognized that the fundamental purpose of a containment vessel may be nullified by the incorporation of pressure relief valves discharging directly into the environment. Vacuum relief devices or systems, including venting with controlled discharge or condensation systems, may be essential to protect against differential pressures in excess of design external pressures.

NE-7111 General Definitions

(a) *Overpressure*, as used in this Article, refers to changes in differential pressure resulting from thermal imbalances and similar phenomena capable of causing a differential pressure change of sufficient duration to be compatible with the dynamic response characteristics of the pressure relief devices listed in this Article.

(b) The basic definitions of pressure relief devices as specified in this Article are given in ASME PTC 25-1994, Safety and Relief Valves.

(c) *Primary Pressure* is the pressure of the fluid at the inlet of the pressure relief device.

(d) *Secondary Pressure* is that value of pressure existing in the passage between the actual discharge area and the outlet for which the discharge system of the pressure relief devices shall be designed.

NE-7120 INTEGRATED OVERPRESSURE PROTECTION

Overpressure protection of the components shall be provided by one of the following methods as an integrated overpressure protection:

(a) the use of vacuum relief or pressure relief devices, or both, and their associated pressure sensing elements; or

(b) a component designed not to exceed Service Limits specified in the Design Specification (pressure relief devices are not required on containment vessels designed and built to safely contain all radioactive substances that may be released into the containment atmosphere).

NE-7130 PROVISIONS FOR CHECKING OPERATION OF PRESSURE RELIEF DEVICES

NE-7131 Design Provisions

Relief devices shall be designed so that potential impairment of the overpressure protection function from service exposure to fluids can be determined by test or examination.

NE-7132 Construction Provisions

Relief devices shall be constructed and installed so that their correct operation and the reliability of their associated pressure sensing elements under service or test conditions can be demonstrated, as may be required by regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

NE-7140 INSTALLATION PROVISIONS

NE-7141 Installation of Relief Devices

(a) The connection between a component and its pressure relief valve shall have a minimum inside diameter equal to or greater than the nominal size of the pressure relief valve inlet. The opening in the connection shall be designed to provide direct and unobstructed flow between the component and its pressure relief valve. Pressure drop resulting from the accumulated line losses between the protected component and the relief valve shall be compatible with the valve performance characteristic.

(b) Spring-loaded pressure relief valves should normally be installed in the upright position with the spindle vertical. Where space or piping configuration precludes such an installation, the valve may be installed in other than the vertical position, provided the following conditions are met:

(1) the valve design is confirmed by the NV Certificate Holder with documentation as being satisfactory for such position; and

(2) the valve has been pressure tested in the same position as the installation.

(c) The area of the discharge piping from a pressure relief device shall not be less than the area of the discharge connection. The size and length of the discharge piping shall be such that any back pressure that may exist or develop will not reduce the relieving capacity below that required to protect the components.

NE-7142 Provisions When Stop Valves Are Used

No stop valves or other devices shall be placed in the inlet or discharge lines of a relief device so that they could reduce the protection below that required by the rules of this Article, unless such stop valves are constructed and installed with controls and interlocks so that the relieving capacity requirements are met under all conditions of operation. Means shall be provided to verify that the operation of controls and interlocks can be verified.

NE-7150 ACCEPTABLE PRESSURE RELIEF DEVICES

NE-7151 Pressure Relief Valves

Pressure relief valves shall meet the Construction requirements applicable to Class 2 valves.

NE-7152 Vacuum Relief Devices

(a) Vacuum relief devices shall meet the construction requirements applicable to Class 2 valves and the additional requirements of this Article.

(b) Balanced self-actuating, horizontally installed, swinging disk valves, or vertically installed, vacuum disk or pallet-type valves, with provisions for adjustment of the differential pressure under which the valves operate, are acceptable types.

(c) Valve devices intended to provide vacuum relief, and which are operated by indirect means depending upon an external energy source, such as electrical, pneumatic, or hydraulic systems, are not acceptable unless the conditions given in (1) and (2) below are met:

(1) at least two independent external power-operated valve and control systems are employed so that the required relieving capacity is obtained if any one of the valve systems should fail to operate when called upon to do so; and

(2) at least one self-actuating vacuum relief device, of a type specified in (b) above, of equivalent relieving capacity is provided in series with each of the external power-operated valves.

NE-7160 UNACCEPTABLE RELIEF DEVICES

NE-7161 Nonreclosing Pressure Relief Devices

Nonreclosing pressure relief devices are unacceptable.

NE-7200

NE-7200 OVERPRESSURE PROTECTION REPORT

NE-7210 RESPONSIBILITY FOR REPORT

The provisions intended to meet the requirements of this Article shall be the subject of an Overpressure Protection Report prepared by the Owner or his designee.

NE-7220 CONTENT OF REPORT

The Overpressure Protection Report shall define the protected vessel and the integrated overpressure protection provided. As a minimum, the report shall include (a) through (k) below:

(a) identification of specific ASME Section III, Article NE-7000 Edition and Addenda and applicable Code Cases used in the design of the overpressure protection system;

Page 171

(b) drawings showing the arrangement of the protected vessel, including the pressure and/or vacuum relief devices employed;

(c) the range of operating conditions, including the effect of discharge piping back pressure under which the pressure relief devices are required to function;

(d) an analysis of the conditions that give rise to the maximum pressure and/or vacuum relieving requirements;

(e) the relief capacity required to prevent a differential pressure in the vessel in accordance with the requirements in NE-7300;

(f) the operating controls or safety controls of the protected vessel upon which the anticipated required relief capacity of (d) above, and the maximum pressure and temperature of (c) above are predicted;

(g) the redundancy and independence of the pressure and/or vacuum relief devices, and their associated pressure sensors and controls employed to preclude a loss of overpressure protection in the event of a failure of any pressure or vacuum relief device, sensing element, associated control, or external power source;

(h) the design secondary pressure, including a justification of the value identified in the Design Specification for pressure relief devices;

(i) the analysis of pressure transient conditions, including those associated with the response time of pressure and/or vacuum relief devices;

(j) consideration of set pressure and blowdown limitations in accordance with NE-7500, taking into account opening pressure tolerances and overpressure of the pressure relief device;

(k) when pressure relief devices are not required, verification is to include reference to the applicable requirement in NE-3000 that demonstrates that the Service Limits for the vessel do not exceed the Service Limits specified in the Design Specification for all service loadings.

NE-7230 CERTIFICATION OF REPORT

The report, after it has been reconciled with the requirements of this Article, shall be certified by one or more Registered Professional Engineers competent in the applicable field of design and qualified in accordance with the requirements of Appendix XXIII of Section III Appendices.

NE-7240 REVIEW OF REPORT AFTER INSTALLATION

(a) After completion of the installation of the protected vessel an as-built drawing shall be prepared. The Owner or his designee shall review the Overpressure Protection Report against the as-built vessel.

(b) The results of this review shall be documented in an addendum to the Overpressure Protection Report. The addendum shall contain a copy of the as-built drawing and shall include either:

- (1) a statement that the as-built vessel meets the requirements of the Overpressure Protection Report; or
 - (2) a revision to the Overpressure Protection Report to make it agree with the as-built vessel; or
 - (3) a description of the changes made to the as-built vessel to make it comply with the Overpressure Protection Report.
- (c) The addendum shall be certified by one or more Registered Professional Engineers competent in the applicable field of design and qualified in accordance with the requirements of Appendix XXIII of Section III Appendices.

NE-7250 FILING OF REPORT

A copy of the Overpressure Protection Report shall be filed at the nuclear power plant site prior to the Inspector or Authorized Nuclear Inspector signing the Owner's Data Report. The report shall be made available to the Authorized Nuclear Inspector and the enforcement authorities having jurisdiction at the plant site.

NE-7300 RELIEVING CAPACITY REQUIREMENTS

NE-7310 RELIEVING CAPACITY OF PRESSURE RELIEF DEVICES

The total rated relieving capacity of the pressure relief devices shall take into account any limitations due to fluid flow-through piping and other components.

NE-7311 Relieving Capacity of Vacuum Relief Devices

(a) The total rated relieving capacity of the vacuum relief devices shall take into account any limitations due to fluid flow-through piping and other components.

(b) The rated capacity of each vacuum relief device shall not be less than that required to prevent a differential

Page 172

pressure in excess of the value specified in the Design Specification.

(c) At least two independent vacuum relief devices shall be provided on each containment vessel, except on vessels designed to withstand the maximum expected differential pressure. The capacity of each vacuum relief device shall not be less than that required to protect the component.

NE-7400 SET PRESSURES OF PRESSURE RELIEF DEVICES

NE-7410 SET PRESSURE LIMITATIONS FOR TESTING CONDITIONS

The set pressure of the pressure relief devices connected to the vessel shall meet the requirements of NE-6000 and NE-7110.

NE-7500 OPERATING DESIGN REQUIREMENTS FOR PRESSURE RELIEF VALVES

NE-7510 PRESSURE RELIEF VALVES

NE-7511 General Requirements

NE-7511.1 Spring-Loaded Valves.

Valves shall open automatically by direct action of the fluid pressure as a result of forces acting against a spring.

NE-7512 Pressure Relief Valve Operating Requirements

Pressure relief valves shall be constructed to attain rated lift at a pressure which does not exceed the set pressure by more than 10% or 3 psi (20.6 kPa), whichever is greater.

NE-7512.1 Opening Pressure Tolerance

(a) The opening pressure tolerance plus or minus from the set pressure of pressure relief valves shall not exceed 2 psi (13.8 kPa) for pressure up to and including 70 psi (483 kPa) and 3% for pressure above 70 psi (483 kPa).

(b) Conformance with the requirements of (a) above shall be established for each production valve by test. Valves shall be tested with air or gas.

NE-7512.2 Blowdown Requirements.

Pressure relief valves shall be constructed to close after blowing down to a pressure not lower than that specified in the valve Design Specification (NCA-3250). The blowdown shall be determined by test or by proration from the Certificate Holder's blowdown test data.

NE-7513 Relieving Capacity

The relieving capacity of pressure relief valves of the types permitted in this Subarticle shall be based on the stamped relieving capacity and proration of capacity as determined by NE-7700.

NE-7514 Sealing Requirements

Means shall be provided in the construction of all pressure relief valves for sealing all external adjustments. Seals shall be installed by the Certificate Holder at the time of setting. Seals shall be installed in such a manner as to prevent changing the adjustment without breaking the seal and shall serve as a means of identifying the Certificate Holder.

NE-7520 POWER ACTUATED PRESSURE RELIEF VALVES

Power actuated pressure relief valves, which depend upon an external energy source such as electrical, pneumatic, or hydraulic systems, and which respond to signals from pressure or temperature sensing devices may be used provided the following requirements are met.

NE-7521 Sensors and Controls

The relief valve and its auxiliary devices treated as a combination shall comply with the following requirements.

(a) The valve opening pressure shall be controlled within a tolerance of $\pm 1\%$ of the set pressure when the automatic control is in use.

(b) The valve blowdown shall be controlled to a pressure not lower than that specified in the valve Design Specification (NCA-3250).

NE-7522 Relieving Capacity

The total stamped relieving capacity of the valve or valves shall be equivalent to or greater than the required relieving capacity.

Page 173

NE-7700 CERTIFICATION REQUIREMENTS

NE-7710 RESPONSIBILITY FOR CERTIFICATION OF PRESSURE RELIEF VALVES

(a) The Certificate Holder shall be responsible for having the relieving capacity of valves certified as prescribed in this Subarticle.

(b) Capacity certification obtained in compliance with other Sections and which complies with this Section is qualified for capacity certification under these rules, and the valve may be stamped with the appropriate symbol of this Section.

NE-7720 CAPACITY CERTIFICATION OF PRESSURE RELIEF VALVES - COMPRESSIBLE FLUIDS

NE-7721

NE-7721 General Requirements

NE-7721.1 Capacity Certification.

Capacity certification procedures shall be as required in NE-7722 through NE-7727.

NE-7721.2 Test Media.

Capacity certification tests for pressure relief valves for air and gas service shall be conducted with dry saturated steam, air, or gas. For test purposes the limits of 98% minimum quality and 20°F (11°C) maximum superheat shall apply. Capacity shall be corrected to the dry saturated condition from within these limits.

NE-7721.3 Test Pressure.

Capacity certification tests of pressure relief valves for air or gas service shall be conducted at a pressure which does not exceed the set pressure by more than 10% or 3 psi (20.6 kPa), whichever is greater.

NE-7721.4 Blowdown.

Valves having an adjustable blowdown construction shall be adjusted prior to testing so that the blowdown does not exceed 5% of the set pressure.

NE-7721.5 Drawings.

Prior to a test, the Certificate Holder shall submit drawings showing the valve construction to the Authorized Observer. The Authorized Observer shall submit the drawings and test results to the National Board of Boiler and Pressure Vessel Inspectors for capacity certification.

NE-7721.6 Design Change.

When changes are made in the design of a pressure relief valve in such a manner as to affect the flow path, lift, or performance characteristics of the valve, new tests in accordance with this Article shall be performed.

NE-7722 Flow Model Test Method - Power Operated Valves

NE-7722.1 Flow Capacity.

In those cases where test facility limitations make it impossible to perform capacity tests of the full-scale pressure relief valves, flow models of three different sizes may be utilized as a basis for capacity certification. Such flow models shall be sized consistent with the capabilities of the approved test laboratory at which the tests will be conducted and shall accurately model those features which affect flow capacity, such as orifice size, valve lift, and internal flow configuration. The test models need not be functional pressure relief valves, provided other tests to demonstrate proper function of the valve design are conducted as prescribed in NE-7724.1. The relieving capacity of valve designs certified by use of flow models shall be established by the coefficient of discharge method similar to that outlined in NE-7724.1 and NE-7724.2. The certified relieving capacity of all sizes and pressures of a given design for which the value of K has been established, based on flow model tests in accordance with the method of NE-7724, shall not exceed the value calculated by the appropriate formula in NE-7724.2 multiplied by the coefficient K .

NE-7722.2 Demonstration of Function.

The function of three valves of the design to be certified shall be demonstrated by test. Such tests may be performed in conjunction with the capacity certification tests outlined above or as separate tests using production valves. The purpose of these tests is to demonstrate to the satisfaction of a designated representative of the ASME that the valve will achieve full lift and will reclose within the required blowdown. If required by test facility limitations, these tests may be conducted at reduced flow capabilities.

NE-7723 Slope Method

(a) For pressure relief valves of a specific design, four valves of each combination inlet size and orifice size shall be tested. These four valves shall be set at a pressure which will cover the appropriate range of pressures for which the valves are to be used, or set within the range of the authorized test facility.

(b) The instantaneous slope of each test point shall be calculated and averaged where it is defined as the measured capacity divided by the absolute inlet pressure. If any of the experimentally determined slopes fall

Page 174

outside of a range of $\pm 5\%$ of the average slope, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average slope shall be determined, excluding the replaced valve test results. If any individual slope is now outside of the $\pm 5\%$ range, then the tests shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design. The certified capacity shall be 90% of the average slope multiplied by the flow rating pressure, psia.

NE-7724 Coefficient of Discharge Method

A coefficient K may be established for a specific pressure relief valve design according to the procedure given in NE-7724.1 and NE-7724.2.

NE-7724.1 Number of Valves to Be Tested.

For each design, at least three valves for each of three different sizes shall be submitted for test. Each valve of a given size shall be set at a different pressure.

NE-7724.2 Establishment of Coefficient of Discharge

(a) Tests shall be made on each pressure relief valve to determine its lift, opening and blowdown pressures, and capacity, in terms of the fluid used in the test. A coefficient of discharge K_D shall be established for each test run as follows:

$$K_D = \frac{\text{Actual Flow}}{\text{Theoretical Flow}} = \text{Coefficient of Discharge}$$

Actual Flow is determined quantitatively by test and Theoretical Flow is calculated by the following formula. For tests with dry saturated steam:

$$W_T = 51.5AP$$

where

W_T	= Theoretical Flow, lb/hr
A	= actual discharge area through the valve at developed lift, sq in.
P	= (set pressure $\times$ 1.03) plus atmospheric pressure, psia, or set pressure plus 2 psi plus atmospheric pressure, whichever is greater, for test pressures determined by NB-7731.3(a)
	= (set pressure $\times$ 1.10) plus atmospheric pressure, psia, or set pressure plus 3 psi plus atmospheric pressure, whichever is

greater, for test pressures determined by NB-7731.1(b) or NB-7731.1(c)

(For compressible fluids other than steam, use Appendix XVIII.) The average coefficient of discharge K_D of the tests required shall be multiplied by 0.90 and the product shall be taken as the coefficient K of that design.

(b) If any of the experimentally determined coefficients fall outside of a range of $\pm 5\%$ of the average coefficient, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average coefficient shall be determined, excluding the replaced valve test results. If any individual coefficient is now outside of the $\pm 5\%$ range, then the test shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design.

NE-7724.3 Calculation of Certified Capacity.

The certified capacity of all sizes and pressures of a given design for which the value of K has been established under the provisions of NE-7724.2, and which are subsequently manufactured, shall not exceed the value calculated by the appropriate formula in NE-7724.2(a) multiplied by the coefficient K .

NE-7725 Single Valve Method

NE-7725.1 Valve Capacity Within Test Facility Limits

(a) Where a single valve is to be capacity tested, the certified capacity may be based on three separate tests associated with each set pressure for which capacity certification is required.

(b) The certified capacity associated with each set pressure shall not exceed 90% of the average capacity established by the tests. Failure of the individual test capacities to fall within $\pm 5\%$ of the average capacity associated with each set pressure shall be cause for rejection of the test. The reason for the failure shall be determined and the test repeated.

(c) Should additional valves of the same design be constructed at a later date, the results of the tests on the original valve may be included as applicable to the particular test method selected.

NE-7725.2 Valve Capacity in Excess of Test Facility Limits

(a) For valves whose capacity exceeds that of the test facility, the certified capacity may be based on a flow coefficient K (NE-7724.2) determined from either blocked open flow tests or flow model tests, provided the orifice area is such that choked flow conditions are obtained. The certified capacity shall be calculated as directed in NE-7724.3.

Page 175

(b) The proper operation of the valve shall be demonstrated as prescribed in NE-7722.2.

NE-7726 Proration of Capacity

(a) The capacity of a pressure relief valve applied to a system may be prorated to an overpressure greater than the overpressure for which the valve design is certified. This overpressure shall be within the allowable limits of the system.

(b) Depending on the method used for the initial capacity certification:

(1) the prorated capacity shall be 90% of the average slope determined in NE-7723 multiplied by the prorated relieving pressure (psia), or;

(2) the prorated capacity shall be calculated using the appropriate formula from NE-7724.2 (where P is the prorated relieving pressure (psia) multiplied by the coefficient K).

NE-7727 Laboratory Acceptance of Pressure Relieving Capacity Tests

Tests shall be conducted at a place where the testing facilities, methods, procedures, and person supervising the tests (Authorized Observer) meet the applicable requirements of ASME PTC 25-1994, Safety and Relief Valves. The tests shall be made under the supervision of, and certified by, an Authorized Observer. The testing facilities, methods, procedures,

and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation of an ASME designee. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designee for review and acceptance.¹

NE-7730 CAPACITY CERTIFICATION OF VACUUM RELIEF VALVES

NE-7731 General Requirements

NE-7731.1 Capacity Certification.

Capacity certification procedures shall be as required in NE-7732 through NE-7735.

NE-7731.2 Test Media.

Capacity certification tests for vacuum relief valves for air and gas service shall be conducted with dry steam, air, or gas. For steam test purposes the limits of 98% minimum quality and 20°F maximum superheat shall apply. Capacity shall be corrected to dry saturated condition from these limits.

NE-7731.3 Test Method and Pressure.

Capacity tests may be conducted by pressurizing the valve instead of using a vacuum, provided the inlet conditions of the valve (not the vessel) are known and the inlet pressure is not greater than 5 psi (35 kPa), and the direction of flow through the valve is the same on pressure as is experienced on vacuum. Tests shall be conducted at twice the set pressure.

NE-7731.4 Blowdown.

Blowdown shall be recorded at the time of the test.

NE-7731.5 Drawings.

Prior to a test, the Certificate Holder shall submit drawings showing the valve construction to the Authorized Observer. The Authorized Observer shall submit the drawings and test results to the ASME designee for review and acceptance.

NE-7731.6 Design Change.

When changes are made in the design of a pressure relief valve in such a manner as to affect the flow path, lift, or performance characteristics of the valve, new tests in accordance with this Article shall be performed.

NE-7732 Single Valve Method

(a) Where a single valve at a single pressure is to be capacity tested, the capacity rating may be based on three separate and distinct tests of the single valve at the specified set pressure. The certified capacity rating of the valve shall not exceed 90% of the average capacity established by the tests. Failure of the individual test capacities to fall within $\pm 5\%$ of the average capacity shall be cause for rejection of the test. The reason for the failure shall be determined and the test repeated.

(b) Should additional valves of the same design be constructed at a later date, the results of the test on the original valve may be included as applicable to the particular test method selected.

NE-7733 Slope Method

Four valves of each combination of pipe size and orifice size shall be tested. These four valves shall be set at pressures which cover the appropriate range of pressures for which the valves are to be used or set within the range of the test facility. The slope of each test shall be calculated and averaged, where slope is defined as the measured capacity divided by the quantity,

$F [(P)(P - P_o)]^{1/2}$, where

$$F = \sqrt{\left(\frac{k}{k-1}\right) (r^{2/k}) \left[\frac{1 - (r)^{\frac{k-1}{k}}}{1 - r}\right]}$$

P	= inlet pressure, psi
P_o	= discharge pressure, psi
k	= ratio of specific heats, C_v/C_p
r	= pressure ratio, P_o/P

If any of the experimentally determined slopes fall outside of a range of $\pm 5\%$ of the average slope, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these new valves, a new average slope shall be determined, excluding the replaced valve test results. If any individual slope is now outside of the $\pm 5\%$ range, then the test shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design. The certified capacity shall be 90% of the average slope multiplied by the quantity $F[(P)(P - P_o)]^{1/2}$.

NE-7734 Coefficient of Discharge Method

Instead of individual capacity tests, the capacity curve method of coefficient K may be established for a specific valve design in accordance with NB-7734.1 and NB-7734.2.

NE-7734.1 Number of Valves to Be Tested.

For each design, three valves of three different sizes, a total of nine valves, shall be tested. Each valve of a given size shall be set at a different pressure.

NE-7734.2 Establishment of Coefficient of Discharge

(a) Tests shall be made on each relief valve to determine its lift, opening and closing pressures, and actual capacity. A coefficient of discharge K_D shall be established for each run as follows:

$$K_D = \frac{\text{Actual Flow}}{\text{Theoretical Flow}} = \text{Coefficient of Discharge}$$

where Actual Flow is determined quantitatively by test and Theoretical Flow is calculated from the appropriate equation for the test fluid. The following formula may be used for other than saturated steam flow:

$$W = 735FA \left[\frac{MP(P - P_o)}{T} \right]^{1/2}$$

$$Q = 279,000FA \left[\frac{P(P - P_o)}{MT} \right]^{1/2}$$

where

$$F = \sqrt{\left(\frac{k}{k-1}\right) (r^{2/k}) \left[\frac{1-(r)^{\frac{k-1}{k}}}{1-r}\right]}$$

or is obtained from Fig. NE-7734.2(a)-1.

A	= flow area, sq in.
M	= molecular weight
P	= inlet pressure, psi
P_o	= discharge pressure, psi
T	= temperature, deg Rankin
k	= ratio of specific heats, C_v/C_p
r	= pressure ratio, P_o/P
Q	= cu ft/hr at 14.7 psi and 60°F
W	= lb/hr

The average of the coefficients of discharge K_D of the tests required shall be multiplied by 0.90 and their product shall be the coefficient K of that design. The coefficient of the design shall not be greater than 0.876 (the product of 0.9×0.975).

(b) If any of the experimentally determined coefficients fall outside of a range of $\pm 5\%$ of the average coefficient, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average coefficient shall be determined, excluding the replaced valve test results. If any individual coefficient is now outside of the $\pm 5\%$ range, then the test shall be considered unsatisfactory and shall be cause for the ASME designee to refuse certification of the particular valve design.

NE-7734.3 Calculation of Relieving Capacity

(a) The certified relieving capacity of all sizes and pressures of a given design, for which the value of K has been established, shall be calculated by the appropriate formula given above multiplied by the coefficient K . Values obtained from pressurized tests may be converted to equivalent vacuum from the above equation.

(b) The coefficient shall not be applied to valves whose beta ratio (the ratio of valve throat and inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that individual coefficients of discharge, K_D , for valves of the extreme ends of a larger range is within $\pm 5\%$ of the average coefficient,

K. For designs where lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio (L/D).

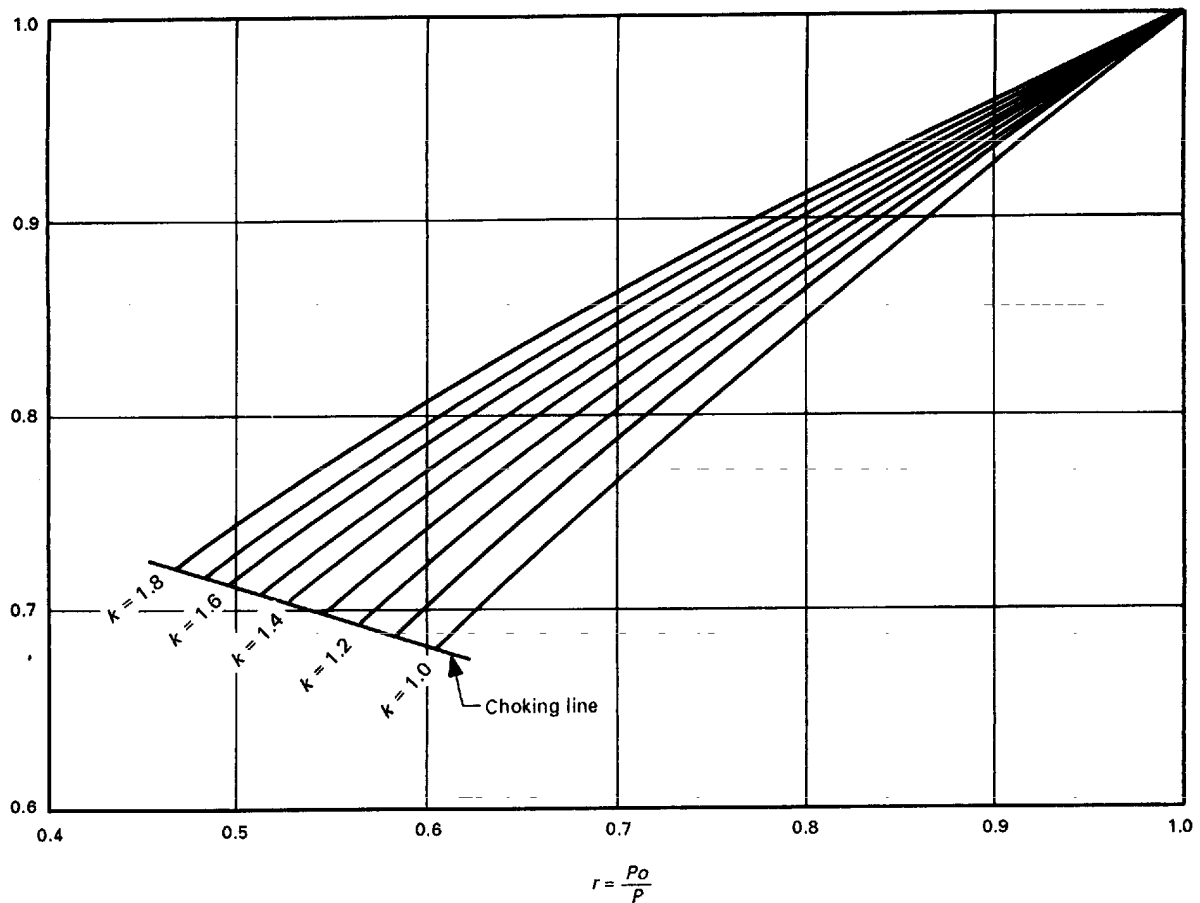


FIG. NE-7734.2(a)-1 VALUES OF F FOR NONCHOKING FLOW

FIG. NE-7734.2(a)-1 VALUES OF F FOR NONCHOKING FLOW

NE-7735 Laboratory Acceptance of Relieving Capacity Tests

Tests shall be conducted at a place where the testing facilities, methods, procedures, and person supervising the tests (Authorized Observer) meet the applicable requirements of ASME PTC 25-1994. The tests shall be made under the supervision of, and certified by, an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation of an ASME designee. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designee for review and acceptance.¹

NE-7800 MARKING, STAMPING, AND DATA REPORTS

NE-7810 PRESSURE AND VACUUM RELIEF VALVES

¹ Valve capacities published in "Pressure Relief Device Certifications." This publication may be obtained from the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, OH 43229.

NE-7811 Marking and Stamping

Each pressure relief valve shall be plainly marked by the Certificate Holder with the required data below in such a way that the marking will not be obliterated

Page 178

in service. The data shall be in characters not less than $\frac{3}{32}$ in. (2.4 mm) high. The marking shall be placed on the valve or on a nameplate securely fastened to the valve. The Code NV Symbol shall be stamped on the valve or nameplate, but the other required data may be stamped, etched, impressed, or cast. The marking shall include the following:

- (a) name, or an acceptable abbreviation, of the Certificate Holder
- (b) Certificate Holder's design or type number
- (c) size _____ (NPS, the nominal pipe size) of the valve inlet
- (d) set pressure _____ psi
- (e) certified capacity and overpressure in percent or psi in accordance with NE-7700

Pressure Relief Valves:

____ lb/hr of saturated steam for valves certified on steam, or
____ scfm (standard cubic feet per minute) at 60°F (16°C) and 14.7 psia (101 kPa) of air for valves certified on air or gas, or
____ gal/min of water at 70°F (21°C) for valves certified on water

Vacuum Relief Valves:

____ scfh (standard cubic feet per hour) at 60°F (16°C) and 14.7 psi (101 kPa)

- (f) applicable official Code Symbol Stamp, as shown in Table NCA-8100-1

In addition to the above, each pressure relief valve shall have a separate nameplate attached to the component that includes the marking requirements of NCA-8220 and NE-3593.3.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NE-8000

ARTICLE NE-8000 NAMEPLATES, STAMPING, AND REPORTS

Page 179

[98]

NE-8100 REQUIREMENTS

Containment vessels shall be stamped with the N symbol. Parts and appurtenances, which are part of the containment vessel, shall be stamped with the NPT symbol. The applicable requirements given in NCA-8000 shall apply to metal containment vessels. In addition to the information required by NCA-8220, both the vessel nameplate and the Certificate Holder's Data Report shall include the lowest service metal temperature as defined in NE-2331, footnote 4.

[98]

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NE SI UNITS

SI UNITS

Page 181

The 1998 Edition of the Boiler and Pressure Vessel Code is based on U.S. Customary (ft-lb) units of measurement which are to be regarded as the standard. This supplement is provided as a convenience to the Code user and contains SI conversion factors for units contained in the Code.

Page 182

Page 183

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

Quantity	Unit	Symbol	Other Units or Limitations
Space and Time			
plane angle	radian	rad	degree (decimalized)
length	meter	m	
area	square meter	m ²	
volume	cubic meter	m ³	liter (L) for liquid only (use without prefix other than in milliliter, mL)
time	second	s	minute (min), hour (h), day (d), week, and year
Periodic and Related Phenomena			
frequency	hertz	Hz	revolutions per second (r/s)
rotational frequency	revolutions per second	s ⁻¹	revolutions per minute (r/m)
Mechanics			
mass	kilogram	kg	
density	kilogram per cubic meter	kg/m ³	
moment of inertia	kilogram · meter ²	kg · m ²	
force	newton	N	
moment of force (torque)	newton-meter	N · m	
pressure and stress	pascal	Pa	(pascal = newton per square meter)
energy, work	joule	J	kilowatt-hour (kW · h)
power	watt	W	
impact strength	joule	J	
section modulus	meter ³	m ³	
moment of section (second moment of area)	meter ⁴	m ⁴	
fracture toughness	Pa · $\sqrt{m}$		
Heat			
temperature — thermodynamic [Note (2)]	kelvin	K	degree Celsius (°C)
temperature — other than thermodynamic	degree Celsius	°C	kelvin (K)
linear expansion coefficient	meter per meter-kelvin	K ⁻¹	°C ⁻¹
quantity of heat	joule	J	
heat flow rate	watt	W	
thermal conductivity	watt per meter-kelvin	W/(m · K)	W/(m · °C)
thermal diffusivity	square meter per second	m ² /s	
specific heat capacity	joule per kilogram-kelvin	J/(kg · K)	J/(kg · °C)
Electricity and Magnetism			
electric current	ampere	A	
electric potential	volt	V	
current density	ampere per meter ²	A/m ²	
magnetic field strength	ampere per meter	A/m	

NOTES:

- (1) Conversion factors between SI units and U.S. customary are given in SI-1, "ASME Orientation and Guide for Use of SI (Metric) Units," and ASTM E 380.
- (2) Preferred use for temperature and temperature interval is degrees Celsius (°C), except for thermodynamic and cryogenic work where kelvins may be more suitable. For temperature interval, 1 K = 1°C exactly.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

COMMONLY USED CONVERSION FACTORS
(For Others See ASTM E 380) [See Note (1)]

Quantity	To Convert From	To	Multiply by [Note (2)]	
plane angle	degree	rad	1.745 329	E-02
length	in	m	2.54*	E-02
	ft	m	3.048*	E-01
	yd	m	9.144*	E-01
area	in ²	m ²	6.451 6*	E-04
	ft ²	m ²	9.290 304*	E-02
	yd ²	m ²	8.361 274	E-01
volume	in ³	m ³	1.638 706	E-05
	ft ³	m ³	2.831 685	E-02
	US gallon	m ³	3.785 412	E-03
	Imperial gallon	m ³	4.546 09	E-03
	liter	m ³	1.0*	E-03
mass	lbm	kg	4.535 924	E-01
	ton (metric) (mass)	kg	1.000 00*	E+03
	ton (short 2000 lbm)	kg	9.071 847	E+02
force	kgf	N	9.806 65*	E+00
	lbf	N	4.448 222	E+00
bending, torque	kgf · m	N · m	9.806 65*	E+00
	lbf · in	N · m	1.129 848	E-01
	lbf · ft	N · m	1.355 818	E+00
pressure, stress	kgf/m ²	Pa	9.806 65*	E+00
	lbf/ft ²	Pa	4.788 026	E+01
	lbf/in ² (psi)	Pa	6.894 757	E+03
	kips/in ²	Pa	6.894 757	E+06
	bar	Pa	1.0*	E+05
energy, work	Btu (IT) [Note (3)]	J	1.055 056	E+03
	ft · lbf	J	1.355 818	E+00
power	hp (550 ft · lbf/s)	W	7.456 999	E+02
fracture toughness	ksi $\sqrt{\text{in}}$	Pa · $\sqrt{\text{m}}$	1.098 843	E+06
temperature	°C	K	$t_K = t_C + 273.15$	
	°F	K	$t_K = (t_F + 459.67)/1.8$	
	°F	°C	$t_C = (t_F - 32)/1.8$	
temperature interval	°C	K	1.0*	E+00
	°F	K or °C	5.555 555	E-01

NOTES:

(1) Care should be taken when converting formulas or equations that contain constant terms or factors. The value of these terms must be understood and may also require conversion.

(2)(a) Relationships that are exact in terms of the base units are followed by a single asterisk.

(b) The factors are written as a number greater than 1 and less than 10 with 6 or less decimal places. The number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example: 3.523 907 E-02 is $3.523\ 907 \times 10^{-2}$ or 0.035 239 07.

(3) International Table

COMMONLY USED CONVERSION FACTORS

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NF A98

1998 ADDENDA SUMMARY OF CHANGES

Page xxv

Changes given below are identified on the pages by a margin note, **98**, placed next to the affected area.

<i>Page</i>	<i>Location</i>	<i>Change</i>
8	NF-1213	Last sentence added
15	NF-2110	Subparagraph (b)(3) revised
43	NF-3112.1	Last sentence corrected by Errata
46	NF-3132	First line corrected by Errata
154	NF-II-3532	In subpara. (a), second line corrected by Errata
157-162	Appendix NF-III	Added
173-182	Appendix NF-B	Added

NOTE:

Volume 42 of the Interpretations to Section III, Divisions 1 and 2, of the ASME Boiler and Pressure Vessel Code follows the last page of the Edition to Subsection NCA.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NF INTRO

INTRODUCTION

1998 ASME
BOILER &
PRESSURE VESSEL CODE
AN INTERNATIONAL CODE

III

Division 1 -

Subsection NF

Supports

RULES FOR
CONSTRUCTION
OF NUCLEAR
POWER PLANT
COMPONENTS

[ASME logo] The American Society of

Mechanical Engineers

IMPORTANT INFORMATION ON THE 1998 BOILER AND PRESSURE VESSEL CODE ADDENDA DISTRIBUTION SCHEDULE

There is a change in the way the Addenda to the 1998 Edition of the ASME Boiler and Pressure Vessel Code are distributed. The 1998 Edition, published July 1, 1998, incorporates the 1998 Addenda revisions, additions, or deletions. There will be no separate 1998 Addenda issued in a replacement page format. Two additional Addenda to the 1998 Edition, in the form of replacement pages, will be issued on July 1, 1999 and July 1, 2000.

The Summary of Changes published with the 1998 Edition lists and describes the revisions that are part of the 1998 Addenda. These changes are identified with a margin note, **98**, denoting the affected area.

The Addenda for 1999 and 2000 will also have a Summary of Changes and identifiers printed on the replacement pages. The revisions, additions, or deletions will be incorporated directly into the affected pages. It is advisable to retain the title sheets and all replaced pages for reference.

The effective dates for Code Editions and Addenda are described in the Foreword.

ASME BOILER AND PRESSURE VESSEL CODE
AN INTERNATIONAL CODE

III

RULES FOR
CONSTRUCTION OF
NUCLEAR POWER
PLANT COMPONENTS

Division 1 -

Subsection NF

Supports

1998 Edition

July 1, 1998

ASME BOILER AND
PRESSURE VESSEL
COMMITTEE
SUBCOMMITTEE ON
NUCLEAR POWER

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
NEW YORK, NEW YORK

Date of Issue - July 1, 1998

(Includes all Addenda dated December 1997 and earlier)

This code or standard was developed under procedures accredited as meeting the criteria for American National Standards. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment which provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not "approve," "rate," or "endorse" any item, construction, proprietary device, or activity.

ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of

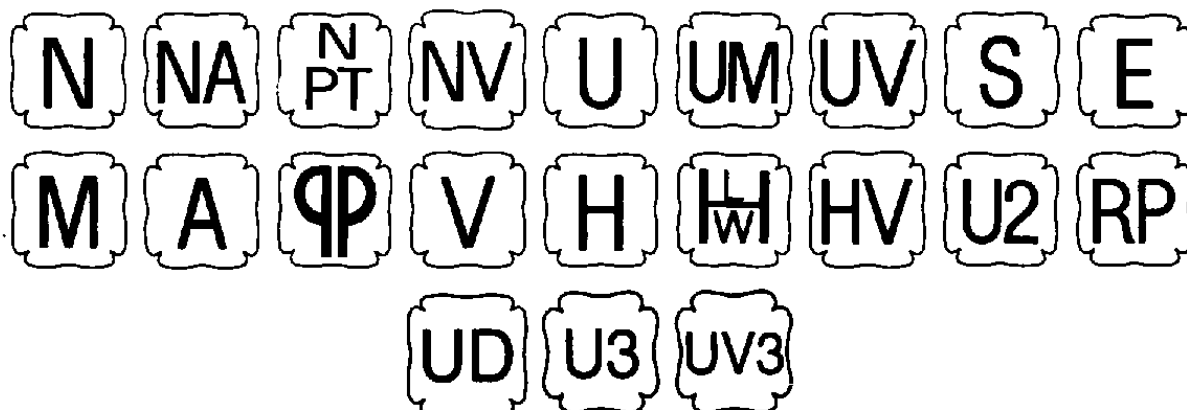
any applicable Letters Patent, nor assume any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations issued in accordance with governing ASME procedures and policies which preclude the issuance of interpretations by individual volunteers.

The footnotes in this document are part of this American National Standard.

[ASME logo] ASME collective membership mark



LOGOS

The above ASME symbols are registered in the U.S. Patent Office.

"ASME" is the trademark of the American Society of Mechanical Engineers.

No part of this document may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Library of Congress Catalog Card Number: 56-3934

Printed in the United States of America

Adopted by the Council of the American Society of Mechanical Engineers, 1914.

Revised 1940, 1941, 1943, 1946, 1949, 1952, 1953, 1956, 1959, 1962, 1965, 1968, 1971, 1974, 1977, 1980, 1983, 1986, 1989, 1992, 1995, 1998

The American Society of Mechanical Engineers
Three Park Avenue, New York, NY 10016-5990

Copyright © 1998 by
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
All Rights Reserved

1998 ASME

BOILER AND PRESSURE VESSEL CODE

SECTIONS

I Rules for Construction of Power Boilers

II Materials

Part A - Ferrous Material Specifications

Part B - Nonferrous Material Specifications

Part C - Specifications for Welding Rods, Electrodes, and Filler Metals

Part D - Properties

III Subsection NCA - General Requirements for Division 1 and Division 2

III Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

III Division 2 - Code for Concrete Reactor Vessels and Containments

III Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

IV Rules for Construction of Heating Boilers

V Nondestructive Examination

VI Recommended Rules for the Care and Operation of Heating Boilers

VII Recommended Guidelines for the Care of Power Boilers

VIII Rules for Construction of Pressure Vessels

Division 1

Division 2 - Alternative Rules

Division 3 - Alternative Rules for Construction of High Pressure Vessels

IX Welding and Brazing Qualifications

X Fiber-Reinforced Plastic Pressure Vessels

XI Rules for Inservice Inspection of Nuclear Power Plant Components

ADDENDA

Colored-sheet Addenda, which include additions and revisions to individual Sections of the Code, are published annually and will be sent automatically to purchasers of the applicable Sections up to the publication of the 2001 Code. The 1998 Code is available only in the loose-leaf format; accordingly, the Addenda will be issued in the loose-leaf, replacement-page format.

INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code. The Interpretations for each individual Section will be published separately and will be included as part of the update service to that Section. They will be issued semiannually (July and December) up to the publication of the 2001 Code. Interpretations of Section III, Divisions 1 and 2, will be included with the update service to Subsection NCA.

CODE CASES

The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 1998 Code Cases book: (1) Boilers and Pressure Vessels and (2) Nuclear Components. Supplements will be sent automatically to the purchasers of the Code Cases books up to the publication of the 2001 Code.

Page v

FOREWORD

The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety governing the design, fabrication, and inspection during construction of boilers and pressure vessels, and to interpret these rules when questions arise regarding their intent. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property and to provide a margin for deterioration in service so as to give a reasonably long, safe period of usefulness. Advancements in design and material and the evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction,¹ and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

¹ Construction, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are responsible for the application of these programs to their design.

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practice as determined by the engineer.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider revisions of the rules, new rules as dictated by

technological development, Code Cases, and requests for interpretations. Only the Boiler and Pressure Vessel Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Mandatory Appendix covering preparation of technical inquiries). Proposed revisions to the Code resulting from inquiries will be presented to the Main Committee for appropriate action. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by ASME.

Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute and published in *Mechanical Engineering*

Page viii

to invite comments from all interested persons. After the allotted time for public review and final approval by ASME, revisions are published annually in Addenda to the Code.

Code Cases may be used in the construction of components to be stamped with the ASME Code symbol beginning with the date of their approval by ASME.

Code Editions may be used on or after the date of issue shown in the Edition. After Code revisions are approved by ASME, they may be used beginning with the date of issue shown on the Addenda. Revisions to material specifications are originated by the American Society for Testing and Materials (ASTM) and other recognized national or international organizations, and are usually adopted by ASME. However, those revisions may or may not have any effect on the suitability of material, produced to earlier editions of specifications, for use in ASME construction. ASME material specifications approved for use in each construction Code are listed in the Appendices of Section II, Parts A and B. These Appendices list, for each specification, the latest edition adopted by ASME, and earlier and later editions considered by ASME to be identical for ASME construction.

Owners of nuclear power plants are cautioned that Code Editions, Addenda, and Cases to be used in construction shall be acceptable to the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

Each state and municipality in the United States and each province in Canada that adopts or accepts one or more Sections of the Boiler and Pressure Vessel Code is invited to appoint a representative to act on the Conference Committee to the Boiler and Pressure Vessel Committee. Since the members of the Conference Committee are in active contact with the administration and enforcement of the rules, the requirements for inspection in this Code correspond with those in effect in their respective jurisdictions. The required qualifications for an Authorized Inspector under these rules may be obtained from the administrative authority of any state, municipality, or province which has adopted these rules.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, method of fabrication, inspection, and safety devices. Permission may be granted to regulatory bodies and organizations publishing safety standards to use a complete Section of the Code by reference. If usage of a Section, such as Section IX, involves exceptions, omissions, or changes in provisions, the intent of the Code might not be attained.

Where a state or other regulatory body, in the printing of any Section of the Boiler and Pressure Vessel Code, makes additions or omissions, it is recommended that such changes be clearly indicated.

The National Board of Boiler and Pressure Vessel Inspectors is composed of chief inspectors of states and municipalities in the United States and of provinces in Canada that have adopted the Boiler and Pressure Vessel Code. This Board, since its organization in 1919, has functioned to uniformly administer and enforce the rules of the Boiler and Pressure Vessel Code. The cooperation of that organization with the Boiler and Pressure Vessel Committee has been extremely helpful.

The Code Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The Scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Code for vessels or components not considered to be within its Scope or may establish additions or deletions in that Scope. Accordingly, inquiries regarding such laws or regulations are to be directed to the issuing enforcement or regulatory body.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME

Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the ASME Boiler and Pressure Vessel Committee. ASME is to be notified should questions arise concerning improper use of an ASME Code symbol.

The specifications for materials given in Section II are identical with or similar to those of specifications published by ASTM, AWS, and other recognized national or international organizations. When reference is made in an ASME material specification to a non- ASME specification for which a companion ASME specification exists, the reference shall be interpreted as applying to the ASME material specification. Not all materials included in the material specifications in Section II have been adopted for use in this Section. Usage is limited to those materials and grades listed in at least one of the tables of Section II, Part D, Subpart 1, identified as applicable to this Section. All materials allowed by this Section and used for construction within the scope of these rules shall be furnished in accordance with material specifications

Page ix

contained in Section II or referenced in Appendices A of Section II, Parts A and B except where otherwise provided in Code Cases or in this Section of the Code. Materials covered by these specifications are acceptable for use in items covered by the Code Sections only to the degree indicated in the applicable Section. Materials for Code use should preferably be ordered, produced, and documented on this basis. Material produced to an acceptable specification with requirements different from the requirements of the corresponding specification listed in Appendix A of Part A or Part B may also be used in accordance with the above, provided the material manufacturer or vessel manufacturer certifies with evidence acceptable to the Authorized Inspector that the corresponding ASME specification requirements of specifications listed in Appendix A of Part A or Part B have been met. Material produced to an acceptable material specification is not limited as to country of origin.

When required by context in this Section, the singular shall be interpreted as the plural, and vice-versa; and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

Publication of the SI (Metric) Edition of the ASME Boiler and Pressure Vessel Code was discontinued with the 1986 Edition. Effective October 1, 1986, the SI Edition was withdrawn as an ASME Boiler and Pressure Vessel Code document.

Page xi

STATEMENT OF POLICY ON THE USE OF CODE SYMBOLS AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use Code Symbols for marking items or constructions which have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the symbols, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications which might so indicate. An organization holding a Code Symbol and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code."

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified items will carry the symbol. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

The ASME logo, which is the cloverleaf with the letters ASME within, shall not be used by any organization other than ASME.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Code Symbol Stamp described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the various Code Symbols shall not be used on any item which is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME which tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

Page xiii

PERSONNEL ASME Boiler and Pressure Vessel Committee Subcommittees, Subgroups, and Working Groups

As of December 31, 1997

MAIN COMMITTEE

D. A. Canonico, *Chair*

G. G. Karcher, *Vice Chair*

J. S. Brzuszkiewicz, *Secretary*

R. W. Barnes

F. P. Barton

D. L. Berger

M. D. Bernstein

M. N. Bressler

W. J. Carter

T. M. Cullen

J. R. Farr

R. E. Feigel

J. G. Feldstein

M. Gold

O. F. Hedden

A. J. Justin

D. F. Landers

W. M. Lundy

J. R. MacKay

T. J. Mawson

T. G. McCarty

G. C. Millman

R. A. Moen

C. C. Neely

C. J. Pieper

R. F. Reedy

B. W. Roberts

F. J. Schaaf, Jr.

A. Selz
K. K. Tam
D. E. Tanner

EXECUTIVE COMMITTEE (MAIN COMMITTEE)

G. G. Karcher, *Chair*
D. A. Canonico, *Vice Chair*
J. S. Brzuszkiewicz, *Secretary*
F. P. Barton
J. R. Farr
J. G. Feldstein
M. Gold
O. F. Hedden
A. J. Justin
J. R. MacKay
T. G. McCarty
T. P. Pastor
T. E. Quaka
R. F. Reedy
A. J. Spencer

HONORARY MEMBERS (MAIN COMMITTEE)

R. D. Bonner
R. J. Bosnak
H. M. Canavan
L. J. Chockie
J. S. Clarke
W. E. Cooper
W. D. 3
R. C. Griffin
E. J. Hemzy
E. C. Kistner, Jr.
J. E. Lattan
J. LeCoff
F. N. Moschini
C. E. Rawlins
W. E. Somers
L. P. Zick, Jr.

HONORS AND AWARDS COMMITTEE

J. R. MacKay, *Chair*
A. J. Spencer, *Vice Chair*
F. R. Lyons, *Secretary*
F. P. Barton
W. J. Carter
J. G. Feldstein
M. Gold
F. E. Gregor

E. C. Kistner, Jr.
T. P. Pastor
R. F. Reedy

MARINE CONFERENCE GROUP

J. Tiratto, *Chair*
C. F. Banks
L. W. Douthwaite
J. L. Jones
G. F. Wright

CONFERENCE COMMITTEE

D. E. Tanner - Tennessee (*Chair*)
R. D. Reetz - North Dakota (*Vice Chair*)
A. J. Justin - National Board of Boiler and Pressure Vessel Inspectors (*Secretary*)
R. J. Aben, Jr. - Michigan
J. S. Aclaro - Los Angeles, California
E. A. Anderson - Chicago, Illinois
J. Anderson - South Dakota
R. Barkdoll - Washington
F. P. Barton - Virginia
C. Castle - Nova Scotia, Canada
R. R. Cate - Louisiana
L. Chase - Northwest Territories, Canada
R. A. Coomes - Kentucky
J. Corcoran - Connecticut
M. H. Diehl, Jr. - Maryland
D. A. Douin - Illinois
D. Eastman - Newfoundland and Labrador, Canada
G. L. Ebeyer - New Orleans, Louisiana
F. Ellis - New Hampshire
E. Everett - Georgia
P. C. Hackford - Utah
D. Hanrath - North Carolina
J. B. Harlan - Delaware
K. Hynes - Prince Edward Island, Canada
D. T. Jagger - Ohio
D. J. Jenkins - Kansas
M. Kotb - Quebec, Canada
J. P. Larson - Minnesota
K. T. Lau - Alberta, Canada
J. Lemire - California
G. A. Lundberg - Florida
W. C. Lundine - Oregon
M. A. Malek - Maine
I. W. Mault - Manitoba, Canada
H. T. McEwen - Mississippi

A. W. Meiring - Indiana
R. Mile - Ontario, Canada
T. J. Monroe - Oklahoma
Y. Nagpaul - Hawaii
J. D. Payton - Pennsylvania
D. K. Peetz - Missouri
D. C. Price - Yukon Territory, Canada
R. S. Pucek - Wisconsin
T. E. Rennie - Arizona
L. Roussinos - British Columbia, Canada
M. Shuff - West Virginia
R. Snyder - New Jersey
N. Surtees - Saskatchewan, Canada
M. J. Verhagen - Wisconsin
R. B. West - Iowa
M. J. Wheel - Vermont
K. A. White - Nevada
R. K. White - New York
T. F. Wickham - Rhode Island
C. S. Withers - Colorado

SUBCOMMITTEE ON POWER BOILERS (SC I)

J. R. MacKay, *Chair*
M. D. Bernstein, *Vice Chair*
P. D. Stumpf, *Secretary*
D. L. Berger
E. Everett
D. N. French
F. R. Gerety
J. Hainsworth
T. E. Hansen
J. S. Hunter
W. L. Lowry
T. C. McGough
P. A. Molvie
D. K. Parrish
J. T. Pillow
R. G. Presnak
B. W. Roberts
R. D. Schueler, Jr.
R. V. Wielgoszinski
R. L. Williams

Page xiv

Subgroup on Design (SC I)

M. D. Bernstein, *Chair*
R. D. Schueler, Jr., *Vice Chair*
P. A. Molvie, *Secretary*

M. A. Farrugia
J. D. Fishburn
C. F. Jeerings
K. C. Morrison
A. Nassif
N. Surtees
R. V. Wielgoszinski

Subgroup on Fabrication and Examination (SC I)

D. L. Berger, *Chair*
R. E. McLaughlin, *Secretary*
R. W. Boyce
D. N. French
J. Hainsworth
T. E. Hansen
M. H. Iken
J. M. Lyons
J. T. Pillow
M. E. Reese
R. D. Schueler, Jr.
R. F. Slack, Sr.
R. V. Wielgoszinski

Subgroup on General Requirements (SC I)

T. C. McGough, *Chair*
M. D. Bernstein, *Vice Chair*
W. L. Lowry, *Secretary*
D. L. Berger
E. Everett
F. R. Gerety
J. Hainsworth
C. F. Jeerings
J. M. Lyons
R. E. McLaughlin
D. K. Parrish
J. T. Pillow
W. E. Somers
R. L. Williams

Subgroup on Materials (SC I)

B. W. Roberts, *Chair*
C. E. Spaeder, Jr., *Chair*
J. S. Hunter, *Secretary*
T. M. Cullen
D. N. French
J. F. Henry
J. P. Libbrecht
F. Masuyama

J. M. Tanzosh

Subgroup on Piping (SC I)

T. E. Hansen, *Chair*

D. L. Berger

M. D. Bernstein

P. D. Edwards

W. L. Lowry

T. C. McGough

R. G. Presnak

E. Whittle

P. L. Ziegler

SUBCOMMITTEE ON MATERIALS (SC II)

M. Gold, *Chair*

T. M. Cullen, *Vice Chair*

F. R. Lyons, *Secretary*

A. P. Ahrendt

M. N. Bressler

A. Cohen

R. Dirscherl

W. D. Doty

W. D. Edsall

D. Gandy

M. H. Gilkey

J. J. Heger

J. F. Henry

G. C. Hsu

F. Masuyama

E. Michalopoulos

R. A. Moen

R. K. Nanstad

E. G. Nisbett

J. T. Parsons

D. W. Raho

B. W. Roberts

E. Shapiro

C. E. Spaeder, Jr.

R. W. Swindeman

J. M. Tanzosh

B. E. Thurgood

A. W. Zeuthen

Subgroup on External Pressure (SC II)

R. W. Mikitka, *Chair*

D. J. Green

D. S. Griffin

E. Michalopoulos

B. R. Morelock
D. Nadel
C. E. Spaeder, Jr.
C. H. Sturgeon

Subgroup on Ferrous Specifications (SC II)

E. G. Nisbett, *Chair*
B. M. Dingman
W. D. Edsall
T. Graham
W. N. Holliday
E. A. Jonas
D. C. Krouse
J. F. Longenecker
W. C. Mack
A. S. Melilli
J. T. Parsons
E. J. Rozic, Jr.
E. Upitis
A. W. Zeuthen
R. H. Zong

Subgroup on International Material Specifications (SC II)

J. T. Parsons, *Chair*
D. C. Agarwal
J. Cameron
R. Dirscherl
W. D. Doty
D. M. Fryer
M. Gold
M. H. Iken
W. M. Lundy
H. Masahisa
T. F. Miskell
F. Osweiller
A. P. Povilonis
R. D. Schueler, Jr.
R. R. Seeley
E. A. Steen
E. Upitis
E. O. Woolridge

Subgroup on Nonferrous Alloys (SC II)

D. W. Rahoi, *Chair*
D. C. Agarwal, *Secretary*
W. R. Apblett
L. G. Coffee
A. Cohen
R. Dirscherl

M. H. Gilkey
G. C. Hsu
M. Katcher
E. Shapiro
L. E. Shoemaker
R. C. Sutherlin

Subgroup on Strength, Ferrous Alloys (SC II)

B. W. Roberts, *Chair*
J. M. Tanzosh, *Secretary*
A. P. Ahrendt
W. R. Apblett
T. M. Cullen
M. Gold
J. J. Heger
C. L. Hoffmann
A. Iseda
F. Masuyama
R. A. Moen
D. W. Rahoi
C. E. Spaeder, Jr.
R. W. Swindeman
B. E. Thurgood

Subgroup on Strength of Weldments (SC II & SC IX)

C. E. Spaeder, Jr., *Chair*
W. D. Doty
D. W. Rahoi
B. W. Roberts
C. Robino
W. J. Sperko
J. M. Tanzosh
B. E. Thurgood

Subgroup on Toughness (SC II)

J. M. Barsom
D. A. Hansen
A. Selz
R. S. Vecchio
S. Yukawa
R. Zawierucha

Page xv

SUBCOMMITTEE ON NUCLEAR POWER (SC III)

C. J. Pieper, *Chair*
R. M. Jessee, *Vice Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
Y. Asada

Y. Asada
R. W. Barnes
J. N. Baysden
W. H. Borter
E. B. Branch
M. N. Bressler
F. C. Cherny
G. D. Cooper
R. P. Deubler
W. D. Doty
F. R. Drahos
K. Ennis
B. A. Erler
D. Hanrath
C. L. Hoffmann
K.-H. Hsu
D. F. Landers
W. C. LaRochelle
T. J. Mawson
W. N. McLean
R. A. Moen
D. B. Nickerson
R. F. Perrin
R. F. Reedy
M. W. Smith
J. D. Stevenson
R. E. Tome
K. R. Wichman

Subgroup on Containment Systems for Spent Fuel and High-Level Waste Transport Packagings (SC III)

J. D. Stevenson, *Chair*
H. H. Chung
R. R. Doggart
E. L. Farrow
K. Goldmann
R. H. Jones
W. H. Lake
R. W. Lambert
H. W. Lee
P. McConnell
R. E. Nickell
D. J. Nolan
D. T. Raske
T. Saegusa
R. H. Smith
K. B. Sorenson
P. Turula

N. Urabe
C. R. Witt
S. Yukawa

Subgroup on Design (SC III)

R. W. Barnes, *Chair*
E. B. Branch, *Vice Chair*
R. S. Hill III, *Secretary*
Y. Asada
M. N. Bressler
C. W. Bruny
J. R. Cole
G. D. Cooper
R. P. Deubler
N. W. Edwards
R. E. Gimple
D. Hanrath
R. W. Haupt
T. Iida
B. Jarman
D. F. Landers
W. N. McLean
D. B. Nickerson
E. C. Rodabaugh
J. R. Santangelo
G. C. Slagis
J. D. Stevenson
J. H. Wawrzeniak
K. R. Wichman
R. Wray

Working Group on Administration (SG-D) (SC III)

E. B. Branch, *Chair*
R. W. Barnes, *Vice Chair*
R. S. Hill III, *Secretary*
C. W. Bruny
G. D. Cooper
R. P. Deubler
J. T. Land
D. F. Landers
W. N. McLean
D. B. Nickerson
J. R. Santangelo
R. Wray

Working Group on Core Support Structures (SG-D) (SC III)

J. T. Land, *Chair*
R. H. Hansen
K. B. Larsen

J. F. Mullooly
B. L. Silverblatt

Working Group on Dynamic and Extreme Load Conditions (SG-D) (SC III)

R. Wray, *Chair*
A. E. Meligi, *Secretary*
P. L. Anderson
M. K. Au-Yang
R. D. Blevins
G. J. Bohm
D. L. Caldwell
P. Y. Chen
A. Hadjian
M. Hartzman
W. S. LaPay
H. Lockert
P. R. Olson
R. F. Perry
J. Wallach

Working Group on Piping (SG-D) (SC III)

D. F. Landers, *Chair*
R. S. Hill III, *Vice Chair*
P. Hirschberg, *Secretary*
T. M. Adams
G. A. Antaki
J. R. Cole
A. B. Glickstein
R. W. Haupt
J. C. Hennart
R. D. Hookway
R. B. Jenkins
K. A. Manoly
J. C. Minichiello
S. E. Moore
A. N. Nguyen
D. B. Nickerson
O. O. Oyamada
R. D. Patel
E. C. Rodabaugh
J. R. Santangelo
M. S. Sills
G. C. Slagis
E. A. Wais

Working Group on Pumps (SG-D) (SC III)

D. B. Nickerson, *Chair*
H. L. Brammer

P. Burchett
R. E. Cornman, Jr.
A. A. Fraser
M. Higuchi
G. R. Jones
J. W. Leavitt
J. E. Livingston
R. A. Schussler
H. Tafarodi
G. K. Vaghasia

Working Group on Supports (SG-D) (SC III)

R. P. Deubler, *Chair*
R. M. Dulin, Jr., *Secretary*
U. S. Bandyopadhyay
F. J. Birch
M. N. Bressler
J. R. Cole
J. C. Finneran, Jr.
R. W. Haupt
J. C. Hennart
A. S. Laurensen
A. Lee
R. J. Masterson
A. E. Meligi
A. N. Nguyen
J. R. Stinson

Working Group on Valves (SG-D) (SC III)

W. N. McLean, *Chair*
E. A. Bake
R. R. Brodin
W. G. Knecht
R. Koester
J. J. McGavin
S. N. Shields
H. R. Sonderegger
J. C. Tsacoyeanes
R. G. Visalli
J. R. Zahorsky

Working Group on Vessels (SG-D) (SC III)

C. W. Bruny, *Chair*
T. K. Burr, Sr.
G. D. Cooper
G. A. Deaver
N. W. Edwards
D. Hanrath

W. J. Heilker
B. Jarman
T. M. Khan
O. Maekawa
K. A. Manoly
A. Merend
G. K. Miller
W. Z. Novak
E. Pelling
H. S. Thornton

Page xvi

Special Working Group on Environmental Effects (SG-D) (SC III)

R. S. Hill III, *Chair*
Y. Asada
W. J. Heilker
C. L. Hoffmann
R. A. Moen
W. Z. Novak
S. Yukawa

Special Working Group on Seismic Piping Rules (SG-D) (SC III)

E. B. Branch, *Chair*
T. M. Adams
G. A. Antaki
R. D. Hookway
J. C. Minichiello
M. S. Sills
E. A. Wais

Subgroup on General Requirements (SC III & SC 3C)

W. C. LaRochelle, *Chair*
K. Ennis, *Secretary*
A. Appleton
J. R. Barbee
J. N. Baysden
L. M. Beason
B. H. Berg
R. E. Kelley
G. S. Korin
A. S. Laurenson
C. Lizotte
M. J. Meyer
M. R. Minick
L. C. Oakes
R. F. Perrin
U. Potapovs
B. B. Scott

D. E. Tanner
D. V. Walshe

Subgroup on Materials, Fabrication, and Examination (SC III)

C. L. Hoffmann, *Chair*
G. P. Milley, *Secretary*
C. W. Allison
D. Doyle
F. R. Drahos
G. M. Foster
G. B. Georgiev
J. E. Harris
R. W. Jackson
R. M. Jessee
C. C. Kim
R. A. Moen
C. J. Pieper
R. R. Seeley
N. M. Simpson
R. C. Soin
W. J. Sperko
K. B. Stuckey
S. Yukawa

Subgroup on Pressure Relief (SC III)

F. C. Cherny, *Chair*
S. F. Harrison, Jr.
E. M. Petrosky
M. W. Smith
A. L. Szeglin
B. S. York
J. R. Zahorsky

Special Working Group on Editing and Review (SC III)

R. F. Reedy, *Chair*
W. H. Borter
M. N. Bressler
R. P. Deubler
B. A. Erler
W. C. LaRochelle
M. W. Smith
J. D. Stevenson
E. O. Woolridge

JOINT ACI-ASME COMMITTEE ON CONCRETE COMPONENTS FOR NUCLEAR SERVICE (SC 3C)

B. A. Erler, *Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
R. M. Attar

A. C. Eberhardt
J. Gutierrez
D. J. Haavik
M. F. Hessheimer
T. E. Johnson
G. R. Murphy
S. F. Putman
B. B. Scott
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Design (SC 3C)

D. G. Adams
A. C. Eberhardt
T. E. Johnson
S. F. Putman
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Materials, Construction, and Examination (SC 3C)

D. J. Haavik, *Chair*
J. F. Artuso
R. M. Attar
B. A. Erler
J. Gutierrez

SUBCOMMITTEE ON HEATING BOILERS (SC IV)

F. P. Barton, *Chair*
P. A. Molvie, *Vice Chair*
B. P. Feder, *Secretary*
R. B. Duggan
W. L. Haag, Jr.
W. M. Hiddleston
J. D. Hoh
K. M. McTague
R. I. Mullican
E. A. Nordstrom
J. L. Seigle
D. E. Tanner
S. V. Voorhees
R. H. Weigel
R. V. Wielgoszinski
J. I. Woodworth
T. L. Bedeaux, *Alternate*

Subgroup on Care and Operation of Heating Boilers (SC IV)

J. I. Woodworth, *Chair*

B. P. Feder, *Secretary*
K. J. Hoey
J. D. Hoh
F. M. Lucas
K. M. McTague
P. A. Molvie
R. I. Mullican
R. H. Weigel
T. F. Wickham
T. L. Bedeaux, *Alternate*

Subgroup on Cast Iron Boilers (SC IV)

K. M. McTague, *Chair*
R. B. Duggan
R. H. Weigel
T. F. Wickham
J. I. Woodworth
T. L. Bedeaux, *Alternate*

Subgroup on Water Heaters (SC IV)

W. L. Haag, Jr., *Chair*
T. D. Gantt
W. M. Hiddleston
F. M. Lucas
K. M. McTague
R. I. Mullican
D. Smith
D. E. Tanner
M. A. Taylor

Subgroup on Welded Boilers (SC IV)

P. A. Molvie, *Chair*
T. L. Bedeaux
D. H. Mapes
E. A. Nordstrom
J. L. Seigle
R. F. Slack, Sr.
R. P. Sullivan
D. E. Tanner
R. V. Wielgoszinski

SUBCOMMITTEE ON NONDESTRUCTIVE EXAMINATION (SC V)

T. G. McCarty, *Chair*
J. E. Batey, *Vice Chair*
F. S. Fitzgerald, *Secretary*
A. S. Birks
B. H. Clark, Jr.
W. T. Clayton
R. A. Coomes

N. Y. Faransso
H. C. Graber
O. F. Hedden
G. W. Hembree
F. B. Kovacs
J. F. Manning
W. C. McGaughey
R. D. McGuire

Page xvii

Subgroup on General Requirements/Personnel Qualifications and Inquiries (SC V)

R D. McGuire, *Chair*
J. E. Batey
W. T. Clayton
N. Y. Faransso
H. C. Graber
G. W. Hembree
J. R. MacKay
J. P. Swezy

Subgroup on Surface Examination Methods (SC V)

H. C. Graber, *Chair*
S. J. Akrin
T. Alexander
A. S. Birks
B. H. Clark
R. A. Coomes
G. W. Hembree

Subgroup on Volumetric Methods (SC V)

J. E. Batey, *Chair*
S. J. Akrin
W. T. Clayton
N. Y. Faransso
H. C. Graber
G. W. Hembree
B. Kellerhall
E. K. Kietzman
F. B. Kovacs
R. W. Kruzic
J. F. Manning
W. C. McGaughey
J. R. Mitchell

Working Group on Acoustic Emissions (SG-VM) (SC V)

B. H. Clark, Jr.
P. M. Horrigan
J. F. Manning
J. R. Mitchell

Working Group on Radiography (SG-VM) (SC V)

G. W. Hembree, *Chair*

S. J. Akrin

T. Alexander

J. E. Batey

N. Y. Faransso

H. C. Graber

F. B. Kovacs

Working Group on Ultrasonics (SG-VM) (SC V)

W. T. Clayton, *Chair*

O. F. Hedden

B. Kellerhall

E. K. Kietzman

J. F. Manning

W. C. McGaughey

R. Paillaman

F. J. Sattler

M. L. Shakinovsky

SUBCOMMITTEE ON PRESSURE VESSELS (SC VIII)

T. P. Pastor, *Chair*

K. Mokhtarian, *Vice Chair*

A. J. Roby, *Secretary*

A. P. Ahrendt

V. Bogosian

S. M. Caldwell

W. J. Carter

S. C. Cyr

R. Dirscherl

R. M. Elliott

J. R. Farr

R. E. Feigel

J. G. Feldstein

G. L. Hollinger

M. J. Houle

W. S. Jacobs

G. G. Karcher

G. B. Komora

K. T. Lau

R. W. Mikitka

U. R. Miller

C. C. Neely

K. J. Schneider

A. Selz

J. R. Sims, Jr.

A. J. Spencer

E. A. Steen
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Design (SC VIII)

U. R. Miller, *Chair*
R. E. Knoblock, *Secretary*
M. R. Bauman
M. R. Breach
S. M. Caldwell
N. W. Edwards
J. R. Farr
J. A. Hayward
G. L. Hollinger
W. S. Jacobs
G. G. Karcher
G. B. Komora
R. W. Mikitka
K. Mokhtarian
T. P. Pastor
M. D. Rana
A. Selz
S. C. Shah
J. W. Stokes
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Fabrication and Inspection (SC VIII)

E. A. Steen, *Chair*
K. Mokhtarian, *Vice Chair*
W. J. Bees
R. W. Boyce
S. C. Cyr
R. E. Feigel
H. E. Gordon
M. J. Houle
W. S. Jacobs
R. A. Johnson
A. S. Lester III
F. C. Ouyang
M. J. Rice
W. P. Webb

Subgroup on General Requirements (SC VIII)

R. M. Elliott, *Chair*
A. P. Ahrendt
V. Bogosian
W. J. Carter

W. P. Crow
J. P. Glaspie
C. R. Good
D. B. Kadakia
J. C. Keenan
W. E. Laveck, Jr.
A. S. Mann
C. C. Neely
A. S. Olivares
K. J. Schneider
A. J. Spencer

Subgroup on Materials (SC VIII)

R. Dirscherl, *Chair*
D. C. Agarwal
A. P. Ahrendt
J. Cameron
W. D. Doty
W. D. Edsall
M. Katcher
W. M. Lundy
E. E. Morgenegg
E. G. Nisbett
J. T. Parsons
D. W. Rahoi
K. K. Tam
B. K. Thakur

Special Working Group on Heat Transfer Equipment (SC VIII)

G. B. Komora, *Chair*
R. P. Zoldak, *Secretary*
C. F. Andreone
D. E. Bolt
S. M. Caldwell
T. K. Haldas
M. J. Holtz
W. G. Jandrasits
R. Mahadeen
U. R. Miller
F. Osweiller
J. E. Soehrens
A. I. Soler
W. A. Treff
S. Yokell

Special Working Group on High-Pressure Vessels (SC VIII)

J. R. Sims, Jr., *Chair*

P. A. Reddington, *Secretary*

L. P. Antalffy

J. E. Baxter

R. C. Biel

T. B. Boyd

D. J. Burns

P. N. Chaku

E. L. Danfelt

R. E. Feigel

D. M. Fryer

J. L. Heck, Jr.

A. H. Honza

V. T. Hwang

M. M. James

P. Jansson

J. A. Kapp

D. P. Kendall

A. K. Khare

S. C. Mordre

G. J. Mraz

E. H. Perez

L. M. Picqueur

E. D. Roll

W. L. Stewart

J. F. Sullivan

F. W. Tatar

Special Working Group on Toughness (SC VIII)

W. S. Jacobs, *Chair*

J. Cameron

W. D. Doty

D. A. Hansen

G. G. Karcher

G. B. Komora

K. Mokhtarian

J. L. Mooney

C. C. Neely

M. D. Rana

J. W. Stokes

SUBCOMMITTEE ON WELDING (SC IX)

J. G. Feldstein, *Chair*

W. J. Sperko, *Vice Chair*

J. Labrador, *Secretary*

R. Barkdoll

D. A. Bowers

M. L. Carpenter

W. D. Doty

P. D. Flenner
M. J. Houle
R. A. Johnson
W. M. Lundy
R. D. McGuire
J. J. Meyer
A. H. Miller
B. R. Newmark
P. P. Norris
S. D. Reynolds, Jr.
W. K. Scattergood
G. W. Spohn III
M. J. Stanko
J. M. Tanzosh
R. R. Young

Subgroup on Brazing (SC IX)

M. J. Houle, *Chair*
A. S. Artayet
M. L. Carpenter
C. F. Jeerings
A. H. Miller
C. Robino

Subgroup on General Requirements (SC IX)

B. R. Newmark, *Chair*
R. Barkdoll
P. R. Evans
P. C. Filean
R. M. Jessee
D. W. Mann
A. S. Olivares
C. E. Wainwright
R. A. Weiss
K. R. Willens

Subgroup on Materials (SC IX)

M. L. Carpenter, *Chair*
L. P. Connor
P. D. Flenner
R. M. Jessee
A. H. Miller
H. A. Sadler
C. E. Sainz
C. E. Spaeder, Jr.
W. J. Sperko
M. J. Stanko
R. R. Young

Subgroup on Performance Qualification (SC IX)

J. J. Meyer, *Chair*
V. A. Bell
D. A. Bowers
L. P. Connor
R. A. Coomes
P. D. Flenner
G. Herrmann
M. J. Houle
W. M. Lundy
R. D. McGuire
S. R. Nordman
P. P. Norris
W. K. Scattergood
G. W. Spohn III

Subgroup on Procedure Qualification (SC IX)

J. J. Meyer, *Chair*
R. K. Brown, Jr.
R. A. Johnson
A. H. Miller
P. P. Norris
A. S. Olivares
F. C. Ouyang
S. D. Reynolds, Jr.
M. J. Rice
W. K. Scattergood
W. J. Sperko
T. C. Wiesner

SUBCOMMITTEE ON FIBER-REINFORCED PLASTIC PRESSURE VESSELS (SC X)

P. J. Conlisk, *Chair*
D. Eisberg, *Vice Chair*
A. J. Roby, *Secretary*
K. M. Agrawal
F. L. Brown
J. L. Bustillos
T. W. Cowley
T. J. Fowler
S. V. Hoa
L. E. Hunt
J. C. Murphy
A. L. Newberry
D. J. Painter
J. A. Rolston
B. F. Shelley
P. R. Wilt

SUBCOMMITTEE ON NUCLEAR INSERVICE INSPECTION (SC XI)

O. F. Hedden, *Chair*
T. J. Mawson, *Vice Chair*
G. L. Fechter, *Secretary*
C. W. Allison
W. H. Bamford, Jr.
R. L. Beverly
J. M. Bloom
R. W. Boyce
C. D. Cowfer
D. D. Davis
R. L. Dyle
T. N. Epps III
R. E. Gimple
F. E. Gregor
L. B. Gross
K. Iida
C. A. Ireland
R. D. Kerr
D. F. Landers
T. F. Lentz
J. T. Lindberg
G. C. Millman
C. R. Osman
P. C. Riccardella
L. Sage
F. J. Schaaf, Jr.
J. E. Staffiera
R. P. Sullivan
R. W. Swayne
R. J. Tamminga
J. C. Tobin
R. A. Yonekawa

Honorary Members (SC XI)

S. H. Bush
L. J. Chockie
J. P. Houstrup
L. R. Katz
R. R. MacCary

Page xix

Subgroup on Evaluation Standards (SC XI)

W. H. Bamford, Jr., *Chair*
M. Kupinski, *Secretary*
J. M. Bloom
R. C. Cipolla
R. M. Gamble

T. J. Griesbach
P. J. Hijeck
K. Iida
Y. Imamura
J. G. Merkle
S. Ranganath
P. C. Riccardella
D. A. Scarth
W. L. Server
C. A. Tomes
W. A. Van Der Sluys
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa

Working Group on Flaw Evaluation (SG-ES) (SC XI)

R. C. Cipolla, *Chair*
W. H. Bamford, Jr.
M. Basol
J. M. Bloom
E. Friedman
T. J. Griesbach
F. D. Hayes
D. N. Hopkins
K. Iida
Y. Imamura
M. Kupinski
H. S. Mehta
J. G. Merkle
J. S. Panesar
R. K. Qashu
S. Ranganath
D. A. Scarth
T. S. Schurman
W. L. Server
F. A. Simonen
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Working Group on Operating Plant Criteria (SG-ES) (SC XI)

T. J. Griesbach, *Chair*
W. H. Bamford, Jr.

H. Behnke
B. A. Bishop
W. F. Brady
E. Friedman
S. R. Gosselin
E. M. Hackett
P. J. Hijeck
S. D. Leshnoff
P. Manbeck
J. S. Panesar
W. E. Pennell
J. H. Phillips
S. Ranganath
S. T. Rosinski
W. L. Server
E. A. Siegel
F. A. Simonen
T. D. Spry
K. K. Yoon
S. Yukawa

Working Group on Pipe Flaw Evaluation (SG-ES) (SC XI)

D. A. Scarth, *Chair*
G. M. Wilkowski, *Secretary*
W. H. Bamford, Jr.
J. M. Bloom
R. C. Cipolla
N. G. Cofie
S. K. Daftuar
G. H. De Boo
E. Friedman
D. N. Hopkins
K. Iida
H. S. Mehta
J. G. Merkle
J. S. Panesar
D. Quinones
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Subgroup on Liquid-Metal-Cooled Systems (SC XI)

C. G. McCargar, *Chair*
W. L. Chase
S. Hattori
R. Hundal
W. Kwant

J. C. Tobin

Working Group on Liquid-Metal Reactor Covers (SG-LMCS) (SC XI)

W. L. Chase, *Chair*

S. Hattori

R. Hundal

W. Kwant

Subgroup on Nondestructive Examination (SC XI)

R. L. Beverly, *Chair*

N. R. Bentley, *Secretary*

D. C. Adamonis

F. L. Becker

F. T. Carr

C. B. Cheezem

W. T. Clayton

C. D. Cowfer

F. J. Dodd

T. N. Epps III

D. O. Henry

M. R. Hum

S. N. Liu

R. D. McGuire

M. C. Modes

C. R. Osman

F. J. Schaaf, Jr.

J. C. Spanner, Jr.

C. J. Wirtz

Working Group on Personnel Qualification and Surface Visual and Eddy Current Examination (SG-NDE) (SC XI)

C. J. Wirtz, *Secretary*

B. L. Curtis

N. Economos

H. B. Garland

D. O. Henry

H. E. Houserman

J. J. McArdle III

R. D. McGuire

S. A. Redner

M. F. Sherwin

A. L. Smith

D. Spake

J. C. Spanner, Sr.

J. C. Spanner, Jr.

T. V. Tran

Working Group on Pressure Testing (SG-NDE) (SC XI)

G. P. Alexander

T. M. Anselmi

T. B. Basso
J. Boughman
T. R. Bugelholl
R. J. Cimoch
C. E. Jensen
W. N. Keisler
D. Lamond
F. J. Schaaf, Jr.
D. Terao

Working Group on Procedure Qualification and Volumetric Examination (SG-NDE) (SC XI)

C. D. Cowfer, *Chair*
C. E. Larsen, *Secretary*
D. C. Adamonis
F. L. Becker
N. R. Bentley
B. Bevins
F. T. Carr
C. B. Cheezem
W. T. Clayton
S. R. Doctor
F. J. Dodd
T. N. Epps III
B. Kellerhall
G. A. Lofthus
J. K. McClanahan
M. C. Modes
M. Saporito
T. T. Taylor
S. M. Walker

Subgroup on Repairs, Replacements, and Modifications (SC XI)

R. E. Gimple, *Chair*
W. C. Holston, *Secretary*
R. W. Boyce
M. N. Bressler
S. B. Brown
C. E. Hartz
R. A. Hermann
C. A. Ireland
R. D. Kerr
D. F. Landers
R. S. Lewis
T. J. Mawson
M. S. McDonald
R. R. Stevenson
R. P. Sullivan

R. W. Swayne
R. E. Tome
D. E. Waskey
R. A. Yonekawa

Page xx

Working Group on Design Reconciliation (SG-RR&M) (SC XI)

W. C. Holston, *Chair*
J. T. Conner, *Secretary*
R. W. Boyce
S. B. Brown
J. E. Charnley
T. E. Hiss
E. V. Imbro
D. N. Irvine, Jr.
D. F. Landers
R. W. Swayne
F. Tehranchi
H. J. Thailer
R. E. Tome

Working Group on Responsibilities and Program Requirements (SG-RR&M) (SC XI)

R. A. Yonekawa, *Chair*
R. R. Stevenson, *Secretary*
S. K. Fisher
G. M. Foster
C. E. Hartz
R. S. Lewis
M. S. McDonald
U. Potapovs
S. M. Swilley
A. J. Walcutt
J. Ghergurovich, *Alternate*

Working Group on Welding and Special Repair Processes (SG-RR&M) (SC XI)

D. E. Waskey, *Chair*
R. E. Cantrell, *Secretary*
D. A. Delsignore
A. L. Finney
P. D. Fisher
A. J. Giannuzzi
R. A. Hermann
R. P. Indap
R. D. Kerr
B. R. Newton
P. P. Norris
J. E. O'Sullivan
J. H. Sodergren

K. R. Willens

Subgroup on Water-Cooled Systems (SC XI)

T. F. Lentz, *Chair*

K. Christian, *Secretary*

C. W. Allison

W. J. Briggs

T. R. Bugelholl

D. D. Davis

A. F. Deardorff

R. L. Dyle

L. B. Gross

T. C. Hinkle

S. D. Kulat

M. P. Lintz

J. E. Staffiera

C. W. Tahnk

R. J. Tamminga

D. Terao

S. M. Walker

R. A. West

Working Group on Concrete Containment (SG-WCS) (SC XI)

W. J. Briggs, *Chair*

B. Talmadge, *Secretary*

H. G. Ashar

K. K. N. Chao

M. J. Ferlisi

H. T. Hill

R. D. Hough

C. N. Krishnaswamy

D. Naus

S. C. Petitgout

C. G. Ranganath

Working Group on Implementation of Risk-Based Examination (SG-WCS) (SC XI)

T. J. Mawson, *Chair*

A. McNeill III, *Secretary*

J. Agold

S. A. Ali

B. A. Bishop

J. W. Connor

A. F. Deardorff

H. Q. Do

R. Fougrousse

S. R. Gosselin

J. T. Lindberg

I. Mach

R. K. Mattu

P. J. O'Regan
J. H. Phillips
F. A. Simonen
T. V. Vo
R. A. West

Working Group on Inspection of Systems and Components (SG-WCS) (SC XI)

R. L. Dyle, *Chair*
G. C. Park, *Secretary*
G. L. Belew
T. W. Brombach
R. Fougereousse
T. C. Hinkle
M. R. Hum
S. D. Kulat
J. T. Lindberg
M. P. Lintz
T. K. McLellan
C. Pendleton
C. M. Ross
C. W. Tahnk
K. B. Thomas
E. Throckmorton
R. A. West
J. Whitman

Working Group on Metal Containment (SG-WCS) (SC XI)

J. E. Staffiera, *Chair*
W. E. Norris, *Secretary*
W. J. Briggs
K. K. N. Chao
M. J. Ferlisi
R. W. Hammelmann
M. P. Lintz
S. C. Petitgout
C. G. Ranganath
G. W. Robin
R. T. Zak

Special Working Group on Low-Temperature Heavy Water Reactors (SG-WCS) (SC XI)

C. D. Cowfer, *Chair*
J. M. Morrison, *Secretary*
B. Awadalla
K. F. Schmidt
P. R. Vormelker
S. H. Zaidi

Working Group on General Requirements (SC XI)

A. T. Roberts III, *Chair*
R. G. Edl, *Secretary*
D. A. Graham
L. B. Gross
C. A. Ireland
D. A. Jackson
R. K. Mattu
L. Sage
R. J. Scott
J. C. Shropshire
R. J. Tamminga

Special Working Group on Editing and Review (SC XI)

R. W. Swayne, *Chair*
R. L. Beverly
L. B. Gross
M. P. Lintz
J. E. Staffiera
C. J. Wirtz

Special Working Group on Plant Life Extension (SC XI)

F. E. Gregor, *Chair*
L. B. Gross, *Secretary*
D. D. Davis
D. A. Graham
D. L. Harrison
M. P. Lintz
P. Manbeck
H. W. Massie, Jr.
D. W. Peltola
D. A. Piccione
C. M. Regan
V. N. Shah
R. J. Tamminga

SUBCOMMITTEE ON TRANSPORT TANKS (SC XII)

A. Selz, *Chair*
P. D. Stumpf, *Secretary*
A. N. Antoniou
S. C. Cyr
K. Ennis
M. Hennemand
C. H. Hochman
G. G. Karcher
P. P. Laluc
G. McRae
M. R. Minick
T. P. Pastor
M. D. Rana

C. M. Serratella
G. R. Stoeckinger
N. Surtees
J. P. Swezy
A. P. Varghese
S. V. Voorhees
W. L. White

Page xxi

Subgroup on Design and Materials (SC XII)

M. D. Rana, *Chair*
D. A. Canonico
W. D. Doty
G. G. Karcher
P. P. Laluc
T. P. Pastor
T. A. Rogers
C. M. Serratella
A. P. Varghese
E. Whittle

Subgroup on Fabrication and Inspection (SC XII)

S. V. Voorhees, *Chair*
D. A. Canonico
M. L. Coats
M. Hennemand
D. J. Kreft
G. McRae
M. R. Minick
N. Surtees
J. P. Swezy

Subgroup on General Requirements (SC XII)

C. H. Hochman, *Chair*
T. Alexander
A. N. Antoniou
D. Carter
K. Ennis
M. A. Garrett
J. C. Keenan
F. A. Licari
G. R. Stoeckinger
W. L. White

SUBCOMMITTEE ON BOILER AND PRESSURE VESSEL ACCREDITATION (SC-BPVA)

A. J. Spencer, *Chair*
A. J. Justin, *Vice Chair*
K. I. Baron, *Secretary*
M. B. Doherty

M. B. Doherty
D. A. Douin
P. D. Edwards
R. M. Elliott
C. E. Ford
J. J. Greene
R. C. Howard
B. B. MacDonald
M. L. Sisk
B. C. Turczynski
R. V. Wielgoszinski
R. L. Williams
V. A. Bell, Alternate
V. Bogosian, Alternate
M. A. De Vries, Alternate
J. R. Farr, Alternate
R. G. Friend, Alternate
W. C. LaRochelle, Alternate
A. S. Lester III, Alternate
K. M. McTague, Alternate
G. P. Milley, Alternate
R. E. Muise, Alternate
P. G. Scheckermann, Alternate
N. Surtees, Alternate

SUBCOMMITTEE ON NUCLEAR ACCREDITATION (SC-NA)

T. E. Quaka, *Chair*
R. R. Stevenson, *Vice Chair*
S. Griffin, *Secretary*
C. W. Allison
M. N. Bressler
G. Deily
F. R. Drahos
J. E. Harris
M. Kotb
W. C. LaRochelle
U. Potapovs
H. B. Prasse
A. J. Spencer
G. M. Tolson
L. M. Beason, Alternate
R. W. Boyce, Alternate
S. Dasgupta, Alternate
P. D. Edwards, Alternate
J. P. Ellenberger, Alternate
R. E. Feigel, Alternate
D. Hanrath, Alternate

K. A. Huber, Alternate
A. J. Justin, Alternate
N. C. Kist, Alternate
A. A. Lotfi, Alternate
R. P. McIntyre, Alternate
O. E. Trapp, Staff Representative

SUBCOMMITTEE ON DESIGN (SC-D)

W. J. Carter, *Chair*
F. S. Fitzgerald, *Secretary*
R. W. Barnes
C. Becht IV
O. F. Hedden
R. W. Mikitka
K. Mokhtarian
W. J. O'Donnell
R. D. Schueler, Jr.
M. P. Schwartz
A. Selz

Subgroup on Design Analysis (SC-D)

T. P. Pastor, *Secretary*
P. J. Conlisk
A. G. Eggers
J. L. Hechmer
G. L. Hollinger
D. P. Jones
A. Kalnins
W. J. Koves
T. H. Liu
O. Maekawa
A. Merend
T. V. Narayanan
E. L. Thomas, Jr.

Subgroup on Elevated Temperature Design (SC-D)

C. Becht IV, *Chair*
J. M. Corum, *Secretary*
C. R. Brinkman
R. D. Campbell
D. S. Griffin
R. I. Jetter
C. Lawton
W. J. O'Donnell
D. A. Osage
C. C. Schultz, Jr.
L. K. Severud
D. F. Shaw
A. L. Snow

B. E. Thurgood

Subgroup on Fatigue Strength (SC-D)

C. R. Brinkman

P. R. Donavin

J. A. Hayward

J. L. Hechmer

D. P. Jones

G. Kharshafdjian

C. Lawton

A. Merend

H. H. Ziada

Subgroup on Openings (SC-D)

M. P. Schwartz, *Chair*

R. W. Mikitka, *Secretary*

M. R. Breach

V. T. Hwang

S. C. Lou

R. B. Luney

J. P. Madden

K. C. Morrison

D. R. Palmer

M. D. Rana

E. C. Rodabaugh

Special Working Group on Bolted Flanged Joints (SC-D)

R. W. Mikitka, *Chair*

G. D. Bibel

G. Kharshafdjian

D. L. Kurle

E. Michalopoulos

S. N. Pagay

J. R. Payne

R. W. Schneider

R. D. Schueler, Jr.

A. Selz

SUBCOMMITTEE ON SAFETY VALVE REQUIREMENTS (SC-SVR)

E. C. Kistner, Jr., *Chair*

M. D. Bernstein, *Vice Chair*

U. D'Urso, *Secretary*

J. F. Ball

J. A. Cox

R. D. Danzy

R. J. Doelling

D. A. Douin

R. G. Friend

H. I. Gregg

H. I. Gregg
S. F. Harrison, Jr.
C. F. Laitner
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson
D. J. Scallan
C. M. Schroepfer
A. J. Spencer
J. C. Standfast
E. A. Steen
L. L. Thompson
J. A. West
T. J. Ferrigan, Alternate

Page xxii

Subgroup on Design (SC-SVR)

R. G. Friend, *Chair*
J. Cahoon, Jr.
R. D. Danzy
D. B. DeMichael
R. J. Doelling
H. I. Gregg
S. R. Irvin
C. F. Laitner
P. R. Sievert
A. J. Spencer
E. A. Steen
T. R. Tarbay
J. A. West

Subgroup on General Requirements (SC-SVR)

M. D. Bernstein, *Chair*
J. F. Ball
V. M. Deluca
D. A. Douin
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson
J. C. Standfast
L. L. Thompson

Subgroup on Testing (SC-SVR)

S. F. Harrison, Jr., *Chair*
S. Cammeresi
J. A. Cox
W. F. Hart

ORGANIZATION OF SECTION III

1. GENERAL

Section III consists of Division 1, Division 2, and Division 3. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter "N" for Division 1, by the letter "C" for Division 2, and by the letter "W" for Division 3. The following eleven books make up the three Divisions.

Subsection NCA - General Requirements for Division 1 and Division 2

Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

Division 2 - Code for Concrete Reactor Vessels and Containments

Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

Division 2 book includes subsection CC - Concrete Containments and Division 2 Appendices.

Division 3 book includes Subsections WA and WB for General Requirements and Class TP (Type B) Containment, respectively.

2. SUBSECTIONS

Subsections are divided into Articles, Subarticles, paragraphs, and, where necessary, subparagraphs and subsubparagraphs.

3. ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections followed by Arabic numbers, such as NB-1000. Where possible, Articles dealing with the same topics are given the same number in each Subsection in accordance with the following general scheme:

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination

7000
8000

Testing
Overpressure Protection
Nameplates, Stamping, and Reports

The numbering of Articles and the material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the rules have been prepared with some gaps in the numbering.

4. SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

5. SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as NB-2130, and generally have no text. When a number such as NB-1110 is followed by text, it is considered a paragraph.

6. PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

7. SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as NB-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

8. SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

Page xxiv

9. REFERENCES

References used within Section III generally fall into one of the following four categories.

A. References to Other Portions of Section III

When a reference is made to another Article, Subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to NB-3000 includes all material in Article NB-3000; reference to NB-3200 includes all material in Subarticle NB-3200; reference to NB-3230 includes all paragraphs NB-3231 through NB-3236.

B. References to Other Sections

Other Sections referred to in Section III are:

Section II, Materials. When a requirement for a material, or for the examination or testing of a material, is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II. These references begin with the letter "S."

Section V, Nondestructive Examination. Section V references begin with the letter "T" and relate to the nondestructive examination of material or welds.

Section IX, Welding and Brazing Qualifications. Section IX references begin with the letter "Q" and relate to welding and brazing requirements.

Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components. When a reference is made to inservice inspection, the rules of Section XI shall apply.

C. Reference to Specifications and Standards Other Than Published in Code Sections

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials. At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E 71-64 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

2 The American National Standards Institute (ANSI) was formerly known as the American Standards Association. Standards approved by the Association were designated by the prefix "ASA" followed by the number of the standard and the year of publication. More recently, the American National Standards Institute was known as the United States of America Standards Institute. Standards were designated by the prefix "USAS" followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the numbers of the standards have remained unchanged.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by the American Society of Mechanical Engineers and approved by the American National Standards Institute.² When a product is to conform to such a standard, for example ANSI B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NB-3132-1, for example ANSI B16.5-1977. Standards published by the American Society of Mechanical Engineers are available from ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-6, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, 127 Park Street, N.E., Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NB-3132-1, for example MSS SP-6-1963.

(4) Specifications for welding and brazing materials are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33135. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix "SF," for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-620 and API-2000. When documents so designated are referred to in Section III, they are standards published by the American Petroleum Institute.

D. References to Appendices

Two types of Appendices are used in Section III and are designated Mandatory and Nonmandatory.

(1) Mandatory Appendices contain requirements which must be followed in construction; such references are designated by a Roman numeral followed by Arabic numerals. References to II-1100 or XI-3212, for example, relate to the Mandatory Appendices.

(2) Nonmandatory Appendices provide information or guidance for the use of Section III; such references are designated by a capital letter followed by Arabic numerals. A reference to D-1100, for example, relates to a Nonmandatory Appendix.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NF-1000

ARTICLE NF-1000 INTRODUCTION

Page 1

NF-1100 SCOPE AND GENERAL REQUIREMENTS

NF-1110 ASPECTS OF CONSTRUCTION COVERED BY THESE RULES

(a) Subsection NF contains rules for the material, design, fabrication, examination, installation, and preparation of reports for supports for components and piping which are intended to conform to the requirements for Class 1, 2, 3, and MC construction as set forth in Subsections NB, NC, ND, and NE, respectively, of this Section.

(b) They *do not* cover deterioration which may occur in service as a result of corrosion, erosion, radiation effects, or metallurgical instability of the materials (NCA-1130).

(c) Nuclear power plant supports for which the rules are specified in this Subsection are those metal elements which transmit loads between components (NCA-1210), including piping systems, and intervening elements and the building structure. However, the term *supports* does not encompass a structural element the sole function of which is to carry dynamic loads caused by a postulated loss of pressure retaining integrity.

(d) The Owner shall be responsible for assuring the adequacy of the building structure and all intervening elements in the support load path in accordance with the requirements of NCA-3240 and NCA-3250. To the extent necessary, the support designer shall consider the structural interaction with intervening elements and the building structure.

NF-1120 RULES FOR SUPPORTS AND THEIR CLASSIFICATION

NF-1121 Rules for Supports

The rules of Subsection NF provide requirements for new construction and include consideration of mechanical stresses and effects which result from the constraint of free-end displacements and anchor point motions defined in NF-3121.12 and NF-3121.13, but not thermal or peak stresses.

NF-1122 Classification of Supports

Supports shall be constructed to the requirements of this Subsection that are applicable to the class of the component, including piping system, they are intended to support. Supports may be optionally classified as permitted in NCA-2134. When the components are optionally classified to a higher class as permitted in NCA-2134(d), the support need not be classified to the higher class.

NF-1130 BOUNDARIES OF JURISDICTION

NF-1131 Boundary Between Components and Supports

The jurisdictional boundary between components, including piping systems, and supports shall meet the requirements of NB-1132, NC-1132, ND-1132, or NE-1132 as applicable to the class of component.

NF-1132 Boundary Between Supports and the Building Structure

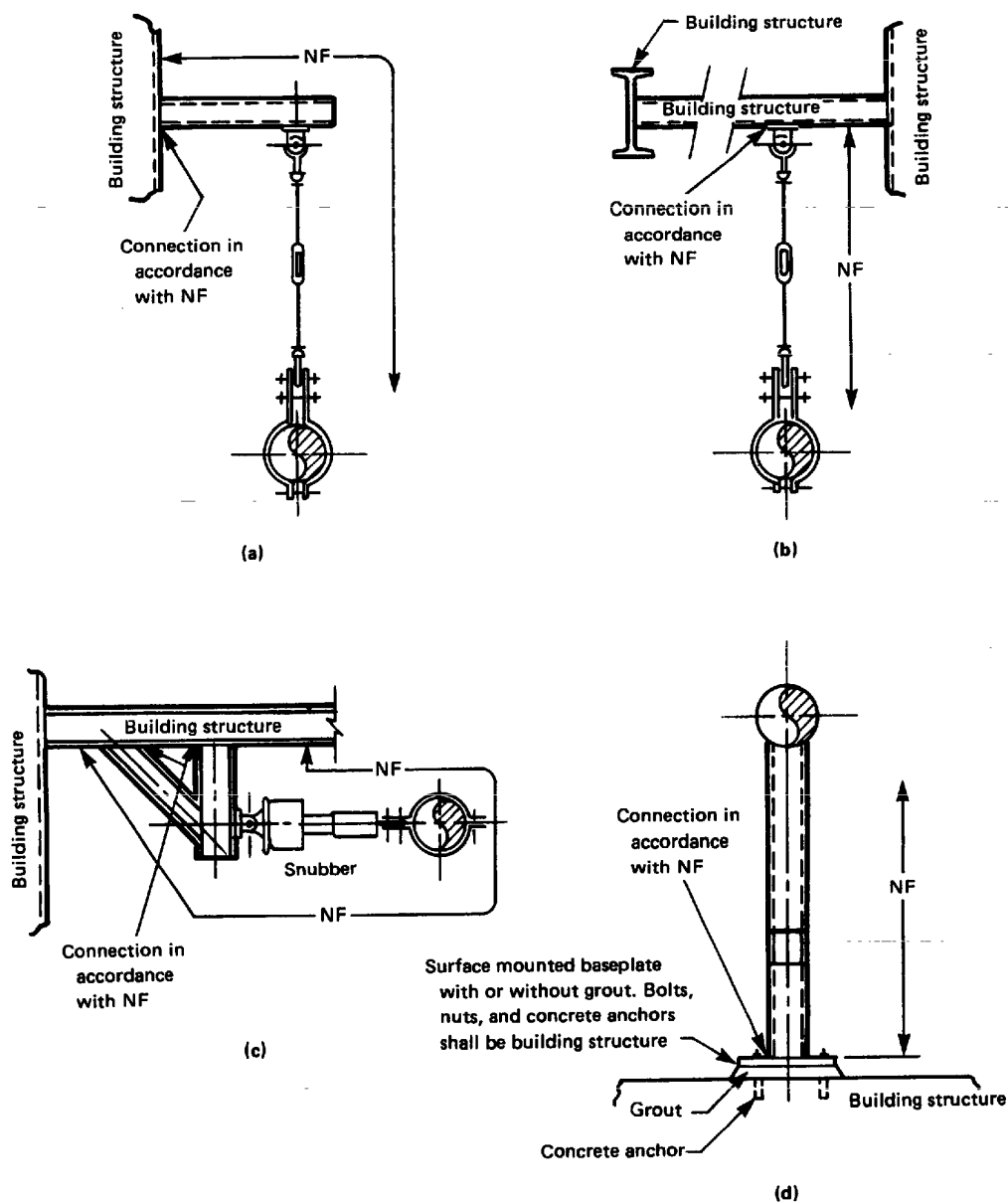
(a) Supports may bear on or may be welded, bolted, pinned, or clamped to the building structure. Typical examples of jurisdictional boundaries defined between supports and building structures are shown in Figs. NF-1132-1 and NF-1132-2.

(b) The jurisdictional boundary between a support and the load carrying building structure as is the surface of the building structure.

(c) For the purpose of defining the jurisdictional boundary between a support and the building structure, structural members shown on the civil/structural drawings of the plant and considered in the building structural analysis may be designated building structure even

Page 4

though located in the support load path. However, structural members, except as defined in (d) below, detailed on support drawings which are installed and used for the primary purpose of supporting piping or components shall be designated supports and be constructed to the rules of this Subsection. Pages 5-6

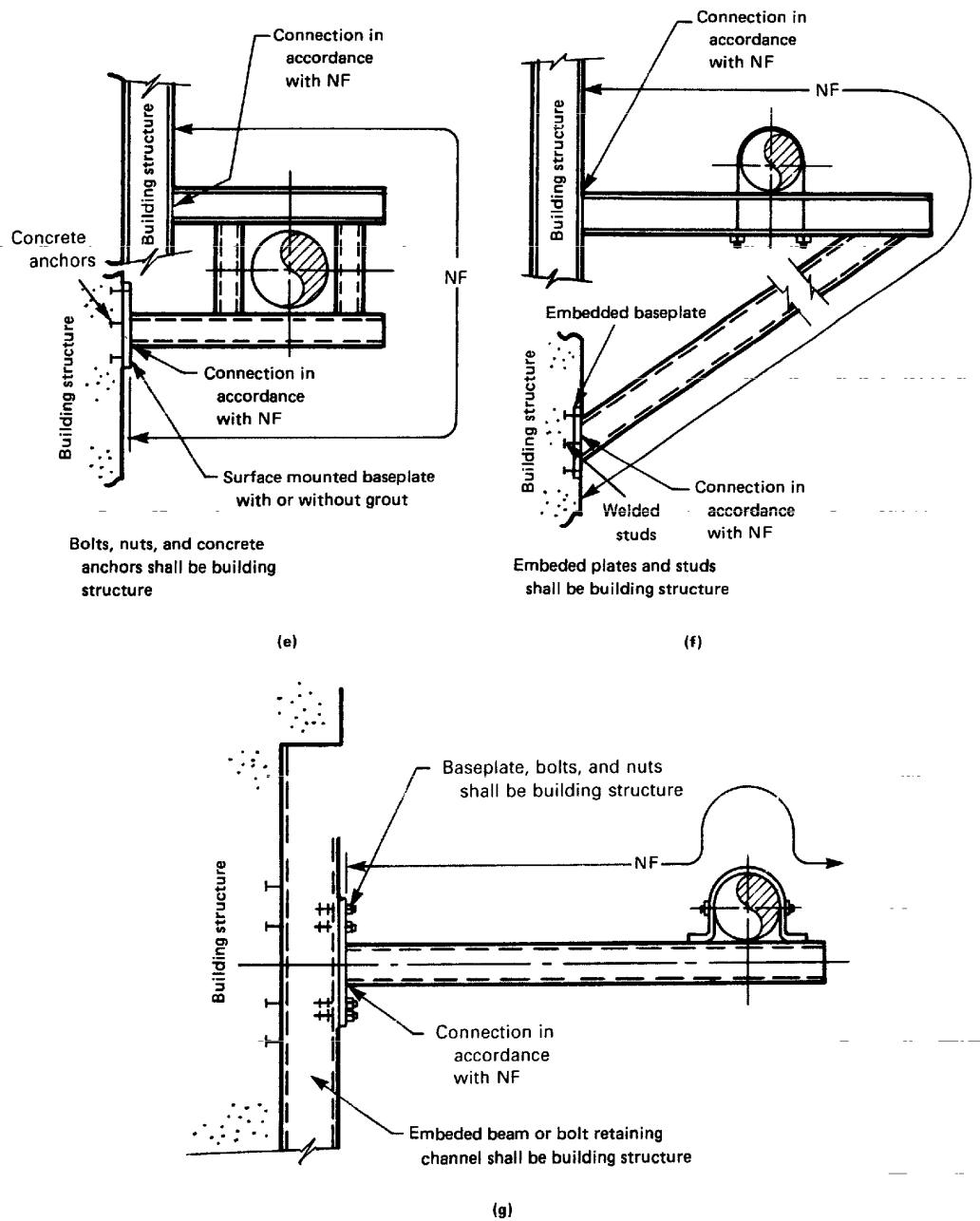


GENERAL NOTE:

These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

FIG. NF-1132-1 TYPICAL EXAMPLES OF JURISDICTIONAL BOUNDARIES BETWEEN PIPING SUPPORTS AND THE BUILDING STRUCTURE

FIG. NF-1132-1 TYPICAL EXAMPLES OF JURISDICTIONAL BOUNDARIES BETWEEN PIPING SUPPORTS

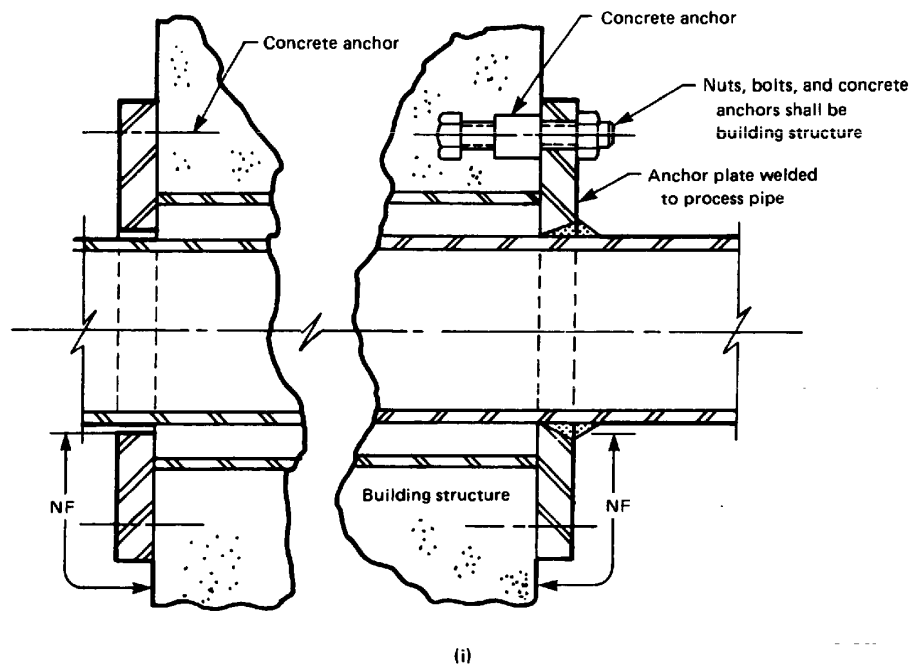
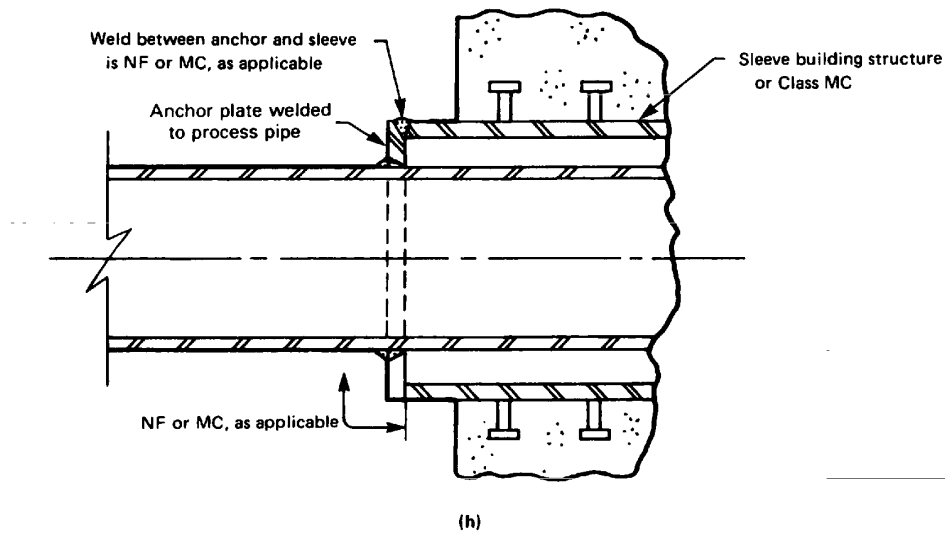


GENERAL NOTE:

These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

FIG. NF-1132-1 TYPICAL EXAMPLES OF JURISDICTIONAL BOUNDARIES BETWEEN PIPING SUPPORTS AND THE BUILDING STRUCTURE (CONT'D)

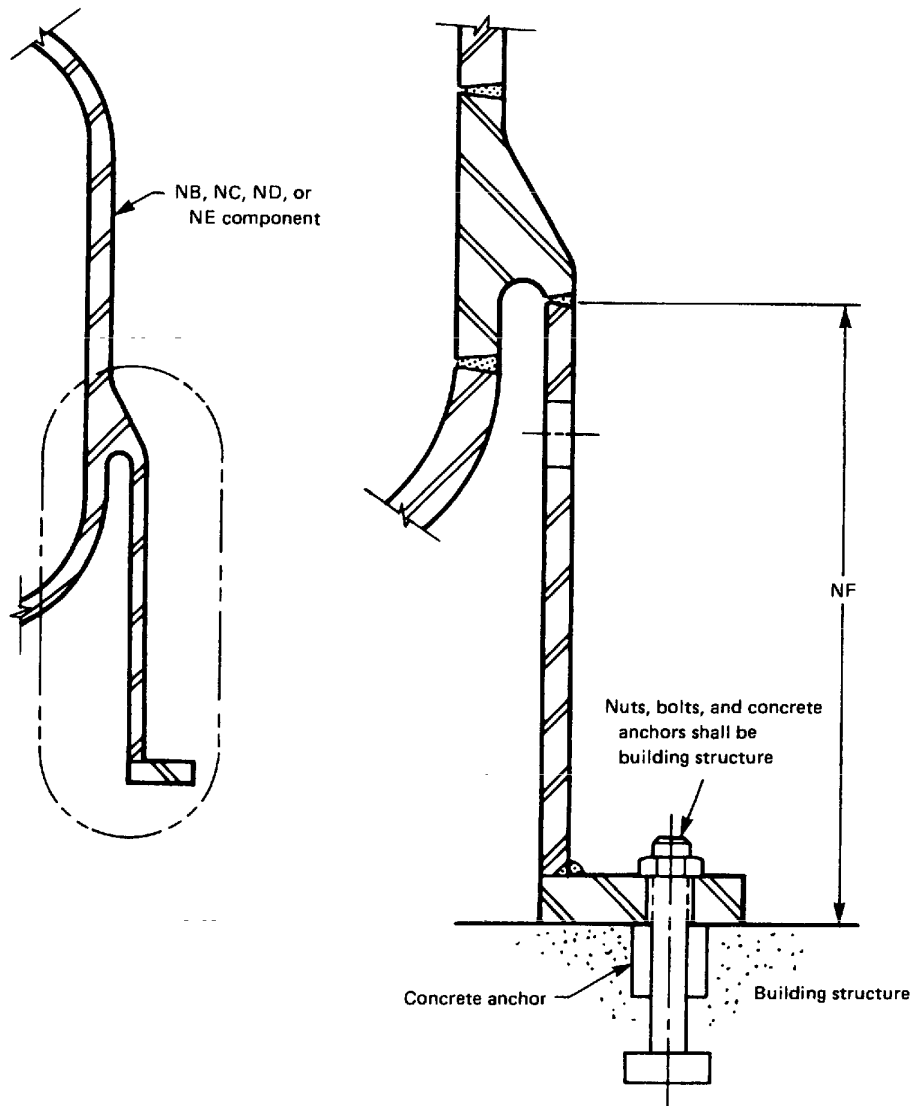
FIG. NF-1132-1 TYPICAL EXAMPLES OF JURISDICTIONAL BOUNDARIES BETWEEN PIPING SUPPORTS AND THE BUILDING STRUCTURE (CONT'D)



GENERAL NOTE:
These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

FIG. NF-1132-1 TYPICAL EXAMPLES OF JURISDICTIONAL BOUNDARIES BETWEEN PIPING SUPPORTS AND THE BUILDING STRUCTURE (CONT'D)

FIG. NF-1132-1 TYPICAL EXAMPLES OF JURISDICTIONAL BOUNDARIES BETWEEN PIPING SUPPORTS AND THE BUILDING STRUCTURE (CONT'D)



GENERAL NOTE:

This sketch is intended to show jurisdictional concepts and should not be considered as a recommended configuration.

FIG. NF-1132-2 TYPICAL EXAMPLE OF JURISDICTIONAL BOUNDARY BETWEEN COMPONENT SUPPORT AND THE BUILDING STRUCTURE

FIG. NF-1132-2 TYPICAL EXAMPLE OF JURISDICTIONAL BOUNDARY BETWEEN COMPONENT SUPPORT AND THE BUILDING STRUCTURE

(d) Surface mounted base plates, with or without grouting; fully or partially embedded steel elements intended to receive loads transmitted by supports; concrete anchors; and hold-down bolts, nuts, and washers shall be designated building structure.

(e) If the means by which the support is connected to the building structure is a weld, the weld shall fall within the jurisdiction of this Subsection.

NF-1133 Boundary Between Supports and Intervening Elements

The jurisdictional boundary between supports and intervening elements in the support load path is the surface of the intervening elements. Supports may bear on or may be welded, bolted, pinned, or clamped to intervening elements. The means by which supports are connected to intervening elements shall fall within the jurisdiction of this Subsection.

NF-1200 TYPES OF SUPPORTS AND ATTACHMENTS

NF-1210 TYPES OF SUPPORTS

NF-1211 General Requirements

In this Subsection all supports are categorized into three separate types based on the general design procedure used for analysis of the support (NF-3140). Requirements for materials, design, fabrication, and examination for each of the three types are provided in the following Articles of this Subsection. These support types are defined in the following paragraphs.

NF-1212 Plate- and Shell-Type Supports

A *Plate- and Shell-Type Support* is a support such as a skirt or saddle which is fabricated from plate and shell elements and is normally subjected to a biaxial stress field.

[98]

NF-1213 Linear-Type Support

A *Linear-Type Support* is defined as acting under essentially a single component of direct stress. Such elements may also be subjected to shear stresses. Examples of such structural elements are tension and compression struts, beams and columns subjected to bending, trusses, frames, rings, arches, and cables. Energy absorbing parts designed to dissipate energy by yielding and which are incorporated into a linear-type piping support shall be constructed in accordance with Appendix NF-III.

[98]

NF-1214 Standard Supports

Typical *Standard Supports* are described in MSS SP-58, Pipe Hangers and Supports, Materials, Design, and Manufacture, which was developed and approved by the Manufacturers Standardization Society of the Valve and Fittings Industry. Typical catalog items are shown in Fig. NF-1214-1. Such units not requiring fabrication by welding shall be considered as material, and may be manufactured and supplied by a Quality System Certificate holder whose scope includes Standard Supports and Catalog items supplied as material including Certification of Load Capacity Data sheets and Design Report summaries. The capacities of standard supports may be determined using plate and shell analysis or linear (working stress) analysis or load rating. Examples of standard supports are:

- (a) rigid supports consisting of anchors, guides, restraints, rolling or sliding supports, and rod-type hangers;
- (b) constant- and variable-type spring hangers;
- (c) snubbers;
- (d) sway braces and vibration dampeners;
- (e) structural attachments such as ears, shoes, lugs, rings, clamps, slings, straps, and clevises.

NF-1215 Primary and Secondary Members

Support members are also categorized as primary or secondary according to function. These member types are defined in the following paragraphs.

(a) *Primary Members.* Primary members of supports are defined as those members designed to carry loads under any postulated load condition.

(b) *Secondary Members.* Secondary members are defined as those members typically used as bracing to maintain primary member system geometry, and which under all loading conditions, are not designed to sustain any significant stress. Significant stress is defined as being in excess of 50% of the allowable stress permitted in the tables of Section II, Part D, Subparts 1 and 2, NF-3300, and applicable Code Cases.

Page 9

Page 10

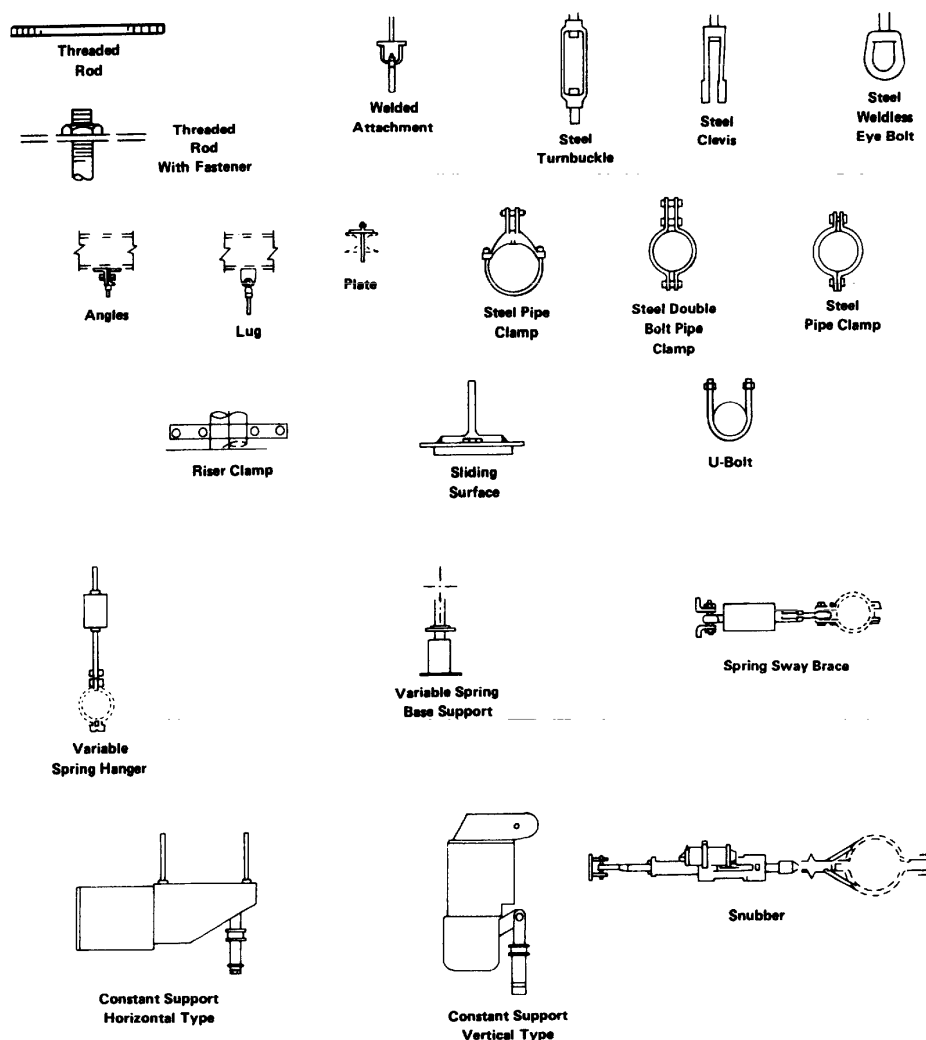


FIG. NF-1214-1 TYPICAL STANDARD SUPPORT UNITS

NF-1230 WELDING BETWEEN TYPES OF SUPPORTS

NF-1231 Welded Joints Between Plate- and Shell-Type, and Linear-Type Supports

Welded joints between Plate- and Shell-Type Supports (NF-1212), and Linear-Type Supports (NF-1213) shall meet the rules of either Plate- and Shell-Type, or Linear-Type welded joints of this Subsection.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NF-2000

ARTICLE NF-2000 MATERIAL

Page 11

NF-2100 GENERAL REQUIREMENTS FOR MATERIAL

[98]

NF-2110 SCOPE OF PRINCIPAL TERMS EMPLOYED

(a) The term *material* as used in this Subsection is defined in NCA-9000. The term *Material Organization* (Metallic) is defined in NCA-9000.

(b) The requirements of this Article make reference to the term *thickness*. For the purpose intended, the following definitions of nominal thickness apply:

(1) *plate* - the thickness is the dimension of the short transverse direction

(2) *forgings* - the thickness is the dimension defined as follows:

(a) *hollow forgings* - the nominal thickness is measured between the inside and outside surfaces (radial thickness)

(b) *disk forgings* (axial length less than the outside diameter) - the nominal thickness is the axial length

(c) *flat ring forgings* (axial length less than the radial thickness) - for axial length ≤ 2 in. (51 mm), the axial length is the nominal thickness. For axial length > 2 in. (51 mm), the radial thickness is the nominal thickness

(d) *rectangular solid forgings* - the least rectangular dimension is the nominal thickness

(3) *castings* - thickness, t , is defined as the largest nominal thickness of the load carrying portion of the casting.

[98]

NF-2120 SUPPORT MATERIAL

NF-2121 Permitted Material Specifications

(a) Except as provided in (b) below, material for supports shall conform to the requirements of the specifications for material listed in the tables of Section II, Part D applicable to the Class of construction, as indicated in Table NF-2121(a)-1.

(b) The requirements of this Article do not apply to items such as gaskets, seals, bushings, wire rope used as a spring, springs, compression spring end plates, bearings, retaining rings, washers, wear shoes, shims, slide plates, hydraulic fluids, etc., or to material used for stops¹ for seismic and other dynamic loads that are designed primarily for compressive loading and are not connected to the support or the pressure boundary. Requirements, if any, for these materials shall be stated in the Design Specifications (NCA-3250). Such items shall be made of material that is not injuriously affected by the fluid, temperature, irradiation, or impact loading conditions to which the item will be subjected. The support manufacturer shall

provide the Owner with a list of such materials. These materials do not require Material Organizations' Certificates of Compliance (NF-2130).

(c) Welding and brazing material used in manufacture of items shall comply with an SFA Specification in Section II, Part C, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article. The requirements of this Article do not apply to materials used as backing rings or backing strips in welded joints.

1 Stops do not include snubbers [NF-1130(e)].

NF-2122 Special Requirements Conflicting With Permitted Material Specifications

(a) Special requirements stipulated in this Article shall apply in lieu of the requirements of the material specifications wherever the special requirements conflict with the material specification requirements [NCA-3856.3(d)]. Where the special requirements include an examination, test, or treatment which is also required by the material specification, the examination, test, or treatment need be performed only once. Required nondestructive examinations shall be performed as specified

Page 16

for each product form in NF-2500. Any examination, repair, test, or treatment required by the material specification or by this Article may be performed by the Material Organization or the Certificate Holder, as provided in NF-4121.1. Pipe or tube material used under the rules of this Subsection need not be hydrostatically or pneumatically tested, provided these materials are not used in a pressure retaining function.

TABLE NF-2121(a)-1
MATERIAL TABLES REQUIRED FOR SUPPORTS^{1,2}

Type and Class	Design Stress Intensity Values S_m	Allowable Stress Values S	Yield Strength Values S_y	Tensile Strength Values S_u
Plate and shell				
Class 1	☒	☒	☒	☒
Class 2 and MC			☒	☒
Class 3		☒	☒	☒
Bolting (all classes)				☒
Linear				
Class 1			☒	☒
Class 2 and MC			☒	☒
Class 3			☒	☒
Bolting (all classes)				☒
Standard support				
Class 1	☒	☒	☒	☒
Class 2 and MC		☒	☒	☒
Class 3		☒	☒	☒
Bolting (all classes)				☒
Applicable Tables	Table 2A C1.1	Table 1A C1.2, C1.3, and MC	Table 4	Table U
			All Classes [Note (3)]	All Classes

NOTES:

- (1) Table Y-2 provides permanent strain limiting factor for plate- and shell-type supports.
- (2) Tables TE and TM provide values of the coefficient of thermal expansion and modulus of elasticity, respectively.
- (3) Multiply tabulated values by 3 to arrive at S_y values. Round up to the next higher 0.5 ksi.

TABLE NF-2121(a)-1 MATERIAL TABLES REQUIRED FOR SUPPORTS^{1,2}

(b) Copper and copper based alloys shall not be used for structural members.

NF-2124 Size Ranges

Material outside the limits of size or thickness given in any specification in Section II may be used if the material is in compliance with the other requirements of the specification and no size limitation is given in the rules for construction. In those specifications in which chemical composition or mechanical properties are indicated to vary with size or thickness, any material outside the specification range shall be required to conform to the composition and mechanical properties shown for the nearest specified range [NCA-3856.3(d)].

NF-2130 CERTIFICATION OF MATERIAL

(a) Material used in the construction of supports shall be certified. Certified Material Test Reports in accordance with NCA-3862 shall be provided for material used for primary members for Class 1 Plate- and Shell-Type Supports, and Class 1 Linear-Type Supports. Material for other Classes of supports and all Classes of Standard Supports shall be provided with Certified Material Test Reports when impact testing is required (NF-231 I). Copies of these certificates shall be provided with the support.

(b) Certificates of Compliance with the material specification, grade, class, and heat treated condition, as applicable, or Certified Material Test Reports shall be provided by the Material Organization for material for all other supports, Standard Supports, and secondary members of all types and Classes of supports.

(c) When Design Documents, such as the Design Report or Load Capacity Data Sheet, permit the use of alternative materials for which certificates of compliance are permitted, the alternative materials may be documented in the Design Documents or the documentation for the support in lieu of documenting the specific material used. The requirements of NF-2150 for identification of materials shall apply.

(d) When material Certificates of Compliance are permitted, the support manufacturer or the support Material Organization who furnishes material (NCA-1221) for supports or supports as material (NF-1214), shall transmit copies of the material Certificates of Compliance applicable to each support. Alternatively, he shall execute and furnish a single document certifying a listing of all material specifications involved in the shipment. When a single document is furnished, his quality program shall provide for his retention of the material Certificates of Compliance for each of the materials incorporated into the supports.

NF-2140 WELDING MATERIAL

For the requirements governing the material to be used for welding, see NF-2400.

NF-2150 MATERIAL IDENTIFICATION

The identification of material requiring Certified Material Test Reports shall meet the requirements of NCA-3856. Material furnished with Certificates of Compliance shall be identified by a controlled system meeting the requirements of the applicable material specification, grade, and class. Identification of the material to the Material Organization's Certificate of Compliance is not required after the support manufacturer, or the Material Organization who furnishes supports as material (NF-1214), has verified that the material meets the requirements of this Section. Material for small items shall be controlled during the manufacture of the supports so that they are identifiable as acceptable material at all times. Welding material shall be controlled during the repair of material and the manufacture and installation of supports so that it is identifiable as acceptable material until the material is actually consumed in the process (NF-4122).

NF-2160 DETERIORATION OF MATERIAL IN SERVICE

Consideration of deterioration of material caused by service is generally outside the scope of this Subsection. It is the responsibility of the Owner to select material suitable for the conditions stated in the Design Specifications (NCA-3250), with specific attention being given to the effect of Service Conditions upon the properties of the material.

NF-2170 HEAT TREATMENT TO ENHANCE IMPACT PROPERTIES

Carbon steel, low alloy steels, and high alloy chromium (Series 4XX) steels may be heat treated by quenching and tempering to enhance their impact properties. Postweld heat treatment of the support at a temperature of not less than 1100°F (593°C) may be considered to be the tempering phase of the heat treatment.

NF-2180 PROCEDURES FOR HEAT TREATMENT OF MATERIAL

When heat treating temperature or time is required by the material specification and the rules of this Subsection, the heat treating shall be performed in temperature-surveyed and -calibrated furnaces or the heat treating shall be controlled by measurement of material temperature thermocouples in contact with the material or attached to blocks in contact with the material or by calibrated pyrometric instruments. Heat treating shall be performed under furnace loading conditions such that the heat treatment is in accordance with the material specification and the rules of this Subsection.

NF-2200 MATERIAL TEST COUPONS AND SPECIMENS FOR FERRITIC STEEL MATERIAL

NF-2210 HEAT TREATMENT REQUIREMENTS

2 Any postweld heat treatment time which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specifications. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

NF-2211 Test Coupon Heat Treatment for Ferritic Material²

If ferritic steel material is subjected to heat treatment during construction of a support, the material used for the impact test specimens shall be heat treated in the same manner as the support, except that test coupons and specimens for P-No. 1 material with a nominal thickness of 2 in. (51 mm) or less are not required to be so heat treated. The support manufacturer shall provide the Material Organization with the temperature and heating and cooling rate to be used. In the case of postweld heat treatment, the total time at temperature or temperatures for the test material shall be at least 80% of the total time at temperature or temperatures during actual postweld heat treatment of the material, and the total time at temperature or temperatures for the test material, coupon, or specimen may be performed in a single cycle.

NF-2212 Test Coupon Heat Treatment for Quenched and Tempered Material

NF-2212.1 Cooling Rates.

When ferritic steel material is subjected to quenching from the austenitizing temperature, the test coupons representing those materials shall be cooled at a rate similar to and no faster than the main body of the material except in the case of certain forgings and castings (NF-2223.3 and NF-2226.4). This rule shall apply for coupons taken directly from the material as well as for separate test coupons representing the material, and one of the general procedures described in NF-2212.2 or one of the specific procedures described in NF-2220 shall be used for each product form.

NF-2212.2 General Procedures.

One of the general procedures in (a), (b), and (c) below may be applied to quenched and tempered material or test coupons representing the material, provided the specimens are taken relative to the surface of the product in accordance with NF-2220. Further specific details of the methods to be used shall be the obligation of the Material Organization and the Certificate Holder.

(a) Any procedure may be used which can be demonstrated to produce a cooling rate in the test material that matches the cooling rate of the main body of the product within 25°F (14°C) and 20 sec at all temperatures after cooling begins.

(b) If cooling rate data for the material and cooling rate control devices for the test specimens are available, the test specimens may be heat treated in the device to represent the material, provided that the provisions of (a) above are met.

(c) When any of the specific procedures described in NF-2220 are used, faster cooling rates at the edges may be compensated for by:

- (1) taking the test specimens at least t from a quenched edge, where t equals the material thickness;
 - (2) attaching a steel pad at least t wide by a partial penetration weld (which completely seals the buffered surface) to the edge where specimens are to be removed; or
 - (3) using thermal barriers or insulation at the edge where specimens are to be removed.
-

It shall be demonstrated (and this information shall be included in the Certified Material Test Report) that the cooling rates are equivalent to (a) or (b) above.

NF-2220 PROCEDURE FOR OBTAINING TEST COUPONS AND SPECIMENS FOR QUENCHED AND TEMPERED MATERIAL

NF-2221 General Requirements

The procedure for obtaining impact test specimens for quenched and tempered material is related to the product form. Coupon and specimen location shall be as required by the material specification, except as stated in the following paragraphs of this Subarticle. References to dimensions signify nominal values.

NF-2222 Plates

NF-2222.1 Number of Tension Test Coupons.

The number of tension test coupons required shall be in accordance with the material specification and with SA-20, except that from carbon steel plates weighing 42,000 lb (20,050 kg) and over and alloy steel plates weighing 40,000 lb (18,140 kg) and over, two tension test coupons shall be taken, one representing the top end of the plate and one representing the bottom end of the plate.

NF-2222.2 Orientation and Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from a rolled surface and with the midlength of the specimen at least t from any heat treated edge, where t is the nominal thickness of the material. The orientation of the coupons shall be as specified in the material specification.

NF-2222.3 Requirements for Separate Test Coupons.

Where a separate test coupon is used to represent the support material, it shall be of sufficient size to ensure that the cooling rate of the region from which the test coupons are removed represents the cooling rate of the material at least $\frac{1}{4}t$ deep and t from any edge of the product. Unless cooling rates applicable to the bulk pieces or product are simulated in accordance with NF-2212.2(b), the dimensions of the coupon shall not be less than $3t \times 3t \times t$, where t is the nominal material thickness.

NF-2223 Forgings

NF-2223.1 Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from any surface and with the midlength of the specimens at least t from any second surface, where t is the maximum heat treated thickness. A thermal buffer as described in NF-2212.2(c) may be used to achieve these conditions, unless cooling rates applicable to the bulk forgings are simulated as otherwise provided in NF-2212.2.

NF-2223.2 Very Thick and Complex Forgings.

Test coupons for forgings which are both very thick and complex, such as trunnions, support forgings, flanges, and other complex forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment, may be removed from prolongations or other stock provided on the product. The Certificate Holder shall

specify the surfaces of the finished product subjected to high tensile stresses in service. The coupons shall be taken so that specimens shall have their longitudinal axes at a distance below the nearest heat treated surface, equivalent to at least the greatest distance that the indicated high tensile stress surface will be from the nearest surface during heat treatment, and with the midlength of the specimens a minimum of twice this distance from a second heat treated surface. In any case, the longitudinal axes of the specimens shall not be nearer than $\frac{3}{4}$ in. to any heat treated surface and the midlength of the specimens shall be at least $1\frac{1}{2}$ in. from any heat treated surface.

NF-2223.3 Coupons From Separately Produced Test Forgings.

Test coupons representing forgings from one heat and one heat treatment lot may be taken from a separately forged piece under the conditions given in (a) through (e) below.

(a) The separate test forging shall be of the same heat of material and shall be subjected to substantially the same reduction and working as the production forging it represents.

(b) The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forging.

(c) The separate test forging shall be of the same nominal thickness as the production forging.

(d) Test coupons for simple forgings shall be taken so that specimens shall have their longitudinal axes at the region midway between midthickness and the surface and with the midlength of the specimens no nearer to any heat treated edge than a distance equal to the forging thickness, except when the thickness-length ratio of the production forging does not permit, in which case a production forging shall be used as the test forging and the midlength of the specimens shall be at the midlength of the test forgings.

Page 20

(e) Test coupons for complex forgings shall be taken in accordance with NF-2223.2.

NF-2223.4 Test Specimens for Forgings.

When test specimens for forgings are to be taken under the applicable specification, the Inspector shall have the option of witnessing the selection, placing an identifying stamping on them, and witnessing the testing of these specimens.

NF-2224 Location of Coupons

(a) *Bars.* Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside or rolled surface and with the midlength of the specimens at least t from a heat treated end, where t is either the bar diameter or thickness.

(b) *Bolting Material.* For bolting material, the coupons shall be taken in conformance with the applicable material specification and with the midlength of the specimen at least one diameter or thickness from a heat treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size, except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

NF-2225 Tubular Products and Fittings

NF-2225.1 Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the inside or outside surface and with the midlength of the specimens at least t from a heat treated end, where t is the nominal wall thickness of the tubular product.

NF-2225.2 Separately Produced Coupons Representing Fittings.

Separately produced test coupons representing fittings may be used. When separately produced coupons are used, the requirements of NF-2223.3 shall be met.

NF-2226 Castings

NF-2226.1 Castings With 2 in. (51 mm) Maximum Thickness and Less.

For castings with a maximum thickness of 2 in. (51 mm) and less, the specimens shall be taken from either the standard separately cast coupons or the casting, in accordance with the material specification.

NF-2226.2 Castings With Thicknesses Exceeding 2 in. (51 mm) Maximum Thickness.

For castings exceeding a thickness of 2 in. (51 mm), the coupons shall be taken from the casting (or an extension of it) so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ of the maximum heat treated thickness from any surface and with the midlength of the specimens at least t from any second surface. A thermal buffer may be used [NF-2212.2 (c)(3)].

NF-2226.3 Separately Cast Test Coupons for Castings With Thicknesses Exceeding 2 in. (51 mm).

In lieu of the requirements of NF-2226.2, separately cast test coupons may be used under the conditions of (a), (b), and (c) below.

(a) The separate test coupon representing castings from one heat and one heat treated lot shall be of the same heat of material and shall be subjected to substantially the same foundry practices as the production casting it represents.

(b) The separate test coupon shall be heat treated in the same furnace charge and under the same conditions as the production casting, unless cooling rates applicable to the bulk castings are simulated in accordance with NF-2212.2.

(c) The separate test coupon shall not be less than $3t \times 3t \times t$, where t equals the nominal thickness of the casting. Test specimens shall be taken with their longitudinal axes at the region midway between midthickness and the surface and with the midlength of the specimens no nearer any heat treated edge than a distance equal to the casting thickness.

NF-2226.4 Castings Machined or Cast to Finished Configuration Before Heat Treatment.

In lieu of the requirements of NF-2226.1, NF-2226.2, or NF-2226.3, test coupons may be removed from prolongations or other stock provided on the product. The coupons shall be taken so that specimens shall have their longitudinal axes at a distance below the nearest heat treated surface equivalent at least to the greatest distance that the indicated high tensile stress surface will be from the nearest surface during heat treatment and with the midlength of the specimens a minimum of twice this distance from a second heat treated surface. In any case, the longitudinal axes of the specimens shall be at least $\frac{3}{4}$ in. (19 mm) from any heat treated surface and the midlength of the specimens shall be at least $1\frac{1}{2}$ in. (38 mm) from any second heat treated surface. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service.

Page 21

NF-2227 Rolled Shapes

For rolled shapes, the coupons shall be taken so that specimens shall have their longitudinal axes on a line representing the center of the thickest element of the shape and with the midlength of the specimen at least t from a heat treated end.

NF-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL

NF-2310 MATERIAL TO BE IMPACT TESTED

NF-2311 Supports for Which Impact Testing of Material Is Required³

(a) Support materials shall be impact tested in accordance with the requirements listed below.

(1) Attachments to the component or piping shall meet the requirements for impact testing stipulated in the applicable Subsection.

(2) Class 1, 2, 3, and MC component supports shall meet the requirements of NF-2300.

(3) For Class 1, 2, and 3 piping supports, Class 1, 2, 3, and MC Standard Supports, and all other types and Classes of supports, the Design Specification (NCA-3250) shall state whether or not impact testing is required for the material of which the support is constructed. When impact testing is required, the tests shall meet the requirements of NF-2300 for Class 1, 2, 3, or MC, respectively and shall become a requirement of this Subsection.

(b) The requirements for supports shall be as specified in NF-2300, except that the materials described in (1) through (13) below are not to be impact tested as a requirement of this Subsection:

- (1) material with a nominal section thickness of $\frac{5}{8}$ in. and less;
- (2) bolting, including studs, nuts, and bolts, with a nominal size of 1 in. (25 mm) and less;
- (3) bars with a nominal cross-sectional area of 1 sq in. (645 mm²) and less;
- (4) material for fittings with all pipe connections of $\frac{5}{8}$ in. (16 mm) nominal wall thickness and less;
- (5) austenitic stainless steels;
- (6) nonferrous materials;

3 When impact testing is required, the methods of Appendix G (Section III, Division 1, Appendices) may be used as an alternative design procedure for assuring protection against nonductile fracture.

**TABLE NF-2311(b)-1
EXEMPTIONS FROM IMPACT TESTING UNDER
NF-2311(b)(9) AND (10) FOR MATERIAL
THICKNESS TO 2½ in., INCLUSIVE**

Material [Note (1)]	Material Condition [Note (1)]	T_{NDT} , °F [Notes (2), (3)]
SA-537, Class 1	N	-30
SA-516, Grade 70	Q & T	-10
SA-516, Grade 70	N	0
SA-508, Class 1	Q & T	+10
SA-533, Grade B	Q & T	+10
SA-299 [Note (4)]	N	+20
SA-216, Grades WCB, WCC	Q & T	+30
SA-36 (Plate)	HR	+40
SA-508, Class 2	Q & T	+40

NOTES:

- (1) Material Condition letters refer to:
N = Normalize
Q & T = Quench and Temper
HR = Hot Rolled
- (2) These values for T_{NDT} were established from data on heavy section steel (thickness greater than 2½ in.). Values for sections less than 2½ in. thick are held constant until additional data are obtained.
- (3) T_{NDT} = temperature at or above nil-ductility transition temperature (ASTM E 208-91); T_{NDT} is 10°F below the temperature at which at least two specimens show no-break performance.
- (4) Materials made to a fine grain melting practice.

TABLE NF-2311(b)-1 EXEMPTIONS FROM IMPACT TESTING UNDER NF-2311(b)(9) AND (10) FOR MATERIAL THICKNESS TO $2\frac{1}{2}$ in., INCLUSIVE

- (7) material for supports when the maximum stress does not exceed 6000 psi (41 MPa) tension or is compressive;
- (8) rolled structural shapes, when the thickness of a flange is $\frac{5}{8}$ in. (16 mm) or less;
- (9) materials for Class 1, 2, or MC supports, listed in Table NF-2311(b)-1, for thicknesses $2\frac{1}{2}$ in. (64 mm) and less when the Lowest Service Temperature⁴ is at least 30°F (17°C) above the tabulated temperature. This exemption from impact testing does not apply to either the weld metal (NF-2430) or the weld procedure qualification (NF-4335).

⁴ Lowest Service Temperature (LST) is the minimum temperature which will be maintained inside the containment vessel during the plant operation (for supports within containment), or alternatively, the calculated or measured minimum metal temperature of the support expected during normal operation when the pressure within the component exceeds 20% of the system hydrostatic test pressure.

- (10) materials for Class 3 supports, listed in Table NF-2311(b)-1, for thicknesses $2\frac{1}{2}$ in. (64 mm) and less, when the Lowest Service Temperature is equal to or greater than the tabulated temperature. This exemption from impact testing does not apply to either the

Page 22

weld metal (NF-2430) or the weld procedure qualification (NF-4335).

- (11) materials for Class 2 and MC supports for which the Lowest Service Temperature exceeds 150°F (66°C);
- (12) materials for Class 3 supports for which the Lowest Service Temperature exceeds 100°F (38°C);
- (13) Materials for Class 2, 3, and MC supports for which the Lowest Service Temperature (LST) is equal or above the Minimum Design Metal Temperature of Fig. NF-2311(b)-1 for the materials listed and the applicable material thicknesses.

(c) The Design Specification (NCA-3250) shall state the Lowest Service Temperature (LST) for the support and the designated impact test temperature, when required.

NF-2320 IMPACT TEST PROCEDURES

NF-2321 Charpy V-Notch Tests

The Charpy V-notch test (C_v), when required, shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Fig. 11, Type A. A test shall consist of a set of three full-size 10 mm × 10 mm specimens. The lateral expansion and absorbed energy, as applicable, and the test temperature, as well as the orientation and location of all tests performed to meet the requirements of NF-2330 shall be reported in the Certified Material Test Report.

NF-2322 Location and Orientation of Test Specimens

Impact test specimens for quenched and tempered material shall be removed from the locations and orientation specified for tensile test specimens in each product form in NF-2220 except that for plates the orientation of the impact test specimens shall be longitudinal. For material in other heat treated conditions, impact test specimens shall be removed from the locations and orientations specified for tensile test specimens in the material specification except that for plates the orientation of the impact specimens shall be longitudinal, and for structural shapes the location and orientation of the impact test specimens shall be as specified in ASTM Specification A 673-77. Alternatively, the orientation may be in the direction of maximum stress regardless of heat treatment. For bolting, the C_v impact test specimens shall be prepared with the longitudinal axis of the specimen located at least one-half radius or 1 in. (25 mm) below the surface plus the machining allowance per side, whichever is less. The fracture plane of the specimen shall be at least one diameter or thickness from the heat treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size, except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts. For all material, the number of tests shall be in accordance with NF-2340.

NF-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS

NF-2331 Material (Excluding Bolting)

When impact testing is required, material (other than bolting) shall be tested as required by (a) and (b) below.

(a) Test three C_v specimens at the designated temperature (NF-2311). All three specimens shall meet one of the acceptance standards applicable to the specific test method.

(1) *Charpy V-Notch Testing for Lateral Expansion Values.* The test results of the three specimens, collectively and singly, shall meet the respective requirements of Table NF-2331(a)-1 for Class 1, of Table NF-2331(a)-2 for Class 2 and MC, and of Table NF-2331(a)-3 for Class 3 supports.

(2) *Charpy V-Notch Testing for Absorbed Energy Values.* The test results of the three specimens, collectively and singly, shall meet the respective requirements of Table NF-2331(a)-4 for Class 1, of Fig. NF-2331(a)-1 for Class 2 and MC, and of Fig. NF-2331(a)-2 for Class 3 supports.

(b) Apply the procedures of (a) above to:

(1) base material;

(2) the base material, the heat affected zone, and weld metal from the weld procedure qualification tests of NF-4330; and

(3) the weld metal of NF-2431.

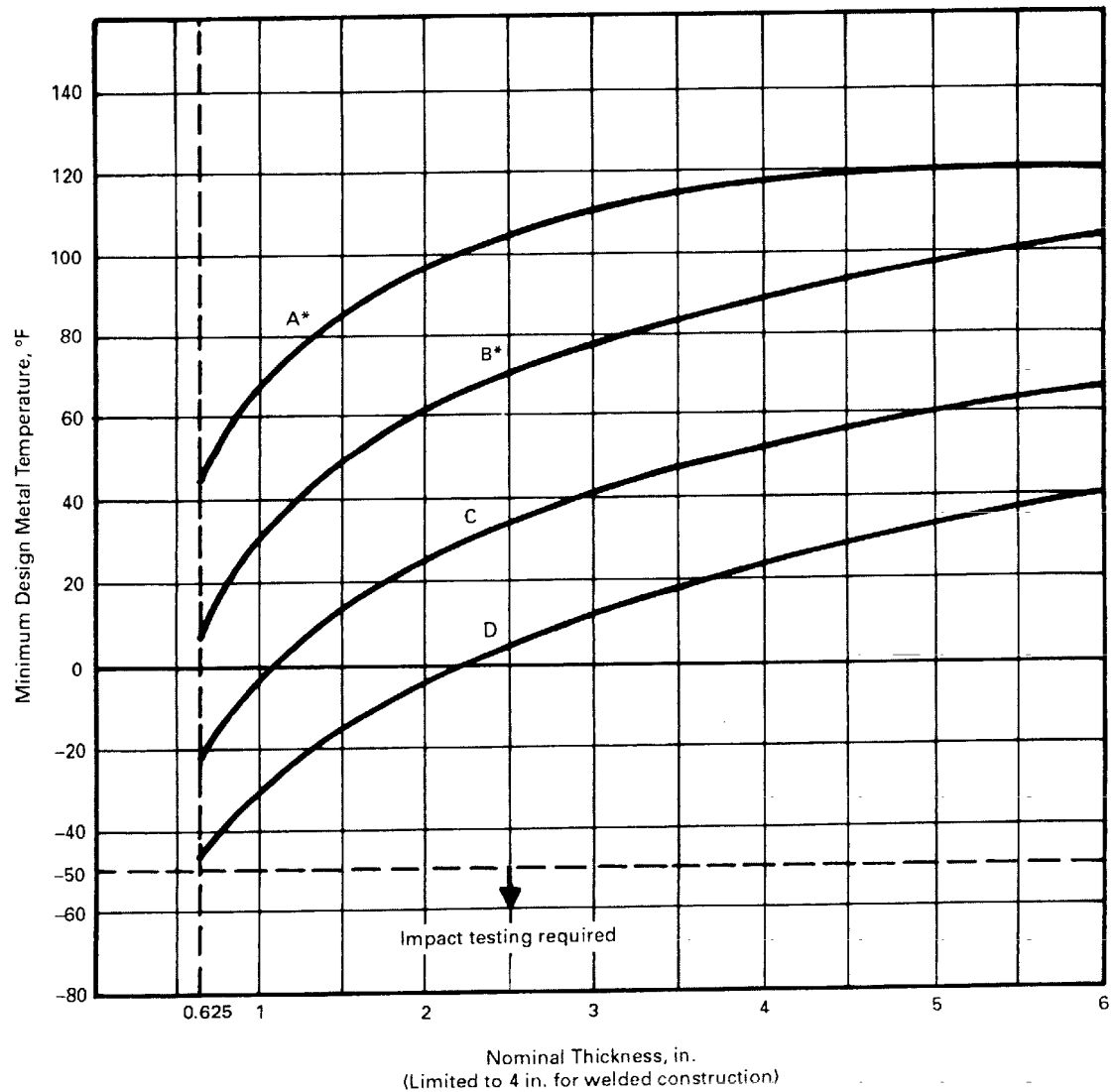
NF-2333 Bolting Material

When impact testing is required, for bolting material including studs, nuts, and bolts, test three C_v specimens at the designated temperature. All three specimens shall meet the requirements of Table NF-2333-1.

Page 23

Page 25

Pages 24-24



*See NF-2311 (b) (12) for Class 3 lowest service temperature limit

FIG. NF-2311(b)-1 IMPACT TEST EXEMPTION CURVES FOR MATERIALS FOR CLASS 2, 3, AND MC SUPPORTS

FIG. NF-2311(b)-1 IMPACT TEST EXEMPTION CURVES FOR MATERIALS FOR CLASS 2, 3, AND MC SUPPORTS

GENERAL NOTES ON ASSIGNMENT OF MATERIALS TO CURVES:

- (a) Curve A — all carbon and all low alloy steel plates, structural shapes, and bars not listed in Curves B, C, and D below
- (b) Curve B
- (1) SA-285 Grades A and B
 - SA-414 Grade A
 - SA-442 Grade 55 > 1 in. if not to fine grain practice and normalized
 - SA-442 Grade 60 if not to fine grain practice and normalized
 - SA-515 Grades 55 and 60
 - SA-516 Grades 65 and 70 if not normalized
 - SA-612 if not normalized
 - SA-662 Grade B if not normalized
 - SA-724 if not normalized
 - (2) all materials of Curve A if produced to fine grain practice and normalized which are not listed for Curves C and D below;
 - (3) except for bolting [see (e) below], plates, structural shapes, and bars, all other product forms (such as pipe, fittings, and tubing) not listed for Curves C and D below
- (c) Curve C
- (1) SA-182 Grades 21 and 22 if normalized and tempered
 - SA-302 Grades C and D
 - SA-336 Grades F21 and F22 if normalized and tempered
 - SA-387 Grades 21 and 22 if normalized and tempered
 - SA-442 Grade 55 ≤ 1 in. if not to fine grain practice and normalized
 - SA-516 Grades 55 and 60 if not normalized
 - SA-533 Grades B and C
 - SA-662 Grade A;
 - (2) all material of Curve B if produced to fine grain practice and normalized and not listed for Curve D below
- (d) Curve D
- SA-203
 - SA-442 if to fine grain practice and normalized
 - SA-508 Class 1
 - SA-516 if normalized
 - SA-524 Classes 1 and 2
 - SA-537 Classes 1 and 2
 - SA-612 if normalized
 - SA-662 if normalized
 - SA-724 if normalized
- (e) For bolting the following impact test exemption temperature shall apply:

Spec. No.	Grade	Impact Test
		Exemption Temperature, °F
SA-193	B5	−20
SA-193	B7	−40
SA-193	B7M	−50
SA-193	B16	−20
SA-307	B	−20
SA-320	L7, L43	Impact tested
SA-325	1	−20
SA-354	BB	−20
SA-354	BC	0
SA-354	BD	+20
SA-449	...	−20

FIG. NF-2311(b)-1 (CONT'D)

FIG. NF-2311(b)-1 (CONT'D)

**TABLE NF-2331(a)-1
REQUIRED C_v LATERAL EXPANSION VALUES
FOR CLASS 1 SUPPORT MATERIAL
OTHER THAN BOLTING**

Nominal Wall Thickness, in.	Lateral Expansion, mils
$\frac{5}{8}$ or less	No test required
Over $\frac{5}{8}$ to 1, incl.	15
Over 1	25

TABLE NF-2331(a)-1 REQUIRED C_v LATERAL EXPANSION VALUES FOR CLASS 1 SUPPORT MATERIAL
OTHER THAN BOLTING

**TABLE NF-2331(a)-2
REQUIRED C_v LATERAL EXPANSION VALUES
FOR CLASS 2 AND MC SUPPORT MATERIAL
OTHER THAN BOLTING**

Nominal Wall Thickness, in.	Lateral Expansion, mils
$\frac{5}{8}$ or less	No test required
Over $\frac{5}{8}$ to 1, incl.	15
Over 1	20

TABLE NF-2331(a)-2 REQUIRED C_v LATERAL EXPANSION VALUES FOR CLASS 2 AND MC SUPPORT MATERIAL OTHER THAN BOLTING

**TABLE NF-2331(a)-3
REQUIRED C_v LATERAL EXPANSION VALUES FOR
CLASS 3 SUPPORT MATERIAL OTHER
THAN BOLTING**

Nominal Wall Thickness, in.	Lateral Expansion, mils
$\frac{5}{8}$ or less	No test required
Over $\frac{5}{8}$	15

TABLE NF-2331(a)-3 REQUIRED C_v LATERAL EXPANSION VALUES FOR CLASS 3 SUPPORT MATERIAL OTHER THAN BOLTING

NF-2340 NUMBER OF IMPACT TESTS REQUIRED

NF-2341 Plates

One test shall be made from each plate as heat treated. Where plates are furnished in the unheat-treated condition and qualified by heat treated test specimens, one test shall be made for each plate as-rolled. The term *as-rolled* refers to the plate rolled from a slab or directly from an ingot, not to its heat treated condition.

NF-2342 Forgings and Castings

(a) Where the weight of an individual forging or casting is less than 1000 lb (454 kg), one test shall be made to represent each heat in each heat treatment lot.

(b) When heat treatment is performed in a continuous-type furnace with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a heat treatment lot shall be considered as the lesser of a continuous run not exceeding 8 hr duration or a total weight, so treated, not exceeding 2000 lb (907 kg).

(c) One test shall be made for each forging or casting of 1000 to 10,000 lb (454 kg to 4540 kg) in weight.

(d) As an alternative to (c), a separate test forging or casting may be used to represent forgings or castings of different sizes in one heat and heat treat lot, provided the test piece is a representation of the greatest thickness in the heat treat lot. In addition, test forgings shall have been subjected to substantially the same reduction and working as the forgings represented.

**TABLE NF-2331(a)-4
REQUIRED C_v ENERGY VALUES FOR CLASS 1 SUPPORT MATERIAL
OTHER THAN BOLTING**

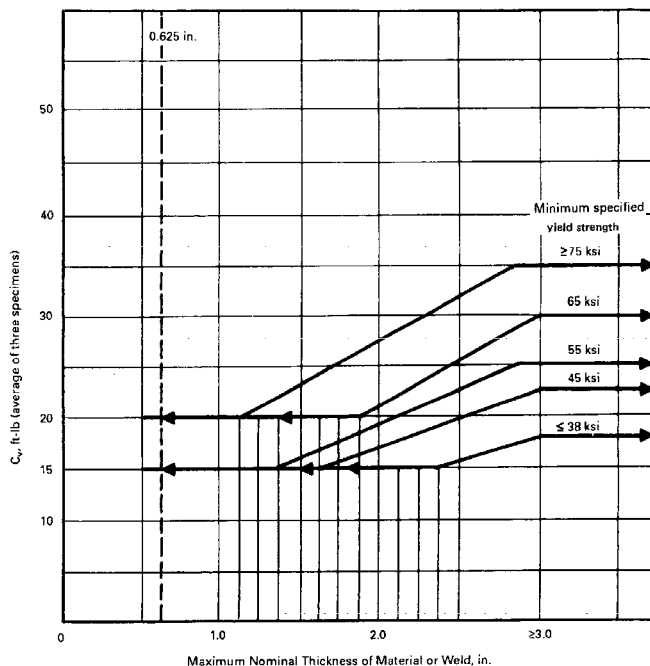
Nominal Wall Thickness, in.	Energy, ft-lb for Base Materials of Specified Minimum Yield Strength, ksi					
	55 ksi or Below		Over 55 ksi to 75 ksi, incl.		Over 75 ksi to 105 ksi, incl.	
	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3
$\frac{5}{8}$ in. or less [Note (1)]	...	...	...	...	...	...
Over $\frac{5}{8}$ in. to 1 in., incl. [Note (2)]	15	10	20	15	25	20
Over 1 in. [Note (2)]	25	20	30	25	35	30

NOTES:

- (1) No test required.
 (2) Where weld metal tests of NF-2400 are made to these requirements, the impact energy shall conform to the requirements of either of the base materials being joined.

TABLE NF-2331(a)-4 REQUIRED C_v ENERGY VALUES FOR CLASS 1 SUPPORT MATERIAL OTHER THAN BOLTING

Page 27

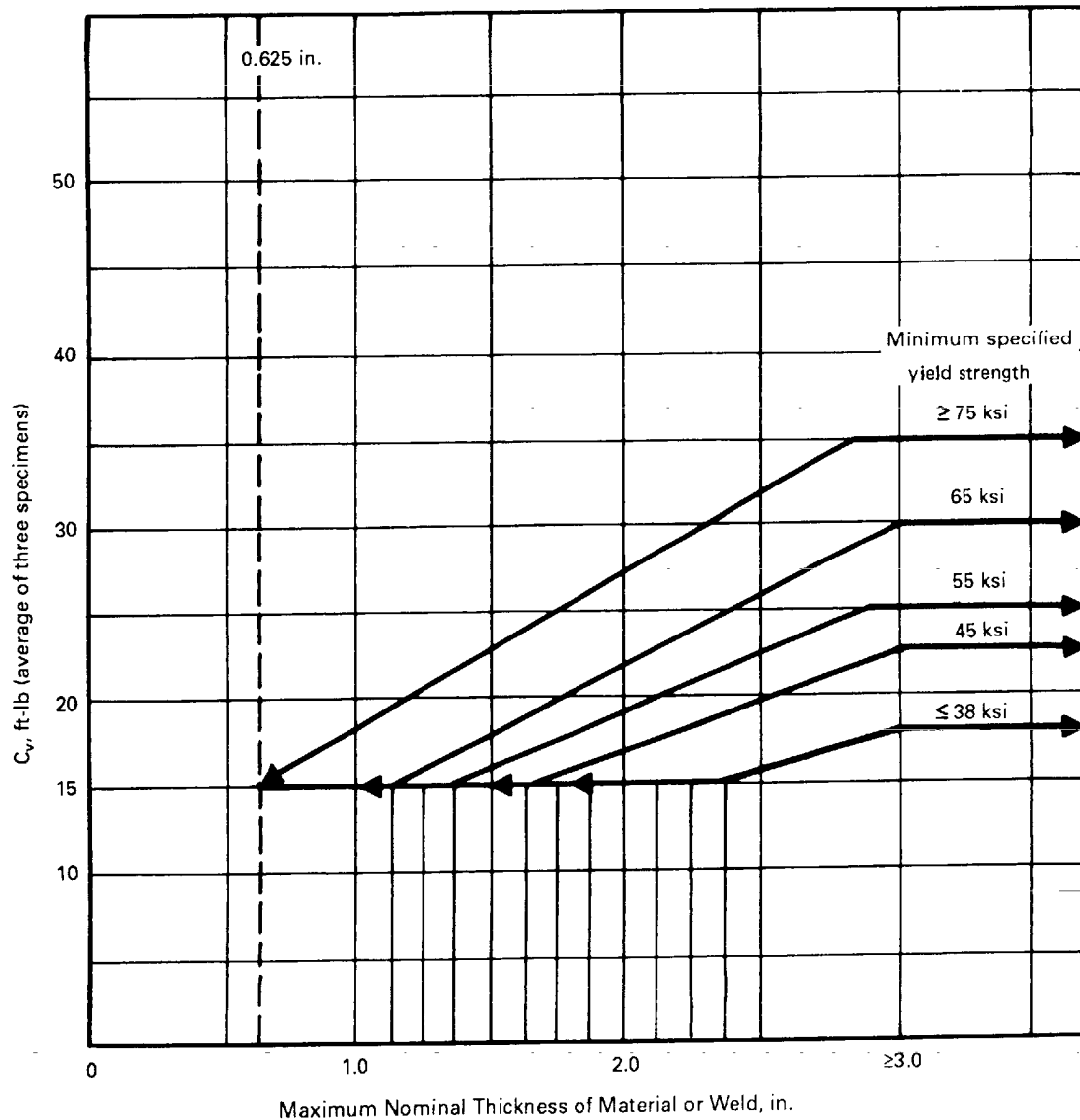


GENERAL NOTES:

- (a) Interpolation between yield strengths shown is permitted.
 (b) The lowest of three specimens tested shall not be less than 5 ft-lbf below the average value required.

FIG. NF-2331(a)-1 REQUIRED C_v ENERGY VALUES FOR CLASS 2 AND MC SUPPORT MATERIAL OTHER THAN BOLTING

FIG. NF-2331(a)-1 REQUIRED C_v ENERGY VALUES FOR CLASS 2 AND MC SUPPORT MATERIAL OTHER THAN BOLTING



GENERAL NOTES:

- (a) Interpolation between yield strengths shown is permitted.
- (b) The lowest of three specimens tested shall not be less than 5 ft-lbf below the average value -- required.

FIG. NF-2331(a)-2 REQUIRED C_v ENERGY VALUES FOR CLASS 3 SUPPORT MATERIAL OTHER THAN BOLTING

FIG. NF-2331(a)-2 REQUIRED C_v ENERGY VALUES FOR CLASS 3 SUPPORT MATERIAL OTHER THAN BOLTING

**TABLE NF-2333-1
REQUIRED C_v VALUES
FOR BOLTING MATERIAL**

Nominal Diameter, in.	Lateral Expansion, mils
1 or less	No test required
Over 1	25

TABLE NF-2333-1 REQUIRED C_v VALUES FOR BOLTING MATERIAL

(e) Forgings or castings larger than 10,000 lb (4540 kg) shall have two tests per part for Charpy V-notch. The location of C_v impact test specimens shall be selected so that an equal number of specimens is obtained from positions in the forging or casting 180 deg. apart.

(f) As an alternative to (e) for static castings, a separately cast test coupon (NF-2226.3) may be used; one test shall be made for Charpy V-notch.

NF-2343 Bars and Rolled Shapes

(a) For bars, one test shall be made for each diameter or size greater than 1 in. in each lot, where a lot is defined as one heat of material:

- (1) as-rolled in one continuous operation; or
- (2) heat treated in one charge, or each 6000 lb (2720 kg) or less from one continuous operation.

(b) For rolled shapes, the frequency of testing shall be one test (a set of three specimens) for at least each 15 tons (13,608 kg) or each single length of 15 tons (13,608 kg) or more, of the same nominal shape size, excluding length, for each heat in the as-rolled condition. If the shapes are heat treated, one test shall be taken from each heat of each nominal shape size, excluding length, in each furnace lot. For shapes heat treated in a continuous furnace, a lot shall not exceed 15 tons (13,608 kg).

NF-2344 Tubular Products and Fittings

On products which are seamless or welded without filler metal, one test shall be made from each lot. On products which are welded with filler metal, one additional test with the specimens taken from the weld area shall also be made on each lot. A lot shall be defined as stated in the applicable material specification, but in no case shall a lot consist of products from more than one heat of material and of more than one diameter, with the nominal thickness of any product included not exceeding that to be impact tested by more than $\frac{1}{4}$ in. (6 mm); such a lot shall be in a single heat treatment load or in

the same continuous run in a continuous furnace controlled within a 50°F (28°C) range and equipped with recording pyrometers.

NF-2345 Bolting Material

One test shall be made for each lot of material where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed in weight the following:

1 ³ / ₄ in. diameter and less	1,500 lb
Over 1 ³ / ₄ in. to 2 ¹ / ₂ in. diameter	3,000 lb
Over 2 ¹ / ₂ in. to 5 in. diameter	6,000 lb
Over 5 in. diameter	10,000 lb

NF-2350 RETESTS

NF-2351 Retests for Class 1, 2, 3, and MC Material Other Than Bolting

(a) For Charpy V-notch tests required by NF-2331 to meet the acceptance standards of Tables NF-2331(a)-1, NF-2331(a)-2, and NF-2331(a)-3, respectively, one retest at the same temperature may be conducted, provided:

- (1) the average value of the test results meets the minimum requirements;
- (2) not more than one specimen per test is below the minimum requirements;
- (3) the specimens not meeting the minimum requirements are not lower than 5 mils (0.13 mm) below the specified requirements; and

(4) a retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall be meet the minimum requirements.

(b) For Charpy V-notch tests required by NF-2331 to meet the acceptance standards of Table NF-2331(a)-4, one retest at the same temperature may be conducted provided:

- (1) the average value of the test results meets the "Average of 3" requirements specified;
- (2) not more than one specimen per test is below the "Lowest 1 of 3" requirements specified;
- (3) the specimen not meeting the requirements is not lower than 5 ft-lb (6.8 J) below the "Lowest 1 of 3" requirements specified; and
- (4) a retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall be

Page 29

equal to or greater than the "Average of 3" requirements specified.

NF-2352 Retests for Bolting for Charpy V-Notch Tests

For Charpy V-notch tests of bolting required by NF-2333 to meet the acceptance standards of Table NF-2333-1, one retest at the same temperature may be conducted, provided:

- (a) the average value of the test results meets the minimum requirements;
- (b) not more than one specimen per test is below the minimum requirements;
- (c) the specimens not meeting the minimum requirements are not lower than 5 mils (0.13 mm) below the specified requirements; and
- (d) a retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall meet the minimum requirements.

NF-2360 CALIBRATION OF INSTRUMENTS AND EQUIPMENT

Calibration of temperature instruments and C_v impact test machines used in impact testing shall be performed at the frequency specified in (a) or (b) below.

(a) Temperature instruments used to control test temperature of specimens shall be calibrated and the results recorded to meet the requirements of NCA-3868 at least once in each 3 month interval.

(b) C_v impact test machines shall be calibrated and the results recorded to meet the requirements of NCA-3858.2. The calibrations shall be performed at least once in each 1 year interval using methods outlined in ASTM E 23-72 and employing standard specimens obtained from the National Institute of Standards and Technology.

NF-2400 WELDING MATERIAL

NF-2410 GENERAL REQUIREMENTS

(a) All welding material used in the construction and repair of supports or material, except welding material used for cladding or hard surfacing, shall conform to the requirements of the welding material specification or to the requirements for other welding material as permitted in Section IX. In addition, welding material shall conform to the requirements stated in this Subarticle and to the rules covering identification in NF-2150.

(b) The Certificate Holder shall provide the organization performing the testing with the information listed below, as applicable:

- (1) welding process;
- (2) SFA Specification and classification;
- (3) other identification if no SFA Specification applies;
- (4) minimum tensile strength [NF-2431.1(e)] in either the as-welded or heat treated condition, or both [NF-2431.1(c)];
- (5) Charpy V-notch test for material as-welded or heat treated, or both (NF-2331); the test temperature, and the lateral expansion or the absorbed energy, shall be provided;
- (6) the preheat and interpass temperatures to be used during welding of the test coupon [NF-2431.1(c)];
- (7) postweld heat treatment time, temperature range, and maximum cooling rate, if the production weld will be heat treated [NF-2431.1(c)];
- (8) elements for which chemical analysis is required per the SFA Specification or WPS, and NF-2432;
- (9) minimum delta ferrite (NF-2433).

NF-2420 REQUIRED TESTS

The required tests shall be conducted for each lot of covered, flux cored, or fabricated electrodes; for each heat of bare electrodes, rod, or wire for use with the OFW, GMAW, GTAW, PAW, and EGW (electro-gas welding) processes (Section IX, QW-492); for each heat of consumable inserts; for each combination of heat of bare electrodes and lot of submerged arc flux; for each combination of lot of fabricated electrodes and lot of submerged arc flux; for each combination of heat of bare electrodes or lot of fabricated electrodes and dry blend of supplementary powdered filler metal and lot of submerged arc flux; or for each combination of heat of bare electrodes and lot of electrosag flux. Tests performed on welding material in the qualification of weld procedures will satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used, provided the tests required by NF-4000 and this Subarticle are made and the results conform to the requirements of this Article. The definitions in (a) through (h) below apply.

(a) A *dry batch of covering mixture* is defined as the quantity of dry covering ingredients mixed at one time in one mixing vessel; a dry batch may be used singly or may be subsequently subdivided into quantities

to which the liquid binders may be added to produce a number of wet mixes as in (c) below.

(b) A *dry blend* is defined as one or more dry batches mixed in a mixing vessel and combined proportionately to produce a uniformity of mixed ingredients equal to that obtained by mixing the same total amount of dry ingredients at one time in one mixing vessel.

(c) A *wet mix* is defined as the combination of a dry batch or dry blend [(a) and (b) above, respectively] and liquid binder ingredients at one time in one mixing vessel.

(d) A *lot of covered, flux-cored, or fabricated electrodes* is defined as the quantity of electrodes produced from the same combination of heat of metal and dry batch, dry blend, or chemically controlled mixes of flux or core materials. Alternatively, a lot of covered, flux-cored, or fabricated electrodes may be considered one type and size of electrode, produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45,360 kg), from chemically controlled tube, wire, or strip and a dry batch, a dry blend, or chemically controlled mixes of flux, provided each container of welding materials is coded for identification and traceable to the production period, the shift, line, and analysis range of both the mix and the rod, tube, or strip used to make the electrode.

(1) *Chemically controlled tube, wire, or strip* is defined as consumable tube, wire, or strip material supplied on coils with maximum of one splice per coil that has been chemically analyzed to assure that the material conforms to the electrode manufacturer's chemical control limits for the specific type of electrode. Both ends of each coil shall be chemically analyzed except that those coils which are splice free need only be analyzed on one end of the coil.

(2) *Chemically controlled mixes of flux* are defined as flux material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the electrode manufacturer's standard for each chemical element for that type electrode. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending.

(e) A *heat of bare electrode, rod, wire, or consumable insert* is defined as the material produced from the same melt of metal.

(f) Alternatively, for carbon and low alloy steel bare electrode, rod, wire, or consumable inserts for use with SAW, OFW, GMAW, GTAW, PAW, and EGW processes, a *heat* may be defined as either the material produced from the same melt of metal or the material produced from one type and size of wire when produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45,360 kg), from chemically controlled wire, subject to requirements of (1), (2), and (3) below.

(1) For the chemical control of the product of the rod mill, coils shall be limited to a maximum of one splice prior to processing the wire. Chemical analysis shall be made from a sample taken from both ends of each coil of mill coiled rod furnished by mills permitting spliced coil practice of one splice maximum per coil. A chemical analysis need be taken from only one end of rod coils furnished by mills prohibiting spliced coil practice.

(2) Carbon, manganese, silicon, and other intentionally added elements shall be determined to identify the material to ensure that it conforms to the SFA or user's material specification.

(3) Each container of wire shall be coded for identification and traceability to the lot, production period, shift, line, and analysis of rod used to make the wire.

(g) A *lot of submerged arc or electroslag flux* is defined as the quantity of flux produced from the same combination of raw materials under one production schedule.

(h) A *dry blend of supplementary powdered filler metal* is defined as one or more mixes of material produced in a continuous period, not to exceed 24 hr and not to exceed 20,000 lb (9070 kg) from chemically controlled mixes of powdered filler metal, provided each container of powdered metal is coded for identification and traceable to the production period, the shift, and the mixing vessel. A *chemically controlled mix of powdered filler metal* is defined as powdered filler metal material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the powdered filler metal manufacturer's standard, for each chemical element, for that type of powdered filler metal. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending. The chemical analysis range of the supplemental powdered filler shall be the same as that of the welding electrode, and the ratio of powder to electrode used to make the test coupon shall be the maximum permitted for production welding.

NF-2430 WELD METAL TESTS

NF-2431 Mechanical Properties Test

Tensile and impact tests shall be made, in accordance with this paragraph, of welding materials which are used to join P-Nos. 1, 3, 4, 5, 6, 7, 9, and 11 base materials in any combination, with the exceptions listed in (a) through (d) below:

Page 31

- (a) austenitic stainless steel and nonferrous welding material used to join the listed P-Numbers;
- (b) consumable inserts (backing filler material);
- (c) welding material used for GTAW root deposits with a maximum of two layers;
- (d) welding material to be used for the welding of base materials exempted from impact testing by NF-2311(b)(1) through (8) and NF-2311(b)(11) and (12) shall likewise be exempted from the impact testing required by this paragraph.

NF-2431.1 General Test Requirements.

The welding test coupon shall be made in accordance with (a) through (f) below using each process with which the weld material will be used in production welding.

- (a) Test coupons shall be of sufficient size and thickness that the test specimens required herein can be removed.
- (b) The weld metal to be tested for all processes except electroslag welding shall be deposited in such a manner as to eliminate substantially the influence of the base material on the results of the tests. Weld metal to be used with the electroslag process shall be deposited in such a manner as to conform to one of the applicable Welding Procedure Specifications (WPS) for production welding, Section IX, QW-201.1. The base material shall conform with the requirements of Section IX, QW-403.1 or QW-403.4, as applicable.

5 Any postweld heat treatment time which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

- (c) The welding of the test coupon shall be performed within the range of preheat and interpass temperatures which will be used in production welding. Coupons shall be tested in the as-welded condition or they shall be tested in the applicable postweld heat treated condition when the production welds are to be postweld heat treated. The postweld heat treatment holding time⁵ shall be at least 80% of the maximum time to be applied to the weld metal in production application. The total time for postweld heat treatment of the test coupon may be applied in one heating cycle. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the support. In addition, weld coupons for weld metal to be used with the electroslag process that are tested in the as-welded condition, or following a postweld heat treatment within the holding temperature ranges of Tables NF-4622.1-1 or NF-4622.4(c)-1, shall have a thickness within the range of 0.5 to 1.1 times the thickness of the welds to be made in production. Electroslag weld coupons to be tested following a postweld heat treatment, which will include heating the coupon to a temperature above the "Holding Temperature Range" of Table NF-4622.1-1 for the type of material being tested, shall have a thickness within the range of 0.9 to 1.1 times the thickness of the welds to be made in production.

- (d) Regardless of the welding process or welding material being tested, the tensile specimens, and the C_v impact specimens where required, shall be located and prepared in accordance with the requirements of SFA-5.1, Specification for Mild Steel Covered Electrodes. For impact specimen preparation and testing, the applicable parts of NF-2321 shall apply. The longitudinal axis of the specimen shall be at a minimum depth of $\frac{1}{4}t$ from a surface, where t is the thickness of the test weld.

- (e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the base material specification. When base materials of different specifications are to be welded, the tensile strength requirements shall conform to the specified minimum tensile strength requirements of either of the base material specifications.

- (f) Impact specimens of the weld metal shall be tested where impact tests are required for either of the base materials of the production weld. The weld metal shall conform to the requirements of NF-2331(a), applicable to the base material.

Where different requirements exist for the two base materials, the weld metal may conform to either of the two requirements.

NF-2431.2 Standard Test Requirements.

In lieu of the use of the General Test Requirements specified in NF-2431.1, tensile and impact tests may be made in accordance with this subparagraph where they are required for mild and low alloy steel covered electrodes; the material combinations to require weld material testing, as listed in NF-2431, shall apply for this Standard Test Requirements option. The limitations and testing under this Standard Test option shall be in accordance with (a) through (f) below.

(a) Testing to the requirements of this subparagraph shall be limited to electrode classifications included in specifications SFA-5.1 or SFA-5.5.

(b) The test assembly required by SFA-5.1 or SFA-5.5, as applicable, shall be used for test coupon preparation, except that it shall be increased in size to obtain the number of C_v specimens required by NF-2331(a), where applicable.

(c) The welding of the test coupon shall conform to the requirements of the SFA Specification for the classification of electrode being tested. Coupons shall

Page 32

be tested in the as-welded condition and also in the postweld heat treated condition. The postweld heat treatment temperatures shall be in accordance with Table NF-4622.1-1 for the applicable P-Number equivalent. The time at postweld heat treatment temperature shall be 8 hr (this qualifies postweld heat treatments of 10 hr or less). When the postweld heat treatment of the production weld exceeds 10 hr, or the PWHT temperature is other than that required above, the general test of NF-2431.1 shall be used.

**TABLE NF-2432.1-1
SAMPLING OF WELDING MATERIALS FOR
CHEMICAL ANALYSIS**

	GTAW/PAW	GMAW	All Other Processes
A-No. 8 filler metal	Filler metal or weld deposit	Weld deposit	Weld deposit
All other filler metal	Filler metal or weld deposit	Filler metal or weld deposit	Weld deposit

TABLE NF-2432.1-1 SAMPLING OF WELDING MATERIALS FOR CHEMICAL ANALYSIS

(d) The tensile and C_v specimens shall be located and prepared in accordance with the requirements of SFA-5.1 or SFA-5.5, as applicable.

(e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirement of the SFA Specification for the applicable electrode classification.

(f) The requirements of NF-2431.1(f) shall be applicable to the impact testing of this option.

NF-2432 Chemical Analysis Test

Chemical analysis of filler metal or weld deposits shall be made in accordance with NF-2420 and as required by the following subparagraphs.

NF-2432.1 Test Method.

The chemical analysis test shall be performed in accordance with this Subparagraph and Table NF-2432.1-1, and the results shall conform to NF-2432.2.

(a) A-No. 8 welding material to be used with GTAW and PAW processes and any other welding material to be used with any GTAW, PAW, or GMAW process shall have chemical analysis performed either on the filler metal or on a weld deposit made with the filler metal in accordance with (c) or (d) below.

(b) A-No. 8 welding material to be used with other than the GTAW and PAW processes and other welding material to be used with other than the GTAW, PAW, or GMAW process shall have chemical analysis performed on a weld deposit of the material or combination of materials being certified in accordance with (c) or (d) below. The removal of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c) below. As an alternative, the deposit shall be made in accordance with (d) below for material that will be used for corrosion resistant overlay cladding. Where the Welding Procedure Specification or the welding material specification specifies percentage composition limits for analysis, it shall state that the specified limits apply for either the filler metal analysis or the undiluted weld deposit analysis or for *in situ* cladding deposit analysis in conformance with the above required certification testing.

(c) The preparation of samples for chemical analysis of undiluted weld deposits shall comply with the method given in the applicable SFA Specification. Where a weld deposit method is not provided by the SFA Specification, the sample shall be removed from a weld pad, groove, or other test weld⁶ made using the welding process that will be followed when the welding material or combination of welding materials being certified is consumed. The weld for A-No. 8 material to be used with the GMAW or EGW process shall be made using the shielding gas composition specified in the Welding Procedure Specification that will be followed when the material is consumed. The test sample for ESW shall be removed from the weld metal of the mechanical properties test coupon. Where a chemical analysis is required for a welding material which does not have a mechanical properties test requirement, a chemical analysis test coupon shall be prepared as required by NF-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of NF-2431.1(c) do not apply.

⁶ The methods given in the Appendix of SFA 5.9, Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Rods and Bare Electrodes, shall be used to establish a welding and sampling method for the pad, groove, or other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution.

(d) The alternate method provided in (b) above for the preparation of samples for chemical analysis of welding material to be used for corrosion resistant overlay cladding shall require a test weld made in accordance with the essential variables of the Welding Procedure Specification that will be followed when the welding material is consumed. The test weld shall be made in conformance with the requirements of Section IX, QW-214.1. The removal of chemical analysis samples shall conform with QW-214.3 for the minimum

thickness for which the Welding Procedure Specification is qualified.

TABLE NF-2432.2(a)-1 WELDING MATERIAL CHEMICAL ANALYSIS

Cr–Ni stainless materials	C, Cr, Mo, Ni, Mn, Si, Cb
---------------------------	------------------------------

TABLE NF-2432.2(a)-1 WELDING MATERIAL CHEMICAL ANALYSIS

NF-2432.2 Requirements for Chemical Analysis.

The chemical elements to be determined, the composition requirements of the weld metal, and the recording of results of the chemical analysis shall be in accordance with (a), (b), and (c) below.

(a) Welding material of ferrous alloy A-No. 8 (Section IX, QW-442) shall be analyzed for the elements listed in Table NF-2432.2(a)-1 and for any other elements specified either in the welding material specification referenced by the Welding Procedure Specification or in the Welding Procedure Specification.

(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition limits. Where the Welding Procedure Specification contains a modification of the composition limits of SFA or other referenced welding material specifications, or provides limits for additional elements, these composition limits of the Welding Procedure Specification shall apply for acceptability.

(c) The results of the chemical analysis shall be reported in accordance with NCA-3862.1. Elements listed in Table NF-2432.2(a)-1 but not specified in the welding material specification or Welding Procedure Specification shall be reported for information only.

NF-2433 Delta Ferrite Determination

A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, QW-442) backing filler metal (consumable inserts); bare electrode, rod, or wire filler metal; or weld metal, except that delta ferrite determinations are not required for SFA-5.4, Type 16-8-2, or A-No. 8 weld filler metal to be used for weld metal cladding.

NF-2433.1 Method.

Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of chemical analysis of NF-2432 in conjunction with Fig. NF-2433.1-1.

(a) Calibration of magnetic instruments shall conform to AWS A4.2-91.

(b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with NF-2432.1(c).

(c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number (FN).

NF-2433.2 Acceptance Standards.

The minimum acceptable delta ferrite shall be 5FN. The results of the delta ferrite determination shall be included in the Certified Material Test Report of NF-2130 or NF-4120.

NF-2440 STORAGE AND HANDLING OF WELDING MATERIAL

Suitable storage and handling of electrodes, flux, and other welding materials shall be maintained. Precautions shall be taken to minimize absorption of moisture by fluxes and cored, fabricated, and coated electrodes.

NF-2500 EXAMINATION AND REPAIR OF MATERIAL

NF-2510 EXAMINATION AND REPAIR OF MATERIAL OTHER THAN BOLTING

Material for supports shall be examined in accordance with the material specification. Defects may be repaired as permitted by the material specification.

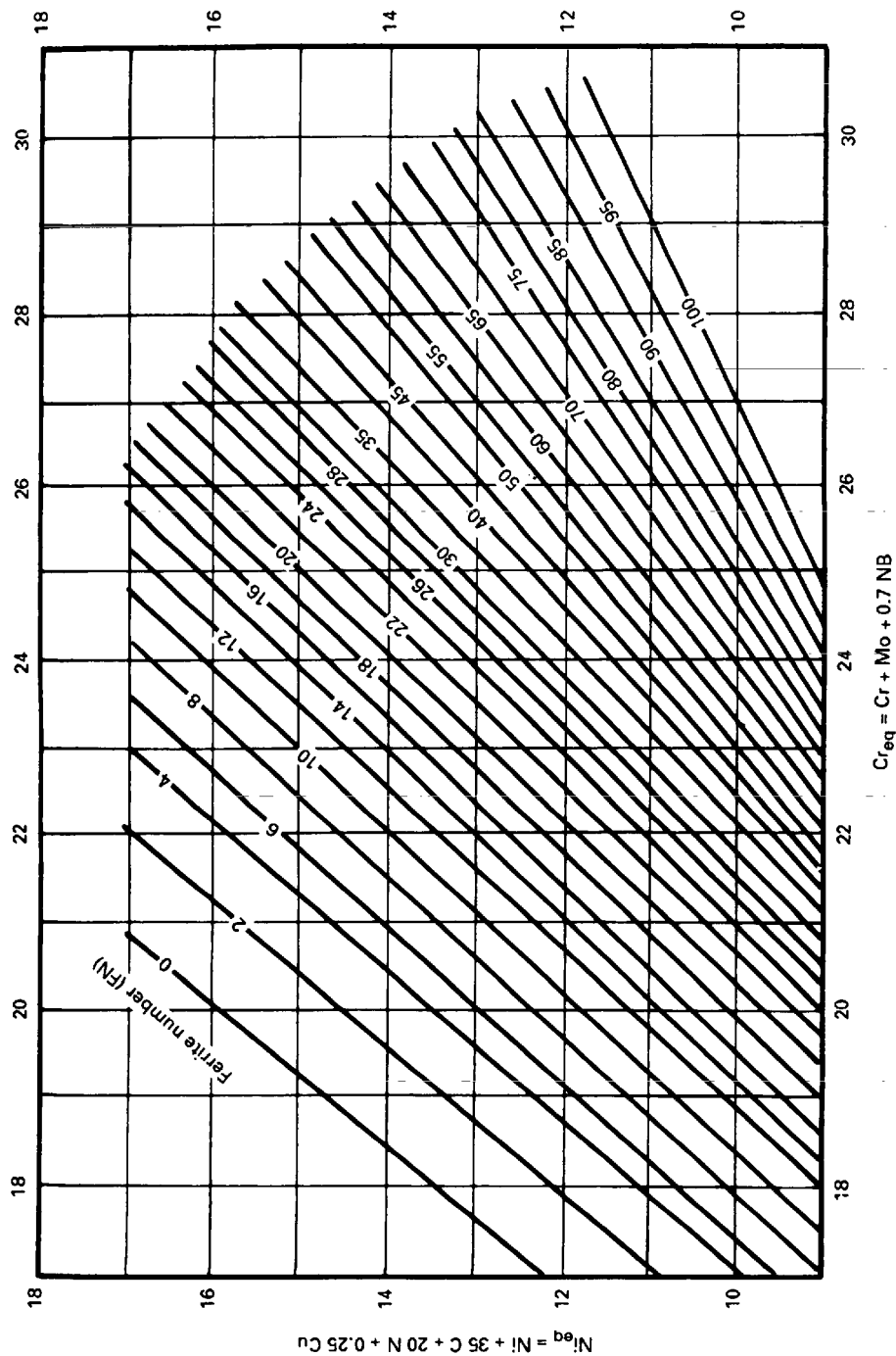
NF-2580 EXAMINATION OF BOLTING MATERIAL AND RODS⁷

NF-2581 Required Examinations

NF-2581.1 Class 1 Supports.

All bolting material and rods shall be visually examined in accordance with NF-2582. Nominal sizes greater than 2 in. shall be examined by either the magnetic particle or liquid penetrant method (NF-2583). In addition, nominal sizes greater than 4 in. shall be ultrasonically examined as required by NF-2584.

⁷ The word rods as used in this Subarticle is intended to cover rods that are threaded. It also includes forged piston rods if they are threaded for a portion of their length. It does not apply to unthreaded bar stock.



GENERAL NOTES:

- (a) The actual nitrogen content is preferred. If this is not available, the following applicable nitrogen value shall be used:
 - (1) GMAW welds - 0.08%, except that when self shielding flux cored electrodes are used - 0.12%.
 - (2) Welds made using other processes - 0.06%.
- (b) This diagram is identical to the WRC-1992 Diagram, except that the solidification mode lines have been removed for ease of use.

FIG. NF-2433.1-1 DELTA FERRITE CONTENT

FIG. NF-2433.1-1 DELTA FERRITE CONTENT

NF-2581.2 Class 2, 3, and MC Supports.

Bolts, studs, and nuts shall be examined in accordance with the requirements of the material specification and NF-2582

NF-2582 Visual Examination

The areas of threads, shanks, and heads of final machined parts shall be visually examined. Harmful discontinuities such as laps, seams, or cracks that would be detrimental to the intended service are unacceptable.

NF-2583 Magnetic Particle or Liquid Penetrant Examination

All bolting material and rods greater than 2 in. (51 mm) nominal size for Class 1 supports shall be examined by a magnetic particle method or a liquid penetrant method. Such examination shall be performed on the finished bolting material after threading or on the material stock at approximately the finished diameter before threading and after heading (if involved). Linear nonaxial indications are unacceptable. Linear axial indications greater than 1 in. in length are unacceptable.

NF-2584 Ultrasonic Examination for Sizes Greater Than 4 in. (102 mm)

All bolting material and rods greater than 4 in. (102 mm) nominal size for Class 1 supports shall be ultrasonically examined over the entire surface prior to threading in accordance with the requirements of the following subparagraphs.

NF-2584.1 Ultrasonic Method.

Examination shall be carried out by the straight beam, radial scan method.

NF-2584.2 Examination Procedure.

Examination shall be performed at a nominal frequency of 2.25 MHz with a search unit not to exceed 1 sq in. (645 mm²) area.

NF-2584.3 Calibration of Equipment.

Calibration sensitivity shall be established by adjustment of the instrument so that the first back reflection is 75%-90% of full screen height.

NF-2584.4 Acceptance Standards.

Any discontinuity which causes an indication in excess of 20% of the height of the first back reflection or any discontinuity which prevents the production of a first back reflection of 50% of the calibration amplitude is not acceptable.

NF-2586 Repair by Welding

Weld repairs of bolting material and rods are not permitted.

NF-2600 MATERIAL MANUFACTURER'S QUALITY SYSTEM PROGRAMS

NF-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS

(a) Except as provided in (b) below, Material Organizations shall have a Quality System Program or an Identification and Verification Program, as applicable, which meets the requirements of NCA-3800.

(b) The requirements of NCA-3862 shall be met as required by NF-2130. The other requirements of NCA-3800 need not be used by Material Organizations for small products, as defined in (c) below, for brazing material, and for material which is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Assurance Program (NCA-4000) shall include measures to provide assurance that the material is furnished in accordance with the material specification and the requirements of this Subsection.

(c) For the purpose of this paragraph, small products are defined as given in (1) through (3) below:

- (1) pipe, tube, pipe fittings, and flanges of 2 in. (51 mm) nominal size and less;
- (2) bolting material, including studs, nuts, and bolts of 2 in. (51 mm) nominal diameter and less;
- (3) structural material with a nominal cross-sectional area of 2 sq in. (1290 mm²) and less.
- (d) When impact testing is required in accordance with NF-2300, the material not exempted by NF-2311 shall be furnished with Certified Material Test Reports in accordance with NCA-3862.
- (e) Structural materials, which are permitted by this Section to be furnished with a Certificate of Compliance, may be repaired by welding using welders, documentation, and examination requirements specified in SA-6 and need not meet the requirements of NCA-3857.3.
- (f) Materials manufactured to a Material Specification prohibiting weld repair without user approval do not require documentation to indicate that weld repairs have not been performed.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NF-3000

ARTICLE NF-3000 DESIGN

Page 37

NF-3100 GENERAL DESIGN REQUIREMENTS

NF-3110 LOADING CRITERIA

NF-3111 Loading Conditions

The loadings that shall be taken into account in designing a support include, but are not limited to, those in (a) through (h) below:

- (a) weight of the piping or component and normal contents under plant and system operating and test conditions, including loads due to static and dynamic head and fluid flow effects;
- (b) weight of the support;
- (c) superimposed static and thermal loads and reactions induced by the supported system components;
- (d) dynamic loads, including loads caused by earthquake and vibration;
- (e) effects from piping thermal expansion;
- (f) anchor and support movement effects;
- (g) environmental loads such as wind and snow loads;
- (h) expansion or contraction of a component produced by internal or external pressure.

Guidelines for classification of these loadings into primary, secondary, or peak are listed in NF-3120 and NF-3220.

NF-3112 Design Loadings

The Design Loadings shall be established in accordance with NCA-2142.1 and the following subparagraphs.

[98]

NF-3112.1 Design Temperature.

The specified Design Temperature shall be established in accordance with NCA-2142.1(b). The metal temperature shall be determined by computation using accepted heat transfer procedures or by measurement from equipment in service under plant and system equivalent operating conditions. In lieu of heat transfer analysis or measurements, the component or piping Design Temperature may be used. In no case shall the temperature at the surface of the metal exceed the maximum temperature listed in Tables 1A, 1B, 2A, 2B, 3, 4, and Y-1 of Section II, Part D, Subpart 1, or exceed the maximum temperature limitations specified elsewhere in this Subsection.

[98]

NF-3112.2 Design Mechanical Loads.

The specified Design Mechanical Loads shall be established in accordance with NCA-2142.1(c), and shall include all loads from the component or piping acting on the support.

NF-3112.3 Design Stress Intensity and Allowable Stress Values.

When the procedures of design by analysis (NF-3220) are employed, the applicable design stress intensity values S_m listed in Tables 2A, 2B, and 4 of Section II, Part D, Subpart 1 shall be used. When the procedures of linear elastic analysis (NF-3320) are employed, the allowable stress values shall be the applicable yield strength values S_y listed in Table Y-1, Section II, Part D, Subpart 1 as modified by the design factors given in NF-3322.

NF-3113 Service Conditions

Each Service Condition to which the piping or component may be subjected shall be categorized in accordance with NCA-2142.2, and Service Limits [NCA-2142.4(b)] shall be designated in the Design Specification in such detail as will provide a complete basis for design in accordance with this Article.

NF-3114 Test Conditions

The component and piping support loadings resulting from test conditions shall be identified (NCA-2142).

NF-3120 DESIGN CONSIDERATIONS

NF-3121 Terms Relating to Design by Analysis

NF-3121.1 General Considerations

(a) Terms that are common to the design by stress analysis of Plate- and Shell-Type, Linear-Type, and

Page 44

Standard Supports are defined in NF-3121.2 through NF-3121.16 below.

(b) Terms unique to the design by stress analysis of Plate- and Shell-Type Supports are defined in NF-3212.

(c) Terms unique to the design by stress analysis of Linear-Type Supports are defined in NF-3313.

NF-3121.2 Primary Stress.

Primary stress is any normal stress or shear stress developed by an imposed loading which is necessary to satisfy the laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses which considerably exceed the yield strength S_y will result in failure or, at least, in gross distortion. A thermal stress is not classified as a primary stress. A general primary membrane stress is one which is so distributed in the support that no redistribution of load occurs in the support as a result of yielding. Examples of primary stress are general membrane stress in a circular cylindrical shell due to a uniformly distributed axial load, and bending stress in a cantilever beam due to a normal end load. In addition to the above, for supports, stresses induced in the support by restraint of free end displacement [NF-3111(e)] and anchor motion [NF-3111(f)] of piping are considered primary stresses.

NF-3121.3 Secondary Stress.

Secondary stress is a normal stress or a shear stress developed by the constraint of adjacent material or by self-constraint of the structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions which cause the stress to occur, and failure from one application of the stress is not to be expected. An example of secondary stress is bending stress at a gross structural discontinuity.

NF-3121.4 Peak Stress.

Peak stress is that increment of stress which is additive to the primary plus secondary stresses by reason of local discontinuities or local thermal stress, including the effects, if any, of stress concentrations. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or brittle fracture. A stress which is not highly localized falls into this category if it is of a type which cannot cause noticeable distortion. Evaluation of peak stresses in the support is not required by this Subsection.

NF-3121.5 Normal Stress.

Normal stress is the component of stress normal to the plane of reference. This is also referred to as direct stress. Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to be made up in turn of two components, one uniformly distributed and equal to the average value of stress across the thickness under consideration, and the other varying from this average value with the location across the thickness.

NF-3121.6 Shear Stress.

Shear stress is the component of stress tangent to the plane of reference.

NF-3121.7 Membrane Stress.

Membrane stress is the component of normal stress which is uniformly distributed and equal to the average of stress across the thickness of the section under consideration.

NF-3121.8 Bending Stress.

Bending stress is the variable component of normal stress. The variation may or may not be linear across the thickness.

NF-3121.9 Total Stress.

Total stress is the sum of the primary and secondary stress contributions. Recognition of each of the individual contributions is essential to establishment of appropriate stress limitations.

NF-3121.10 Critical Buckling.

Critical buckling occurs when a support is loaded to a state at which an infinitesimal additional load or disturbance causes the support to change from an equilibrium condition to one of instability.

NF-3121.11 Thermal Stress.

Thermal stress is a self-equilibrating stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally would under a change in temperature. Evaluation of thermal stresses in the support is not required by this Subsection.

NF-3121.12 Free End Displacement.

Free end displacement consists of the relative motions that would occur between an attachment and connected structure or equipment if the two members were separated and permitted to move.

NF-3121.13 Anchor Point Motion Stress.

Anchor point motion stresses are those stresses resulting from the differential motion of support points. An example is differential building settlement.

NF-3121.14 Gross Structural Discontinuity.

Gross structural discontinuity is a geometric or material discontinuity which affects the stress or strain distribution through the entire thickness of the member. Gross discontinuity-type stresses are those portions of the actual stress distributions that produce net bending and membrane force resultants when integrated through the thickness. Examples of gross structural discontinuities

Page 45

are junctions between parts of different diameters or thicknesses and flange-to-shell junctions.

NF-3121.15 Limit Analysis - Collapse Load.

The methods of limit analysis are used to compute the maximum load or combination of loads a structure made of ideally plastic (nonstrain-hardening) material can carry. The deformations of an ideally plastic structure increase without bound at this load, which is termed the collapse load.

NF-3121.16 Collapse Load - Lower Bound.

If, for a given load, any system of stresses can be found which everywhere satisfies equilibrium and nowhere exceeds the material yield strength, using shape factors associated with the cross section under consideration, the load is at or below the collapse load. This is the lower bound theorem of limit analysis which permits calculations of a lower bound to the collapse load.

NF-3122 Piping or Component Deformation Limits

Deformation limits for the supported piping or component shall be stipulated in the Design Specifications, if required.

NF-3123 Functional Requirements

When a support is to be designed to perform a specific function during any Service Condition, the functional requirements shall be designated in the Design Specifications.

NF-3124 Rolling and Sliding Supports

(a) Rolling and sliding supports shall permit free movement of the piping or component, or the piping or component shall be designed to include the imposed load and frictional resistance of these types of supports; their dimensions shall provide for the designed movement of the supported piping or component.

(b) Sliding supports (or shoes) and brackets shall be designed to accommodate the forces caused by friction in addition to the loads imposed by bearing. The dimensions of the support shall provide for the design movement of the supported piping or component. Material and lubricants used in sliding supports shall be suitable for the environment of the metal at the point of sliding contact and shall be specified in the Design Documents.

NF-3125 Sway Braces and Vibration Dampeners

Sway braces and vibration dampeners may be used to limit the effects of vibration and may be of the rigid strut (linear type) tension-compression type. If employed in the design or added as a result of observation under startup or initial operating conditions, the effect of sway braces shall be included in the stress analysis of the piping or component for all of the specified conditions.

NF-3127 Provisions for Movement of Supported Piping or Component

Consideration shall be given to the relative motion of the supported piping or component and the support. When clearances or travel ranges or both are required to accommodate piping or component movements, sufficient design margins shall be introduced to allow for variations due to fabrication and installation. Care shall be taken to ensure that design clearances and travel ranges are based on the maximum range that might occur between two operating conditions

and not necessarily on the maximum cold to hot range. All parts of the support shall be fabricated and assembled so that they will not be disengaged by movement of the supported piping or component. Supports needed only to provide stability during Level C or Level D Service Conditions shall be designed and installed so as not to overstress the piping or component during Level A or Level B Service Conditions.

NF-3128 Snubbers

The end connection of the snubber shall be designed to accommodate vertical and horizontal movement of the piping or component, as required.

NF-3130 GENERAL DESIGN REQUIREMENTS

NF-3131 Requirements for Acceptability

The requirements for acceptability of support design are given in (a) through (e) below.

(a) The design shall be such that the stress intensity values or the stress values (whichever are applicable) will not exceed the limits given in this Subarticle. Table NF-3131(a)-1 indicates the rules and limits to be used for the various classes and types of design procedures. The applicable tables of allowable stress

Page 46

values for materials to be used with a specific design procedure are referenced in Table NF-2121(a)-1.

**TABLE NF-3131(a)-1
REFERENCE PARAGRAPHS FOR PROCEDURES FOR DESIGN OF
COMPONENT SUPPORTS, PIPING SUPPORTS, AND STANDARD SUPPORTS**

Type and Class of Support	Plate and Shell					Linear				
	Design by Analysis	Bolting	Weld Joint	Experimental Analysis	Load Rating	Design by Analysis	Bolting	Weld Joints	Experimental Analysis	Load Rating
Component										
Class 1	NF-3220 NF-3522	NF-3225 NF-3525	NF-3226 NF-3526	NF-3270	NF-3280	NF-3320 NF-3523	NF-3324 NF-3525	NF-3324 NF-3526	NF-3370	NF-3380
Class 2 and MC [Note (1)]	NF-3250 NF-3552	NF-3255 NF-3555	NF-3256 NF-3556	NF-3270	NF-3280	NF-3350 NF-3553	NF-3324 NF-3555	NF-3324 NF-3556	NF-3370	NF-3380
Class 3	NF-3260 NF-3552	NF-3265 NF-3555	NF-3266 NF-3556	NF-3270	NF-3280	NF-3360 NF-3553	NF-3324 NF-3555	NF-3324 NF-3556	NF-3370	NF-3380
Piping										
Class 1	NF-3220 NF-3622	NF-3225 NF-3625	NF-3226 NF-3626	NF-3270	NF-3280	NF-3320 NF-3623	NF-3324 NF-3625	NF-3324 NF-3626	NF-3370	NF-3380
Class 2	NF-3250 NF-3652	NF-3255 NF-3655	NF-3256 NF-3656	NF-3270	NF-3280	NF-3350 NF-3653	NF-3324 NF-3655	NF-3324 NF-3656	NF-3370	NF-3380
Class 3	NF-3260 NF-3652	NF-3265 NF-3655	NF-3266 NF-3656	NF-3270	NF-3280	NF-3360 NF-3653	NF-3324 NF-3655	NF-3324 NF-3656	NF-3370	NF-3380
Standard										
Class 1 [Note (1)]	NF-3220 NF-3422	NF-3225 NF-3425	NF-3226 NF-3426	NF-3270	NF-3280	NF-3320 NF-3423	NF-3324 NF-3425	NF-3324 NF-3426	NF-3370	NF-3380
Class 2 and MC [Note (1)]	NF-3250 NF-3452	NF-3255 NF-3455	NF-3256 NF-3456	NF-3270	NF-3280	NF-3350 NF-3453	NF-3324 NF-3455	NF-3324 NF-3456	NF-3370	NF-3380
Class 3	NF-3260 NF-3452	NF-3265 NF-3455	NF-3266 NF-3456	NF-3270	NF-3280	NF-3360 NF-3453	NF-3324 NF-3455	NF-3324 NF-3456	NF-3370	NF-3380

NOTE:

(1) Supports for Class 2 vessels designed to NC-3200 shall be designed in accordance with Class 1 requirements.

TABLE NF-3131(a)-1 REFERENCE PARAGRAPHS FOR PROCEDURES FOR DESIGN OF COMPONENT SUPPORTS, PIPING SUPPORTS, AND STANDARD SUPPORTS

- (b) The design procedure shall be one of those given in Table NF-3131(a)-1 as being applicable to supports.
- (c) The design details shall conform to the rules of this Subarticle or to those referenced herein.
- (d) For configurations where compressive stresses occur, the critical buckling stress shall be taken into account in addition to the requirements of (a), (b), and (c) above.
- (e) For Class 1 supports, protection against nonductile fracture shall be provided. An acceptable procedure for nonductile failure prevention is given in Appendix G of Section III, Division 1, Appendices.

[98]

NF-3132 Dimensional Standards

Dimensions of component and piping supports may comply with the standards and specifications listed in Table NF-3132-1 but are not mandatory. Compliance

Page 47

with these standards does not replace or eliminate the requirements for stress analysis or load rating. Guidance on tolerances for supports is provided in Appendix K of Section III, Division 1, Appendices.

[98]

TABLE NF-3132-1
DIMENSIONAL STANDARDS

Standard	Description
Pipe and Tubing	
Welded and Seamless Wrought Steel	ANSI B36.10M-1985
Stainless Steel Pipe	ANSI B36.19M-1985
Bolting	
Square and Hex Bolt and Screws, Including Askew Head Bolts and Cap Screws and Lag Screws	ANSI B18.2.1-1981 (R 1992)
Square and Hex Nuts	ANSI B18.2.2-1987 (R 1993)
Socket Cap, Shoulder and Set Screws	ANSI B18.3-1986
Threads	
Unified Inch Threads (UN and UNR Thread Form)	ANSI B1.1-1989
Pipe Threads (Except Dryseal)	ANSI B1.20.1-1983 (R 1992)
Dryseal Pipe Thread	ANSI B1.20.3-1976 (R 1991)
Gaging for Dryseal Piping Threads	ANSI B1.20.5-1991
Standard Supports	
Pipe Hangers and Supports — Fabrication and Installation Practices	MSS SP-89-1991
Structural Plates, Shapes, Sheet Piling and Bars	
General Requirements for Rolled Steel Plates, Shapes Sheet Piling, and Bars for Structural Use	ASME SA-6

TABLE NF-3132-1 DIMENSIONAL STANDARDS

NF-3133 Stress Analysis

A detailed stress analysis or Design Report, as required by NCA-3550 for all supports, shall be prepared in sufficient detail to show that each of the stress limits of NF-3200 or NF-3300 is satisfied when the piping or component support is subjected to the loadings of NF-3110.

NF-3140 GENERAL DESIGN PROCEDURES

NF-3141 Types of Procedures

(a) The design procedure which may be used is dependent on the type of support being designed and the Class of construction involved. Three design procedures are recognized, namely:

(1) design by analysis:

(a) maximum shear stress theory

(b) maximum stress theory

(2) experimental stress analysis (Section III, Division 1, Appendices, Appendix II)

(3) load rating

(b) Unless either the experimental stress analysis procedure or the load rating procedure is used, the requirements of the following paragraphs apply.

NF-3142 Plate- and Shell-Type Supports - Analysis Procedure

(a) Elastic analysis based on maximum shear stress theory in accordance with the rules of NF-3200 shall be used in the design of Plate- and Shell-Type Supports of Class 1 construction.

(b) Elastic analysis based on maximum stress theory shall be used in the design of Plate- and Shell-Type Supports of Class 2, 3, and MC construction. Supports for Class 2 vessels designed to NC-3200 shall be designed in accordance with Class 1 requirements.

NF-3143 Linear-Type Supports - Analysis Procedure

(a) The analysis procedure shall comply with (1) or (2) below.

(1) Elastic analysis based on maximum stress theory in accordance with the rules of NF-3300 shall be used for the design of Linear-Type Supports for Class 1, 2, 3, and MC construction.

(2) Limit analysis in accordance with the procedures of NF-3340 shall be used in the design of Linear-Type

Page 48

Supports for Class 1, 2, 3, and MC construction when members and their connections are subject to high cycle fatigue as defined in NF-3331.

(b) High cycle fatigue analysis in accordance with procedures of NF-3330 shall be used in the design of Linear-Type Supports for Class 1 construction.

NF-3144 Standard Supports - Analysis Procedure

Standard Supports designed by analysis shall be designed to either the requirements of NF-3142 or NF-3143, according to whether they are Plate- and Shell-Type or Linear-Type Standard Supports.

NF-3200 DESIGN RULES FOR PLATE- AND SHELL-TYPE SUPPORTS

NF-3210 GENERAL REQUIREMENTS

NF-3211 Basis for Determining Stresses in Design by Analysis

The theory of failure used in the rules of this Subsection for combining stresses for the design of Class 1 Plate- and Shell-Type Supports is the maximum shear stress theory; for Class 2, 3, and MC Plate- and Shell-Type Supports, it is the maximum stress theory.

NF-3212 Definitions

Terms used in the design of Plate- and Shell-Type Supports by stress analysis are defined in NF-3121 and in NF-3212.1 below.

NF-3212.1 Stress Intensity.¹

Stress intensity is defined as twice the maximum shear stress. The stress intensity is the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tensile stresses are considered positive and compressive stresses are considered negative.

NF-3220 DESIGN BY ANALYSIS FOR CLASS 1

¹ This definition of stress intensity is not related to the definition of stress intensity applied in the field of fracture mechanics.

NF-3221 Stress Limits

Stress limits for elements of Class 1 supports are given in this paragraph. Stress limits for bolts and welds are given in NF-3225 and NF-3226. General requirements concerning stress determinations, definitions, derivations of stress intensities, and classification of stresses are given in NF-3210.

Plate- and Shell-Type Supports may be designed by either elastic or limit analysis, stress intensity limits for which are given in the following subparagraphs.

NF-3221.1 Design Limits.

The stress intensity limits which must be satisfied for the Design Loadings stated in the Design Specification are the two limits of this paragraph and the Special Stress Limits of NF-3223. The design stress intensity values S_m are given in NF-3224.

(a) General primary membrane stress intensity P_m is derived from the average value across the thickness of a section of the general primary stresses produced by specified Design Mechanical Loads, but excluding all secondary stresses. Averaging is to be applied to the stress components prior to determination of the stress intensity values. The allowable value of this stress intensity is S_m at the Design Temperature.

(b) Primary membrane plus primary bending stress intensity $P_m + P_b$ is derived from the highest value across the thickness of a section of the general membrane stresses plus primary bending stresses produced by the specified Design Mechanical Loads, but excluding all secondary stresses. The allowable value of this stress intensity is $1.5S_m$.

NF-3221.2 Service Level A Through D Service Limits.

The rules and stress limits which must be satisfied in an elastic analysis for any Level A through D Service Loadings stated in the Design Specification are those given in NF-3221.1 and NF-3223 multiplied by the appropriate stress intensity limit factor from Tables NF-3522(b)-1 and NF-3622(b)-1 for the particular loading and stress categories.

NF-3221.3 Test Limits.

The rules and stress limits which must be satisfied for any Test Loadings stated in the Design Specification are those given in NF-3221.1 and NF-3223 multiplied by the appropriate stress intensity limit factor in Tables NF-3522(b)-1 and NF-3622(b)-1 under Test Loadings.

NF-3221.4 Limit Analysis.

The limits on primary membrane plus primary bending stress intensity [NF-3221.1(b)] need not be satisfied at a specific location if it can be shown by means of limit analysis or by tests that the specified loadings do not exceed two-thirds of the lower bound collapse load for Design Loadings and Service Level A and B Loadings, and do not exceed 0.8 times the lower bound collapse load for Service Level C Loadings. The rules of Appendix F (Section III, Division 1, Appendices) shall apply for

Service Level D Loadings. For materials in Section II, Part D, Subpart 1 for which allowable stresses, or stress intensities, may reach 90% of the yield strength S_y at temperature, the specified loading shall not exceed the product of the applicable permanent strain limiting factor of Table Y-2, Section II, Part D, Subpart 1 times the lower bound collapse load.

NF-3222 Derivation of Stress Intensities

One requirement for the acceptability of a design (NF-3130) is that the calculated stress intensities shall not exceed specified allowable limits. These limits differ depending on the stress category (primary, secondary, etc.) from which the stress intensity is derived. This paragraph describes the procedure for the calculation of the stress intensities which are subject to the specified limits. The steps in the procedure are stipulated in (a) through (e) below.

(a) At the point on the support which is being investigated, choose an orthogonal set of coordinates, such as tangential, longitudinal, and radial, and designate them by the subscripts t , l , and r . The stress components in these directions are then designated σ_t , σ_l , and σ_r for direct stresses and T_{lt} , T_{lr} , and T_{rt} for shear stresses.

(b) Calculate the stress components for each type of loading to which the item will be subjected and assign each set of stress values to one or a group of the following categories:

(1) general primary membrane stress P_m (NF-3121.7)

(2) primary bending stress P_b (NF-3121.8)

(3) secondary stress Q (NF-3121.3)

(c) For each category, calculate the algebraic sum of the values of σ_t which result from the different types of loadings, and similarly for the other five stress components. Certain combinations of the categories must also be considered.

(d) Translate the stress components for the t , l , and r directions into principal stresses σ_1 , σ_2 , and σ_3 .

(e) Calculate the stress differences S_{12} , S_{23} , and S_{31} from the relations:

$$S_{12} = \sigma_1 - \sigma_2$$

$$S_{23} = \sigma_2 - \sigma_3$$

$$S_{31} = \sigma_3 - \sigma_1$$

The stress intensity S is the largest absolute value of S_{12} , S_{23} , and S_{31} .

NOTE: Membrane stress intensity is derived from the stress components averaged across the thickness of the section. The averaging shall be performed at the component stress level in step (b) or (c) above.

NF-3223 Special Stress Limits

The following deviations from the basic stress limits are provided to cover special Service Loadings or configurations. Some of these deviations are more restrictive and some are less restrictive than the basic stress limits. In cases of conflict between these requirements and the basic stress limits, the rules of this paragraph take precedence for the particular situations to which they apply.

NF-3223.1 Bearing Loads

(a) The average bearing stress for resistance to crushing under the maximum load, experienced as a result of Design Loadings, Test Loadings, or any Service Loadings, except those for which Level D Limits are designated, shall be limited to S_y at temperature, except that when the distance to a free edge is larger than the distance over which the bearing load is applied, a stress of $1.5S_y$ at temperature is permitted.

(b) When bearing loads are applied near free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. The average shear stress shall be limited to $0.6S_m$ in the case of primary stress (NF-3121.2) and $0.5S_y$ in the case of primary stress plus secondary stress (NF-3121.9).

(c) When considering bearing stresses in pins and similar members, the S_y at temperature is applicable, except that a value of $1.5S_y$ may be used if no credit is given to the bearing area within one pin diameter from a plate edge.

NF-3223.2 Pure Shear

(a) The average primary shear stress across a section loaded in pure shear, experienced as a result of Design Loadings, Test Loadings, or any Service Loadings, except those for which Level D Limits are designated, shall be limited to $0.6S_m$.

(b) The maximum primary shear, experienced as a result of Design Loadings, Test Loadings, or any Service Loadings except those for which Level D Limits are designated, exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.8S_m$. Primary plus secondary shear stresses shall be converted to stress intensities (equal to two times pure shear stress) and as such shall not exceed the basic stress limits of Tables NF-3522(b)-1 and NF-3622(b)-1.

Page 50

NF-3223.3 Triaxial Stresses.

The algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) shall not exceed four times the tabulated value of S_m .

NF-3223.4 Applications of Elastic Analysis for Stresses Beyond the Yield Strength.

Certain of the allowable stresses permitted in the design criteria are such that the maximum stress calculated on an elastic basis may exceed the yield strength of the material.

NF-3224 Design Stress Values

The design stress intensity values S_m are given in Tables 2A, 2B, and 4, Section II, Part D, Subpart 1 for support material. Values for intermediate temperatures may be found by interpolation. These form the basis for the various stress limits. Values of yield strength are given in Table Y-1, Section II, Part D, Subpart 1. S_m values for bolting materials listed in Table 4, Section II, Part D, Subpart 1 are based on $(1/3)S_y$. Multiply S_m by three to arrive at S_y values for the material (Round up to next higher 0.5 ksi). Values of the coefficient of thermal expansion and of the modulus of elasticity are given in Tables TE and TM, Section II, Part D, Subpart 2. The basis for establishing stress values is given in Appendix III (Section III, Division 1, Appendices).

NF-3225 Design of Bolting

NF-3225.1 Design Limits.

The rules and stress limits which must be satisfied for any Design Loading stated in the Design Specification are those given in NF-3324.6.

NF-3225.2 Service Limits, Level A Through D.

The rules and stress limits which must be satisfied for any Level A through D Service Loading stated in the Design Specification are those given in NF-3324.6 multiplied by the appropriate stress limit factor for the particular service loading level and stress category specified in Table NF-3225.2-1. This product shall not exceed the yield strength of the material at temperature.

NF-3225.3 Test Limits.

The rules and stress limits which must be satisfied for any Test Loadings stated in the Design Specification are those given in NF-3324.6 multiplied by the appropriate stress limit factor for the particular Service Loading Level and stress category specified in Table NF-3225.2-1.

NF-3225.4 Friction-Type Joints.

Multiplying factors normally used to increase the allowable limits for Service Level B, C, and D are not applicable to friction-type joints [see NF-3324.6(a)(4)].

NF-3226 Design of Welded Joints

NF-3226.1 Permissible Types of Welded Joints in Plate- and Shell-Type Supports.

All welded joints in Plate- and Shell-Type Supports shall be continuous and shall be of one of the types listed in (a) through (c) below. Typical examples of those permitted types are shown in Fig. NF-3226.1-1. Fillet and partial penetration welds shall meet the requirements of NF-3324.5(d), except that NF-3324.5(d)(7) does not apply.

(a) *Butt Joints.* Butt joints shall be one of the following:

- (1) full penetration, single or double welded [Fig. NF-3226.1-1, sketches (a-1) and (a-2)];
- (2) partial penetration, double welded [Fig. NF-3226.1-1, sketch (b)];
- (3) the applicable welds may be either square groove, V groove, bevel groove, J groove, U groove, flare V groove, or flare bevel groove [see Fig. NF-3226.1(a)-1];
- (4) when angle joints are used for connecting a transition in diameter to a cylinder, the angle α of Fig. NF-3226.1-1, sketch (f) shall not exceed 30 deg.
- (5) A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections, as shown in Fig. NF-3226.1(a)-2, shall be provided at joints between sections that differ in thickness by more than one-fourth of the thickness of the thinner section or by more than $\frac{1}{8}$ in. (3.2 mm), whichever is less. The transition may be formed by any process that will provide a uniform taper. The weld may be partly or entirely in the tapered section, or adjacent to it. This paragraph also applies when there is a reduction in thickness within a spherical shell, or cylindrical course or plate.
- (6) When the use of backing rings will result in undesirable conditions such as severe stress or corrosion, the requirements of NF-4240 shall be met.

(b) *Corner Joints.* Corner joints shall be one of the following:

- (1) full penetration, as shown in Fig. NF-3226.1-1, sketch (d-1);
- (2) partial penetration with a fillet weld as shown in Fig. NF-3226.1-1, sketches (d-2) and (d-3);
- (3) the applicable welds are fillet, square groove, V groove, bevel groove, U groove, J groove, flare V groove and flare bevel groove.

(c) *Tee Joints.* Tee joints shall be one of the following:

- (1) full penetration, Fig. NF-3226.1-1, sketches (c) and (g);
- (2) partial penetration, double welded with or without additional fillet welds, Fig. NF-3226.1-1, sketch (e);

**TABLE NF-3225.2-1
STRESS LIMIT FACTORS
FOR CLASS 1, 2, 3, AND MC BOLT DESIGN BY ANALYSIS**

Stress Category	Stress Limit Factors for Loading Levels Stated in Design Specification [Note (1)]					
	Design	Service Level A	Service Level B	Service Level C	Service Level D	Test Loading
Tension and shear	$K_{bo} = 1.0$	$K_{bo} = 1.0$	$K_{bo} = 1.15$	$K_{bo} = 1.25$	[Note (2)]	$K_{bo} = 1.25$

GENERAL NOTE:

K_{bo} = stress limit factor applicable to the Design allowable tensile and shear stresses

NOTES:

- (1) Not to be used for friction type connections.
(2) Use Appendix F.

TABLE NF-3225.2-1 STRESS LIMIT FACTORS FOR CLASS 1, 2, 3, AND MC BOLT DESIGN BY ANALYSIS

(3) partial penetration, single welded between the end surface of a closed tubular section or a closed formed section, Fig. NF-3226.1-1, sketch (h);

(4) the applicable welds may be square groove, bevel groove, J groove, flare V groove or flare bevel groove.

NF-3226.2 Stress Intensities and Stress Limits for Welded Joints in Plate- and Shell-Type Supports

(a) *Design Limits.* The stress intensity and allowable stress limits which must be satisfied for welds for the Design Loadings stated in the Design Specification shall be the following.

(1) *Full Penetration Groove Welds.* The stress intensity limits for full penetration groove welds shall not exceed the applicable stress intensity value for the base metal being joined, as specified in NF-3221.1 and Table NF-3324.5(a)-1. See NF-3111.

(2) *Partial Penetration Groove Welds*

(a) *Compression Normal to Effective Throat or Shear on Effective Throat.* The stress intensity and stress limits shall be the same as those for the base metal as required in NF-3221.1.

(b) *Tension Normal to the Axis on the Effective Throat.* The stress limits shall be as specified in Table NF-3324.5(a)-1.

(3) *Fillet Welds.* The allowable stress limits for fillet welds shall be as specified in Table NF-3324.5(a)-1.

(b) *Service Limits, Level A Through D, and Test.* The rules and stress limits which must be satisfied for welds for any Level A through D Service and Test Loadings stated in the Design Specification are those given in NF-3226.2(a) multiplied by the appropriate base material stress limit factor given in Table NF-3622(b)-1 for Piping Supports and Table NF-3522(b)-1 for Component Supports.

(c) The effective sizes of welds shall be as given in NF-3324.5(d) and NF-3324.5(f).

NF-3250 DESIGN BY ANALYSIS FOR CLASS 2 AND MC

Plate- and Shell-Type Supports may be designed by either elastic or limit analysis, limits for which are given in the following subparagraphs. Limits for bolts and welds are given in NF-3255 and NF-3256. For general requirements and definitions, see NF-3100 and NF-3210.

NF-3251 Stress Limits

NF-3251.1 Design Loadings.

The stress² limits are satisfied for the Design Loadings (NCA-2142.1) stated in the Design Specifications if the requirements of Eqs. (1) and (2) are met.

$$(1) \sigma_1 \leq 1.0S$$

$$(2) \sigma_1 + \sigma_2 \leq 1.5S$$

² Stress means the maximum normal stress (principal stress).

where

σ_1

= membrane stress, ksi, which is the average stress across the solid section under consideration. It includes the effects of discontinuities, but not local stress concentrations.

σ_2

= bending stress, ksi, which is the linear varying portion of the stress across the solid section under consideration. It excludes the effects of discontinuities and concentrations.

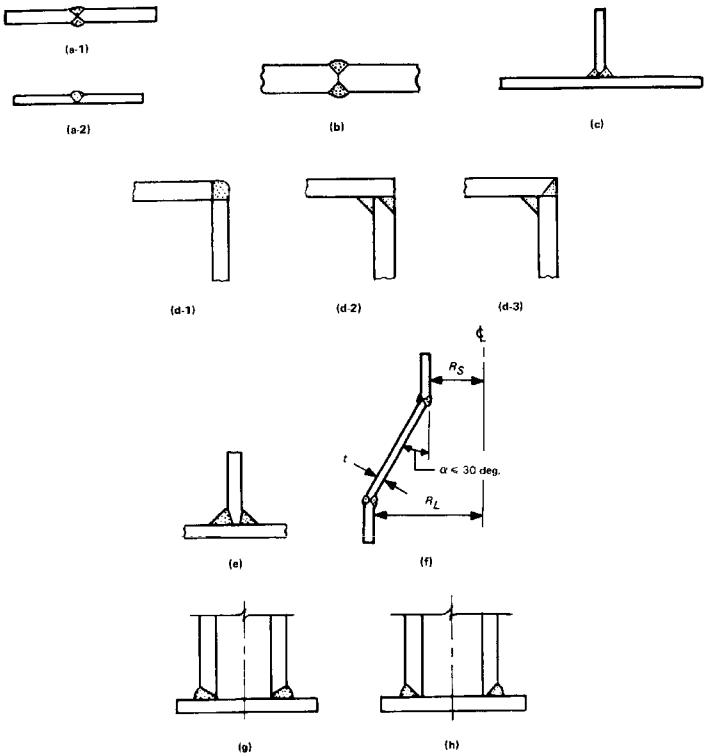


FIG. NF-3226.1-1 PERMISSIBLE WELDED JOINTS FOR CLASS 1 PLATE- AND SHELL-TYPE SUPPORTS

c

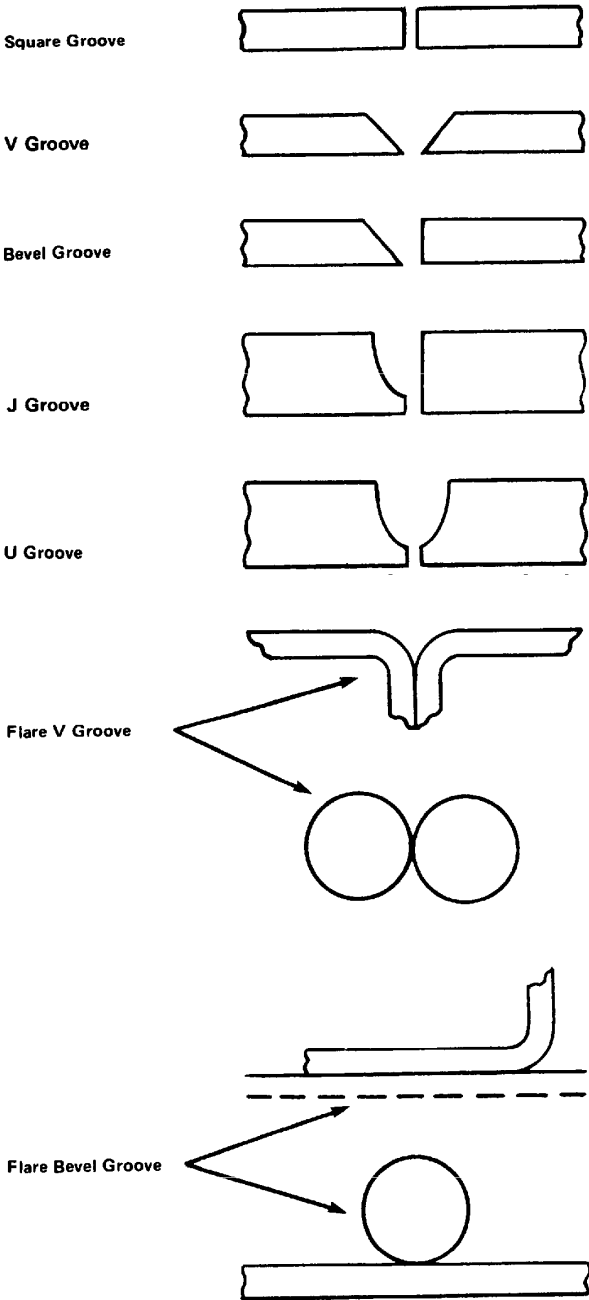
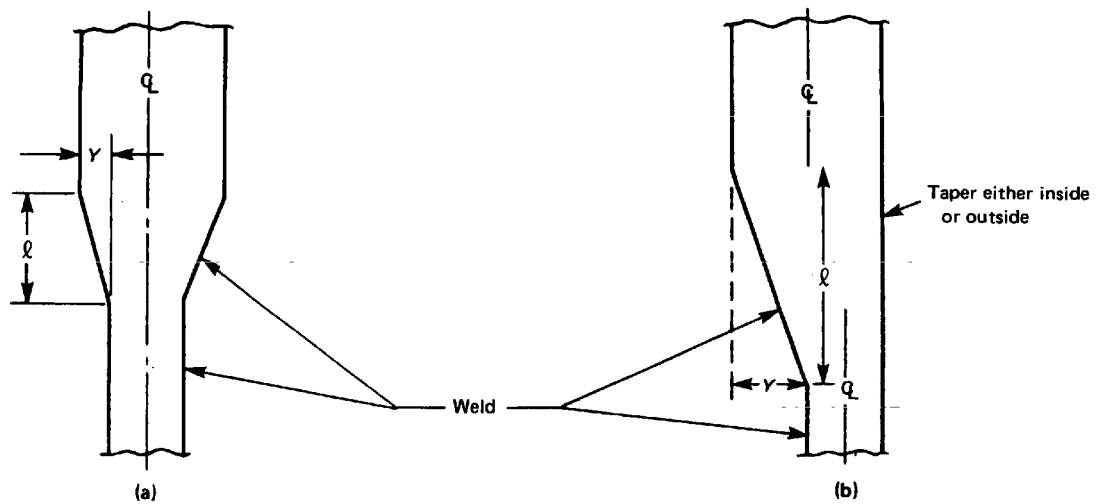


FIG. NF-3226.1(a)-1 TYPICAL WELD DETAILS REFERENCED

FIG. NF-3226.1(a)-1 TYPICAL WELD DETAILS REFERENCED

S

= allowable stress value, ksi, from the applicable table of Section II, Part D, Subpart 1, as referenced in Table NF-2121(a)-1



GENERAL NOTES:

- (a) $l \geq 3y$, where l is required length of taper and y is the offset between the adjacent surfaces of abutting sections.
- (b) Length of required taper l may include the width of the weld.
- (c) In all cases l shall not be less than $3y$.

FIG. NF-3226.1(a)-2 BUTT WELDING OF PLATES OF UNEQUAL THICKNESS

FIG. NF-3226.1(a)-2 BUTT WELDING OF PLATES OF UNEQUAL THICKNESS

NF-3251.2 Service Loadings - Service Level A Through D.

The rules and stress limits which must be satisfied in an elastic analysis for any Level A through D Service Loading stated in the Design Specification are those given for Design Loadings in NF-3251.1 multiplied by the appropriate stress limit factor specified in Tables NF-3552(b)-1 and NF-3652(b)-1.

NF-3251.3 Test Loadings.

The rules and stress limits which must be satisfied for any Test Loadings stated in the Design Specification are those given for Design Loadings in NF-3251.1 multiplied by the appropriate stress limit factor specified in Tables NF-3552(b)-1 and NF-3652(b)-1.

NF-3251.4 Limit Analysis.

The limits for Class 1 Plate- and Shell-Type Supports designed by limit analysis apply.

NF-3252 Special Stress Limits

The following deviations from the basic stress limits are provided to cover special Service Loadings or configurations. Some of these deviations are more restrictive and some are less restrictive than the basic stress limits. In cases of conflict between these requirements and the basic stress limits, the rules of this paragraph take precedence for the particular situations to which they apply.

NF-3252.1 Bearing Loads

(a) The average bearing stress for resistance to crushing under the maximum load, experienced as a result of Design Loadings, Test Loadings, or any Service Loadings, shall be limited to S_y at temperature, except that when the distance to a free edge is larger than the distance over which the bearing load is applied, a stress of $1.5S_y$ at temperature is permitted.

(b) When bearing loads are applied near free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. In the case of load controlled stress only, the average shear stress shall be limited to $0.6S$ in the case of primary stress (NF-3121.2).

Page 55

(c) When considering bearing stresses in pins and similar members, the S_y at temperature value is applicable, except that a value of $1.5S_y$ may be used if no credit is given to the bearing area within one pin diameter from a plate edge.

NF-3252.2 Pure Shear

(a) The average primary shear stress across a section loaded in pure shear, experienced as a result of Design Loadings, Test Loadings, or any Service Loadings, shall be limited to $0.6S$.

(b) The maximum primary shear, experienced as a result of Design Loadings, Test Loadings, or any Service Loadings exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.8S$.

NF-3255 Design of Bolting

The provisions of NF-3225 apply.

NF-3256 Design of Welded Joints

NF-3256.1 Permissible Types of Welded Joints in Plate- and Shell-Type Supports.

All welded joints in Plate- and Shell-Type Supports shall be continuous and shall be of one of the types listed in (a) through (d) below. Typical examples of those permitted types are shown in Fig. NF-3256.1-1. Fillet and partial penetration welds shall meet the requirements of NF-3324.5(d), except that NF-3324.5(d)(7) does not apply. Plug and slot welds shall meet the requirements of NF-3324.5(e). Lap joints shall meet the requirements of NF-3324.3.

(a) *Butt Joints.* Butt joints shall be one of the following:

(1) full penetration, single and double welded, Fig. NF-3256.1-1, sketches (a-1) and (a-2);

(2) partial penetration, double welded, Fig. NF-3256.1-1, sketch (b);

(3) when angle joints are used for connecting a transition in diameter to a cylinder, the angle α of Fig. NF-3256.1-1, sketch (n) shall not exceed 30 deg.

(4) A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections, as shown in Fig. NF-3226.1(a)-2, shall be provided at joints between sections that differ in thickness by more than one-fourth of the thickness of the thinner section or by more than $\frac{1}{8}$ in. (3.2 mm), whichever is less. The transition may be formed by any process that will provide a uniform taper. The weld may be partly or entirely in the tapered section or adjacent to it.

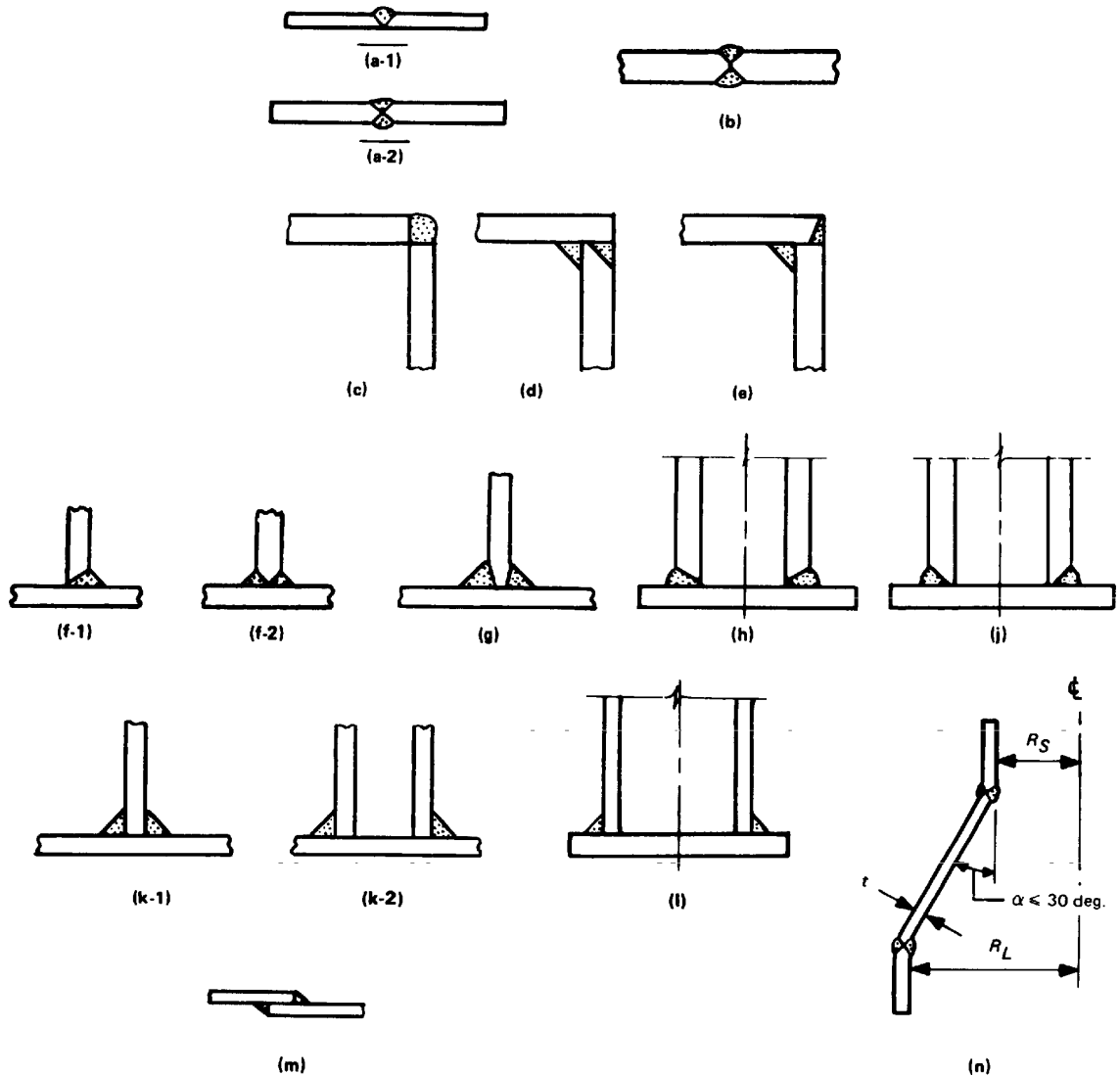
(5) When the use of backing rings will result in undesirable conditions such as severe stress or corrosion, the requirements of NF-4240 shall be met.

(b) *Corner Joints.* Corner joints shall be one of the following:

- (1) full penetration, as shown in Fig. NF-3256.1-1, sketch (c);
- (2) partial penetration with a fillet weld as shown in Fig. NF-3256.1-1, sketches (d) and (e).
- (c) *Tee Joints.* Tee joints shall be one of the following:
 - (1) full penetration, single or double welded, Fig. NF-3256.1-1, sketches (f-1), (f-2), and (h);
 - (2) partial penetration, with or without additional fillet welds, Fig. NF-3256.1-1, sketch (g);
 - (3) partial penetration, single welded between a plate and the end surface of a closed tubular section or a closed formed section, Fig. NF-3256.1-1, sketch (j);
 - (4) fillet, double welded, Fig. NF-3256.1-1, sketch (k-1); single welded when double members are used, Fig. NF-3256.1-1, sketch (k-2);
 - (5) fillet, single welded between a flat surface and the end surface of a closed tubular section or a closed formed section, Fig. NF-3256.1-1, sketch (l);
- (d) *Lap Joints.* Lap joints shall be fillet, double welded, Fig. NF-3256.1-1, sketch (m).
- (e) The applicable welds for the joints permitted in (a) through (d) above are:
 - (1) square groove, bevel groove, J groove, flare bevel groove, U groove and V groove.
 - (2) plug and slot welds are permitted in (c) and (d) only.
 - (3) Fillet welds are permitted in (c)(4), (c)(5), and (d) only.

NF-3256.2 Allowable Stress Limits

- (a) *Design Limits.* The allowable stress limits which must be satisfied for the Design Loadings stated in the Design Specification shall be the following.
 - (1) *Full Penetration Groove Welds.* The allowable stress limits for full penetration groove welds shall not exceed the applicable allowable stress value for the base metal being jointed, as specified in NF-3251.1 and Table NF-3324.5(a)-1.
 - (2) *Partial Penetration Groove Welds*
 - (a) *Compression Normal to Effective Throat or Shear on Effective Throat.* The allowable stress limits shall be as specified in Table NF-3324.5(a)-1.
 - (b) *Tension Normal to the Axis on the Effective Throat.* The stress limits shall be as specified in Table NF-3324.5(a)-1.



GENERAL NOTE:

For weld sketches (c), (d), (e), (f-1), (f-2), (g), (k-1), and (k-2), the welds may be intermittent for class 3 only.

FIG. NF-3256.1-1 PERMISSIBLE WELDED JOINTS FOR CLASS 2, 3, AND MC PLATE- AND SHELL-TYPE SUPPORTS

FIG. NF-3256.1-1 PERMISSIBLE WELDED JOINTS FOR CLASS 2, 3, AND MC PLATE- AND SHELL-TYPE SUPPORTS

(3) *Fillet Welds.* The allowable stress limit for fillet welds shall be as specified in Table NF-3324.5(a)-1.

(b) Service Limits. Level A Through D, and Test. The rules and stress limits which must be satisfied for welds for any Level A through D Service and Test Loading stated in the Design Specification are those given in NF-3356.2(a) multiplied by the appropriate base material stress limit factor given in Table NF-3652(b)-1 for Piping Supports and Table NF-3562(b)-1 for Component Supports.

NF-3256.3 Effective Size.

The effective sizes of welds shall be as given in NF-3324.5(d), (e), and (f).

NF-3260 DESIGN BY ANALYSIS FOR CLASS 3

NF-3261 Stress Limits

The design of Class 3 supports shall be in accordance with the requirements of NF-3250 using one of the design procedures indicated in Table NF-3131(a)-1 for Class 3 construction.

NF-3265 Design of Bolting

The provisions of NF-3225 apply.

NF-3266 Design of Welded Joints

The types of welded joints shall be as stipulated in NF-3256 for Class 2 and MC supports, except that for groove welded T-joints, groove welded corner joints, and fillet welded T-joints, as listed in NF-3256.1(a)(2) and (3), the welds may be intermittent instead of continuous. Intermittent fillet welds shall meet the requirements of NF-3324.5(d)(7). The allowable stress limits shall be as stipulated in NF-3256.2.

NF-3270 EXPERIMENTAL STRESS ANALYSIS

Supports may be designed by experimental stress analysis in accordance with Appendix II (Section III, Division 1, Appendices).

NF-3280 DESIGN BY LOAD RATING

NF-3281 Procedure for Load Rating

The procedure for load rating shall consist of imposing a total load on one or more duplicate full-size samples of a support equal to or less than the load under which the support fails to perform its required function. Full-size samples composed of various parts may have each part or a number of parts load rated, provided that all parts in the load path are either load rated or otherwise qualified per NF-3200, or by experimental stress analysis. When parts are connected by bolting or welding, the connection shall be either load rated or qualified per NF-3225 or NF-3226. Should more than one part be load rated in a single load test, then the load rating equations of NF-3280 shall be evaluated for each part using the part's $S_{y(alt)}$ and $S_{u(alt)}$ values. The part having the lowest load rating shall establish the load rating for the combination of parts. A single test sample is permitted but, in that case, the load ratings shall be reduced by 10%. Otherwise, tests shall be run on a statistically significant number of samples. The permissible types of welded joints shall be as permitted for the specific class of construction in NF-3226.1, NF-3256.1, and NF-3266. The full-size sample shall be fabricated for testing using welds not exceeding weld sizes stipulated in the Design Drawings. Bolted joints in the test sample shall be made up using the lowest strength bolt material and minimum edge distance allowed by the specification.

NF-3282 Load Ratings in Relation to Design Service and Test Loadings

The load rating for Design Loadings shall be determined in accordance with the requirements for Service Level A limits. The load ratings for Service Loadings for which Level A, Level B, or Level C Limits have been designated shall be determined by means of the equations in the following subparagraphs. For Level D Limits, see Appendix F of Section III, Division 1, Appendices. The load rating for Test Loadings shall be determined in accordance with the requirements for Service Level B limits.

NF-3282.1 Nomenclature.

The symbols used in this paragraph are defined as follows:

TL_y	= support test load at or below yield
TL_u	= support test load at which a substantial increase in load displacement results in zero or negative increase in actual support load
S	= allowable stress value at the Design Temperature (NF-3112.1) from the applicable tables of Section II, Part D, Subpart 1, ksi
S_u	= specified minimum tensile strength of the material used in the support as given in the applicable tables of Section II, Part D, Subpart 1, ksi
$S_{u(act)}$	= actual tensile strength of the material used in
	the part or support which had reached ultimate capacity during the test
$S_{y(act)}$	= actual yield strength of the material used in the part or support which yielded during the test
KI	= load rating coefficient for support in compression

Page 58

NF-3282.2 Plate- and Shell-Type Supports.

The load ratings for Plate- and Shell-Type Supports for the Service Loadings shall be determined by the following equations:

Design and Level A Limits (lower of the two values)

$$\text{load rating}_{(yield)} = TL_y \times 1.0 \frac{S}{S_{y(act)}} \quad (5)$$

$$\text{load rating}_{(ult.)} = TL_u \times 1.0 \frac{S}{S_{u(act)}}$$

(5)

Test and Level B Limits (lower of the two values)

$$\text{load rating}_{(\text{yield})} = TL_y \times 1.33 \frac{S}{S_{y(\text{act})}} \quad (6)$$

$$\text{load rating}_{(\text{ult.})} = TL_u \times 1.33 \frac{S}{S_{u(\text{act})}}$$

(6)

Level C Limits (lower of the two values)

$$\text{load rating}_{(\text{yield})} = TL_y \times 1.5 \frac{S}{S_{y(\text{act})}} \quad (7)$$

$$\text{load rating}_{(\text{ult.})} = TL_u \times 1.5 \frac{S}{S_{u(\text{act})}}$$

(7)

NF-3282.3 Supports Loaded in Compression.

The load rating for supports loaded in compression shall be determined for Service Level A, B, and C by the methods of NF-3282.2. In addition, for cases where buckling governs, TL_u shall be corrected for the ratio of Young's Modulus at the Design Temperature to Young's Modulus at the test temperature. The load rating shall be determined by the following equations:

Design and Level A Limits

$$\text{load rating} = 0.50 Kl \times TL_u$$

Test and Level B Limits

$$\text{load rating} = 0.50 Kl \times TL_u$$

Level C Limits

$$\text{Load rating} = 0.50 Kl \times TL_u$$

Kl

= 1.0 for elastic buckling

$$Kl = \frac{S_y}{S_{y(\text{act})}} \text{ for inelastic buckling}$$

NF-3282.4 Alternative Load Rating Method Using TL_y or TL_u Test Results Only.

Either TL_y or TL_u test results may be used to establish a support load rating, provided the load rating as determined by the method of NF-3282.2 or NF-3282.3 is modified as follows.

(a) For load rating based on TL_y test results only:

(1) for supports constructed of materials having definitely determinable yield points and specified minimum S_y/S_u ratios not greater than 0.625, the load rating shall be multiplied by 0.83. If $S_{y(\text{act})}$ of the material is not known, 150% of the material specified minimum yield strength shall be assumed as the $S_y/S_{y(\text{act})}$ in place of multiplier 0.83;

(2) for supports constructed of carbon steel with specified minimum tensile strengths of not over 70,000 psi (480 MPa), $S_{y(\text{act})}$ shall be increased by 5,000 psi (34 MPa) prior to determining the load rating;

(3) for all other materials the determined load rating shall be multiplied by 0.67.

For supports loaded in compression, a TL_u test shall be performed with the compressive load rating determined in accordance with NF-3282.3.

(b) For load rating based on TL_u test results, the determined load rating shall be multiplied by 0.50.

NF-3300 DESIGN RULES FOR LINEAR-TYPE SUPPORTS

NF-3310 GENERAL REQUIREMENTS

This Subarticle provides rules for the design of Linear-Type Supports by either linear elastic analysis (NF-3320) or plastic (limit) analysis (NF-3340). Linear elastic analytical procedures are also provided (NF-3330) for the design of members and connections which will be subjected to high cycle fatigue conditions in service.

Page 59

NF-3311 Design Considerations

NF-3311.1 Linear Elastic Analysis.

The rules for linear elastic analysis are based on the yield strength values at temperature of the materials used in constructing linear type supports which are set forth in Tables 4 and Y-1 of Section II, Part D, Subpart 1. The allowable stresses are determined in NF-3320 by applying factors of safety dependent on the structural member involved to these specified yield strength values.

S_m values for bolting materials listed in Table 4, Section II, Part D, Subpart 1 are based on $(1/3)S_y$. Multiply S_m by three to arrive at S_y values for the material (round up to next higher 0.5 ksi) if an S_y value for the material is needed.

NF-3311.2 High Cycle Fatigue Analysis.

The rules for designing Linear-Type Supports given in NF-3330 are essentially the same as those given in NF-3320 for linear elastic analysis, except that the maximum range of stress, namely, the difference between the minimum and maximum value of the stress throughout each cycle and the frequency with which the support will be subjected to this range of stress, shall be taken into consideration when so stipulated by the Design Specification (NCA-3250).

NF-3311.3 Limit Analysis.

The rules for limit (plastic) analysis given in NF-3340 may be used as an alternative to the linear elastic analysis method. These rules permit proportioning Linear-Type Supports on the basis of limit design by determining their lower bound collapse loads. The requirements set forth in NF-3320 governing allowable stresses to be used in designing Linear-Type Supports are waived when the limit design procedure is employed, but all other pertinent provisions of NF-3320 shall apply.

NF-3311.4 Basis for Determining Stress in Design by Analysis.

The theory of failure used in the rules for the design of Linear-Type Supports is the maximum stress theory. In the maximum stress theory, the controlling stress is the maximum principal stress.

NF-3311.5 Terms Relating to Design by Analysis.

Terms used in the design of Linear-Type Supports by stress analysis are defined in NF-3313.

NF-3312 Analysis Methods

Linear-Type Supports may be designed by either elastic or limit analysis, limits for which are given in the following subparagraphs.

NF-3312.1 Elastic Analysis.

In elastic analysis it is assumed that all component and support stiffnesses remain constant.

(a) *Design Limits.* The rules and stress limits which must be satisfied in an elastic analysis for any Design Loading shall be stated in the Design Specification.

(b) *Service Limits, Level A Through D.* The rules and stress limits which must be satisfied in an elastic analysis for any Level A through D Service Loading stated in the Design Specification are those given in NF-3321 multiplied by the appropriate stress limit factor from Tables NF-3523(b)-1 and NF-3623(b)-1 for the particular loading and stress category.

(c) *Test Limits.* The rules and stress limits which must be satisfied for any Test Loadings stated in the Design Specification are those given in NF-3321 multiplied by the appropriate stress limit factor in Tables NF-3523(b)-1 and NF-3623(b)-1 under Test Loadings.

NF-3313 Nomenclature and Numbering of Equations

NF-3313.1 Nomenclature.

Except where symbols are used in the text of the paragraphs which follow to represent the value of complex algebraic expressions, the nomenclature adopted in NF-3300 is defined as follows:

A	= gross area of an axially loaded compression member, sq in.
A_b	= nominal body area of a fastener, sq in.; area of an upset rod based upon the major diameter of its threads, i.e., the diameter

of a coaxial cylinder which would bound the crests of the upset threads, sq in.

A_e	= effective net area of an axially loaded tension member, sq in.
A_f	= area of compression flange, sq in.
A_n	= net area of an axially loaded tension member, sq in.
A_{st}	= cross-sectional area of stiffener or pair of stiffeners, sq in.
A_w	= area of girder web, sq in.
C	= ratio of bolt tensile strength to tensile strength of connected part
C_b	= bending coefficient dependent upon moment gradient
C_c	= slenderness ratio separating elastic and inelastic buckling
C'_c	= effective column slenderness ratio
C_m	= coefficient applied to bending term in interaction equation and dependent upon column curvature caused by applied moments

Page 60

C_t	= reduction coefficient in computing effective net area of an axially loaded tension member
C_v	= ratio of critical web stress, according to the linear buckling theory, to the shear yield stress of web material
C_1	= increment used in computing minimum spacing of oversized and slotted holes
C_2	= increment used in computing minimum edge distance for oversized and slotted holes
D	= factor dependent upon type of transverse stiffeners = outside diameter of tubular members, in.
E	= modulus of elasticity of steel, ksi
F_a	= axial compressive stress permitted in the absence of bending moment, ksi
F_{as}	= axial compressive stress permitted in the absence of bending moment, for bracing and other secondary members, ksi
F_b	= bending stress permitted in the absence of axial force, ksi
F'_b	= allowable bending stress in compression flange of plate girders as reduced for hybrid girders or because of large web depth-thickness ratio, ksi
F'_e	= Euler stress divided by factor of safety, ksi
F_p	= allowable bearing stress on the projected area of bolts or pins, or on contact area of milled surfaces and ends of rollers, rockers, or fitted bearing stiffeners at temperature, ksi

F_{sr}	= stress range, ksi
F_t	= allowable tensile stress, ksi
F_{tb}	= allowable tensile stress at temperature, ksi
F_v	= allowable shear stress, ksi
F_{vb}	= allowable shear stress at temperature, ksi
F_{yc}	= column yield stress, ksi
F_{yst}	= stiffener yield stress, ksi
K	= effective length factor
L	= span length = distance from center of bolt hole to edge of connected part, in.
M	= moment, in.-kip (NF-3320); factored bending moment, in.-kip (NF-3340)
M'	= lesser of the factored moments at the ends of unbraced segment, in.-kip
M_1	= smaller moment at end of unbraced length of beam column, in.-kip
M_2	= larger moment at end of unbraced length of beam column, in.-kip
M_m	= critical moment that can be resisted by a plastically designed member in the absence of axial load, in.-kip
M_p	= plastic moment, in.-kip
N	= length of bearing of applied load, in.
P	= force transmitted by a fastener, kips (NF-3320); factored axial load, kips (NF-3340) axial load, kips (NF-3340)
P_{bf}	= factored beam flange or connection plate force in a restrained connection = the computed force delivered by the flange or moment connection plate, multiplied by five-thirds when the computed force is due to live and dead loads only, or by four-thirds when the computed force is due to live and dead loads in conjunction with wind or earthquake forces, kips
P_{cr}	= maximum strength of axially loaded compression member or beam, kips
P_e	= Euler buckling load, kips
P_s	= maximum slip resistance of the joint, lb
P_y	= axial plastic load, equal to member area times specified minimum yield stress, kips
Q_a	= ratio of effective area of an axially loaded member to its total area

Q_s	= axial stress reduction factor
R	= reaction or concentrated transverse load applied to beam or girder, kips; radius, in.
S_u	= tabulated values of ultimate tensile strength of material at temperature (Table U, Section II, Part D, Subpart 1), ksi
S_y	= yield strength at temperature (Table Y-1, Section II, Part D, Subpart 1), ksi
T_b	= specific pretension of a high strength bolt, kips
T_i	= initial clamping force per bolt, lb
V_u	= shear produced by required factored loading, ultimate load, kips
Y	= ratio of yield stress of web steel to yield stress of stiffener steel
Z_x	= plastic section modulus for axis of bending, in. ³
a	= clear distance between transverse stiffeners; dimension parallel to the direction of stress, Table NF-3332.3-1, in.
d	= distance required at ends of welded partial length cover plate to develop stress, in.
b	= actual width of stiffened and unstiffened compression elements
	= dimensions normal to the direction of stress, Table NF-3332.3-1, in.
b_e	= effective width of stiffened compression element, in.
b_f	= flange width of rolled beam or plate girder, in.
d	= depth of beam or girder
	= diameter of roller or rocker bearing
	= nominal diameter of fastener, in.
d_c	= column web depth clear of fillets, in.
e	= horizontal displacement, in the direction of the span, between top and bottom of simply supported beam at its ends, in.

f	= axial compression stress on member based on effective area, ksi
f_a	= computed axial stress, ksi
f_b	= computed bending stress, ksi
f_c	= specified compression strength of concrete, ksi
f_p	= computed bearing stress, ksi

f_t	= computed tensile stress, ksi
f_v	= computed shear stress, ksi
f_{vs}	= shear between girder web and transverse stiffeners, kips/linear in. of single stiffener or pair of stiffeners
g	= transverse spacing (gage) between successive holes in line of stress, in.
h	= clear distance between flanges of a beam or girder at the section under investigation, in.
k	= coefficient relating linear buckling strength of a plate to its dimensions and condition of edge support = also distance between outer face of column flange and web toe of its fillet if column is a rolled shape, or equivalent distance if column is a welded shape, in.
k_s	= slip coefficient for the particular surface condition taken from Table NF-3324.6(a)(4)-1
l	= for beams, distance between cross section braced against twist or lateral displacement of the compression flange, in. = for columns, actual unbraced length of member, in., unsupported length of lacing bar, in.
l_b	= actual unbraced length in plane of bending, in.
l_{cr}	= critical unbraced length adjacent to plastic hinge, in.
m	= number of shear planes per bolt
n	= number of bolts in the joint
r	= governing radius of gyration, in.
r_b	= radius of gyration about axis of concurrent bending, in.
r_c	= radius of gyration of a section comprising the compression flange plus one-third of the compression web area, taken about an axis in the plane of the web, in.
r_y	= radius of gyration of a member about its weak axis, in.
s	= longitudinal center-to-center spacing (pitch) of any two consecutive holes, in.
t	= girder, beam, or column web thickness, in.; thickness of a connected part, in. = wall thickness of a tubular member, in.
t_b	= thickness of beam flange or moment connection plate at rigid beam to column connection, in.
t_f	= flange thickness, in.
t_l	= thickness of thinner part joined by partial penetration groove weld, in.
x	= subscript relating to bending about the strong principal axis

y	= subscript relating to bending about the weak principal axis
α	= ratio of hybrid girder web yield stress to flange yield stress
Δ	= displacement of the neutral axis of a loaded member from its position when the member is not loaded, in.

NF-3313.2 Numbering of Equations.

A separate series of equation numbers is used for each paragraph and each series, beginning with Eq. (1).

NF-3320 DESIGN BY LINEAR ELASTIC ANALYSIS FOR CLASS 1

NF-3321 General Design Requirements

NF-3321.1 Design and Service Conditions

(a) Except as otherwise provided in this Subarticle, all items of the structure shall be so proportioned that the stress, ksi, for Design and Level A Service Limits, shall not exceed the values of NF-3322. For Level B, C, and D Service Limits, allowable stresses may be increased by the factors shown in Tables NF-3523(b)-1 and NF-3623(b)-1. Bearing-type stress limits are excluded from rules for Level D Service Limits.

(b) To avoid column buckling in compression members, local instability associated with compression flange buckling in flexural members, and web buckling in plate girders, the allowable stress shall be limited to two-thirds of the critical buckling stress.

NF-3321.2 Design for High Cycle Fatigue Conditions.

Design for high cycle fatigue conditions shall be in accordance with the requirements of NF-3330, using the allowable stresses of NF-3322 as modified by NF-3332.4.

NF-3322 Design Requirements for Structural Steel Members

NF-3322.1 Allowable Stresses - Design and Level A Service Conditions

(a) *Stress in Tension.* The allowable stress in tension shall be as given in (a)(1), (2), and (3) below:

(1) Except for pin-connected and threaded members, F_t shall be:

$$(1) F_t = 0.60S_y$$

but not more than 0.5 times S_u on the effective net area.³

(2) For pin-connected members, using the net area.³

$$(2) F_t = 0.45S_y$$

(3) For threaded parts in tension, see NF-3324.6(a)(1).

(b) *Stress in Shear*

(1) Except as provided in (b)(2) below and NF-3324.6(a)(2), on the cross-sectional area effective in resisting shear:

$$(3a) F_v = 0.40S_y$$

The effective area in resisting shear of rolled and fabricated shapes may be taken as the overall depth times the web thickness.

(2) At the beam end connections where the top flange is coped, and in similar situations where failure might occur by shear along a plane through the fasteners, or by a combination of shear along a plane through the fasteners plus tension

along a perpendicular plane, on the effective area in resisting tearing failure shall be:

$$(3b) F_v = 0.30 S_u$$

The effective area is the minimum net failure surface, bounded by the bolt holes.

(c) *Stress in Compression.* The allowable stress in compression shall be as required by (c)(1) through (3) below. The allowable compressive stress for columns, except those fabricated from austenitic stainless steel, shall be as required by (c)(1). The allowable compressive stress for columns fabricated from austenitic stainless steel shall be as required by (c)(2). The allowable compressive stress for member elements other than columns constructed of any material, including austenitic stainless steel, shall be as required by (c)(3).

(1) *Gross Sections of Columns, Except Those Fabricated of Austenitic Stainless Steel*

(a) *Where Kl/r Is Less Than C_c .* On the gross section of axially loaded compression members whose cross sections meet the provisions of NF-3322.2(d), when Kl/r (the largest effective slenderness ratio of any unbraced segment as defined in NF-3322.2) is less than C_c , the allowable stress in compression shall be:

3 For determination of effective net area, see NF-3322.8.

$$F_a = \frac{[1 - (Kl/r)^2 / 2C_c^2] S_y}{5/3 + [3(Kl/r) / 8C_c] - [(Kl/r)^3 / 8C_c^3]} \quad (4)$$

(4)

where

$$C_c = \sqrt{2\pi^2 E / S_y}$$

(b) *Where Kl/r Is Greater Than C_c .* On the gross section of axially loaded compression members when Kl/r exceeds C_c , the allowable stress in compression shall be:

$$F_a = \frac{12\pi^2 E}{23 (Kl/r)^2} \quad (5)$$

(5)

(c) *Where the Slenderness Ratio Exceeds 120.* On the gross section⁴ of axially loaded bracing and secondary members, when l/r exceeds 120 the allowable stress in compression shall be:

$$F_{as} = \frac{F_a [\text{Eq. (4) or (5)}]}{1.6 - \left(\frac{1}{200r} \right)} \quad (6)$$

(6)

(2) *Gross Sections of Columns Fabricated From Austenitic Stainless Steel.* On the gross section of axially loaded compression members whose cross sections meet the provisions of NF-3322.2(d) the allowable stress in compression shall be as required by (c)(2)(a) and (b) below.

(a) *Where Kl/r Is Less Than or Equal to 120.*

$$F_a = S_y \left(0.47 - \frac{Kl/r}{444} \right) \quad (6a)$$

(6a)

(b) *Where Kl/r Is Greater Than 120.* The following compressive stress limit applies to bracing and secondary members as well as main members.

$$F_a = S_y \left(0.40 - \frac{Kl/r}{600} \right) \quad (6b)$$

(6b)

(3) *Member Elements Other Than Columns*

(a) *Plate Girder Stiffeners.* On the gross area of plate girder stiffeners, the allowable stress in compression shall be:

4 For this case, K is taken as unity.

$$(7) F_a = 0.60 S_y$$

(b) *Webs of Rolled Shapes.* On the web of rolled shapes at the toe of the fillet, the allowable stress in compression shall be:

$$(8) F_a = 0.75 S_y$$

For the use of stiffeners to avoid web crippling, see NF-3322.6(a).

(d) *Stress in Bending.* The allowable bending stress resulting from tension and compression in structural members shall be as required by (d)(1) through (6) below.

(1) *Compact Sections*

(a) Tension and compression on extreme fibers of compact hot rolled or built-up members (except hybrid beams and members made from 65 ksi or greater S_y material) symmetrical about and loaded in the plane of their minor axes and meeting the requirements of Subsection NF shall result in a maximum bending stress:

$$(9) F_b = 0.66 S_y$$

In order to qualify, a member shall meet the requirements of (d)(1)(a)(1) through (7) below.

(1) The flanges shall be continuously connected to the web or webs.

(2) The width-thickness ratio of unstiffened projecting elements of the compression flange [as defined in NF-3322.2(d)] shall not exceed $65/\sqrt{S_y}$.

(3) The width-thickness ratio of stiffened elements of the compression flange [as defined in NF-3322.2(d)] shall not exceed $190/\sqrt{S_y}$.

(4) The depth-thickness ratio of the web or webs shall not exceed the value given by Eq. (10) or (11), as applicable:

$$(10) d/t = (640/\sqrt{S_y}) [1 - 3.74 (f_d/S_y)]$$

when $f_d/S_y \leq 0.16$;

$$(11) d/t = 257/\sqrt{S_y}$$

when $f_d/S_y > 0.16$.

(5) The laterally unsupported length of the compression flange of members other than box-shaped members shall not exceed the value $76b/\sqrt{S_y}$ nor $20,000/[(d/A_f) S_y]$.

(6) The laterally unsupported length of the compression flange of a box-shaped member of rectangular cross section, whose depth is not more than six times the width and whose flange thickness is not more than two times the web thickness, shall not exceed the value:

$$(12) [1950 + 1200 (M_1/M_2)] (b/S_y)$$

except that it need not be less than $1200(b/S_y)$.

(7) The diameter-thickness ratio of hollow circular sections shall not exceed $3300/S_y$.

(b) Beams and girders (except for hybrid girders and members made from 65 ksi or greater S_y material) which meet the requirements of (d)(1)(a)(1) through (7) above and are continuous over supports or are rigidly framed to columns by means of high strength bolts or welds may be proportioned for nine-tenths of the negative moments produced by gravity loading which are maximum at points of support, provided that for such members the maximum positive moment shall be increased by one-tenth of the average negative moments. This reduction shall not apply to moments produced by loading on cantilevers. If the negative moment is resisted by a column rigidly framed to the beam or girder, the one-tenth reduction may be used in proportioning the column for the combined axial and bending loading, provided that the stress f_a due to any concurrent axial load on the member does not exceed $0.15 F_a$

(2) *Members With High Flange Width-Thickness Ratio.* Members which meet the requirements of (d)(1) above,

except that $b_f/2t_f$ exceeds $65/\sqrt{S_y}$ but is less than $95/\sqrt{S_y}$, may be designed on the basis of an allowable bending stress:

$$(13) F_b = S_y [0.79 - 0.002 (b_f/2t_f)\sqrt{S_y}]$$

(3) *Doubly Symmetrical Members With Bending About the Minor Axis.* Tension and compression on extreme fibers of doubly symmetrical I and H shaped members (except for hybrid girders and members made from 65 ksi or greater S_y material) which are bent about their minor axis, meeting the requirements of (d)(1)(a) and (b) above; solid round and square bars; and solid rectangular sections bent about their weaker axis shall not exceed a bending stress of:

$$(14) F_b = 0.75S_y$$

Doubly symmetrical I and H shaped members bent about their minor axis (except for hybrid girders and members made from 65 ksi or greater S_y material), meeting the requirements of (d)(1)(a) above, except

Page 64

where $b_f/2t_f$ exceeds $65/\sqrt{S_y}$ but is less than $95/\sqrt{S_y}$, may be designed on the basis of an allowable bending stress:

$$(15a) F_b = S_y [1.075 - 0.005 (b_f/2t_f)\sqrt{S_y}]$$

Rectangular tubular sections meeting the requirements of (d)(1)(a)(1), (3), and (4) above, and bent about their minor axis, may be designed on the basis of an allowable bending stress:

$$(15b) F_b = 0.66S_y$$

(4) *Box-Type Flexural Members.* Tension and compression on extreme fibers of box-type flexural members whose compression flange or web width-thickness ratio does not meet the requirements of (d)(1) above, but does conform to the requirements of NF-3322.2(d), shall not exceed a bending stress of:

$$(16) F_b = 0.60S_y$$

Lateral torsional buckling need not be investigated for a box section whose depth is less than six times its width. Lateral support requirements for box sections of larger depth-width ratios must be determined by special analysis.

(5) *Miscellaneous Members*

(a) Tension on extreme fibers of flexural members not covered in (d)(1) through (4) above, shall not exceed a bending stress as determined by using Eq. (16).

(b) Compression on extreme fibers of flexural members included in (d)(5)(a) above, meeting the requirements of NF-3322.2(d)(1)(b), and having an axis of symmetry in and loaded in the plane of their web and compression on extreme fibers of channels⁵ bent about their major axis, shall have the larger value of bending stress computed by Eqs. (17), (18), and (19), as applicable, but not more than $0.60S_y$.⁶

When

$$[(102 \times 10^3 C_b) / S_y]^{1/2} \leq l / r_c \leq [(510 \times 10^3 C_b) / S_y]^{1/2}$$

then

$$F_b = \{2/3 - [S_y (l/r_c)^2 / (1530 \times 10^3 C_b)]\} S_y \quad (17)$$

(17)

5 Only Eq. (19) is applicable to channels.

6 See NF-3322.3 for further limitations in plate girder flange stress.

When

$$l/r_c \geq \sqrt{(510 \times 10^3 C_b) / S_y}$$

then

$$(18) F_b = (170 \times 10^3 C_b) / (l/R)^2$$

When the compression flange is solid and approximately rectangular in cross section and its area is not less than that of the tension flange,

$$(19) F_b = (12 \times 10^3 C_b) / (l d / A_f)$$

where

C_b

$= 1.75 + 1.05(M_1/M_2) + 0.3 (M_1/M_2)^2 \leq 2.3$, where M_1 is the smaller and M_2 is the larger bending moment at the ends of the unbraced length taken about the strong axis of the member, and where M_1/M_2 (the ratio of end moments) is positive when M_1 and M_2 have the same sign (reverse curvature bending) and is negative when they are of opposite signs (single curvature bending). When the bending moment at any point within an unbraced length is larger than that at both ends of this length, the value of C_b shall be taken as 1. When computing F_{bx} and F_{by} to be used in Eq. (20), C_b may be computed by the equation given above for frames subject to joint translation. C_b may conservatively be taken as 1 for cantilever beams.⁷

For cantilevers braced against twist only at the support, l may be conservatively taken as the actual length.

(c) For hybrid plate girders, S_y for Eqs. (17) and (18) is the yield stress of the compression flange. Equation (19) shall not apply to hybrid girders.

(6) *Miscellaneous Members Braced Laterally*. Compression in extreme fibers of flexural members meeting the requirements of NF-3322.2(d)(1)(b), but not included in (d)(5)(b) above, shall result in a maximum bending stress as determined by using Eq. (16), provided that sections bent about their major axis are braced laterally in the region of compression stress at intervals not exceeding $76b_f \sqrt{S_y}$.

⁷ For the use of larger C_b values, see: The Structural Stability Research Council, *Guide to Stability Design Criteria for Metal Structures*, 3rd edition, p. 135.

(e) *Combined Stresses*

(1) *Axial Compression and Bending*. For members subjected to both axial compression and bending, including bending moment resulting in secondary stress,

stresses shall be proportioned to satisfy the requirements of Eqs. (20), (21), and (22):

$$\frac{f_a}{F_a} + \frac{C_{mx} f_{bx}}{(1 - f_a / F'_{ex}) F_{bx}} + \frac{C_{my} f_{by}}{(1 - f_a / F'_{ey}) F_{by}} \leq 1.0 \quad (20)$$

$$\frac{f_a}{0.60 S_y} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1.0 \quad (21)$$

(20 - 21)

After evaluating primary stresses, the right-hand side of Eq. (22) may be replaced by 1.5 when both primary and secondary bending stresses are considered. When $f_a / F_a \leq 0.15$, Eq. (22) may be used in lieu of Eqs. (20) and (21):

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1.0 \quad (22)$$

(22)

In Eqs. (20), (21), and (22), the subscripts x and y indicate the axis of bending about which a particular stress or design property applies, and:

$$F'_e = \frac{12\pi^2 E}{23(Kl_b / r_b)^2}$$

for all members except those fabricated of austenitic stainless steel, or

$$F'_e = \frac{\pi^2 E}{2.15(Kl_b / r_b)^2}$$

for members fabricated of austenitic stainless steel (in the expression for F'_e , as in the case of F_a , F_b , and $0.60S_y$, F'_e may be multiplied by the appropriate stress limit factor from the Tables NF-3523(b)-1 and NF-3623(b)-1 for the particular stress category), where C_m is a coefficient whose value shall be as given in (e)(1)(a) through (c) below:

(a) For compression members in frames subject to joint translation (sidesway), $C_m = 0.85$.

(b) For (rotationally) restrained compression members in frames braced against joint translation and not subject to transverse loading between their supports in the plane of bending,

$$C_m = 0.6 - 0.4 (M_1/M_2)$$

where

$$M_1/M_2$$

= the ratio of the smaller to larger moments at the ends of that portion of the member unbraced in the plane of bending under consideration. M_1/M_2 is positive when the member is bent in reverse curvature and negative when it is bent in single

curvature.

(c) For compression members in frames braced against joint translation in the plane of loading and subjected to transverse loading between their supports, the value of C_m may be determined by rational analysis; however, in lieu of such analysis, the following values may be used:

(1) for members whose ends are restrained (against rotation in the plane of bending):

$$C_m = 0.85$$

(2) for members whose ends are unrestrained (against rotation in the plane of bending):

$$C_m = 1.0$$

(2) *Axial Tension and Bending.* Members subject to both axial tension and bending stresses shall be proportioned at all points along their length to satisfy the requirements of Eq. (21), where f_b is the computed bending tensile stress. However, the computed bending compressive stress, taken alone, shall not exceed the applicable value according to NF-3322.1(d), "Stress in Bending."

(3) *Shear and Tension.* Bolts subject to combined shear and tension shall be proportioned in accordance with the requirements of NF-3324.

(f) *Bearing on Contact Area*

(1) *Milled Surfaces.* On contact area of milled surfaces and ends of fitted bearing stiffness⁸ on projected area of pins in reamed, drilled, or bored holes, the maximum bearing stress shall be:

$$(23) F_p = 0.90S_y$$

(2) *Rollers and Rockers.* The maximum bearing load, kips/linear in., shall be:

$$F_p = \left(\frac{S_y - 13}{20} \right) 0.66d \quad (24a)$$

(24a)

(3) *Bolts.* The maximum bearing load on projected area of bolts in bearing connections shall be:

8 When parts in contact have different yield stresses, S_y shall be the smaller value.

$$(24b) F_p = 1.5S_u$$

(4) *Concrete Bearing.* In the absence of any other Code rules governing bearing stresses on concrete, the maximum bearing stress values shall be as given in (f)(4)(a) and (b) below:

(a) on the full area of a concrete support:

$$(25) F_p = 0.35f_c$$

(b) on less than the full area of a concrete support:

$$(26) F_p = 0.35F_c' \sqrt{A_2/A_1} \leq 0.7f_c$$

where

- A_1 = bearing area, sq in.
 A_2 = full cross-sectional area of concrete support, sq in.

(g) *Single Angle Members.* Single angle members shall be designed in accordance with Appendix NF-II.

NF-3322.2 Stability and Slenderness and Width-Thickness Ratios

(a) General Requirements

(1) General stability shall be provided for the structure as a whole and for each compression element. Design consideration shall be given to significant load effects resulting from the deflected shape of the structure or of individual elements of the lateral load resisting system, including the effects on beams, columns, bracing, connections, and shear walls.

(2) In determining the slenderness ratio of an axially loaded compression member, except as provided in NF-3322.1 (c)(3), the length shall be taken as its effective length Kl , and r shall be taken as the corresponding radius of gyration.

(b) Lateral Stability

(1) *Braced Frames.* In frames [where lateral stability is provided by adequate attachment to diagonal bracing (to shear walls), to an adjacent structure having adequate lateral stability, or to floor slabs (or roofdecks) secured horizontally by walls or bracing systems parallel to the plane of the frame] and in trusses, the effective length factor K for the compression members shall be taken as 1.0, unless analysis shows that a smaller value may be used.

(2) *Unbraced Frames.* In frames where lateral stability is dependent upon the bending stiffness of rigidly connected beams and columns, the effective length Kl of compression members shall be determined by a rational method and shall not be less than the actual unbraced length.

(c) Maximum Slenderness Ratios

(1) The slenderness ratio Kl/r of compression members shall not exceed 200.

(2) The slenderness ratio l/r of tension members, other than rods, preferably should not exceed 240 for main members, and 300 for lateral bracing members and other secondary members.

(d) Width Ratios

(1) Unstiffened Elements Under Compression

(a) *Effective Width.* Unstiffened (projecting) compression elements are those having one free edge parallel to the direction of compression stress. The width of unstiffened plates shall be taken from the free edge to the first row of fasteners or welds; the width of legs of angles, channel and zee flanges, and stems of tees shall be taken as the full nominal dimension; the width of flanges of I and H shaped members and tees shall be taken as one-half of the full nominal width. The thickness of a sloping flange shall be measured at a section halfway between a free edge and the corresponding face of the web.

(b) *Determination of Effective Width.* Unstiffened elements subject to axial compression or compression due to bending shall be considered as fully effective when the width-thickness ratio is not greater than the following:

(1) for single angle struts and double angle struts with separators, $76/\sqrt{F_y}$;

(2) for struts comprising double angles in contact; angles or plates projecting from girders, columns, or other compression members; compression flanges of beams; and stiffeners on plate girders, $95/\sqrt{F_y}$;

(3) for stems of tees, $127/\sqrt{F_y}$.

When the actual width-thickness ratio exceeds these values, the design stress shall be governed by the provisions of (e) below.

(2) Stiffened Elements Under Compression

(a) *Effective Width.* Stiffened compression elements are those having lateral support along both edges which are parallel to the direction of the compression stress. The width of such elements shall be taken as follows:

(1) For webs of rolled, built-up, or formed sections, h is the clear distance between flanges.

(2) For webs of rolled, built-up, or formed sections, d is the full nominal depth.

(3) For flange or diaphragm plates in built-up sections, the width b is the distance between adjacent lines of fasteners or lines of welds.

(4) For flanges of rectangular hollow structural sections, the width b is the clear distance between

webs less the inside corner radius on each side. If the corner radius is not known, the flat width may be taken as the total section width minus three times the thickness.

(b) *Determination of Effective Width.* Stiffened elements subject to axial compression or to uniform compression due to bending, as in the case of the flange of a flexural⁹ member, shall be considered as fully effective when the width-thickness ratio is not greater than the following:

(1) for flanges of square and rectangular box sections of uniform thickness, $238/\sqrt{S_y}$;

(2) for unsupported width of cover plates perforated with a succession of access holes,¹⁰ $317/\sqrt{S_y}$;

(3) for all other uniformly compressed stiffened elements, $253/\sqrt{S_y}$.

Except in the case of perforated cover plates, when the actual width-thickness ratio exceeds these values, the design stress shall be governed by the provisions of (e) below.

(c) *Circular Tubular Elements.* Circular tubular elements subject to axial compression shall be considered as fully effective when the ratio of the outside diameter to the wall thickness is not greater than $3300/S_y$. For diameter to thickness ratios greater than $3300/S_y$ but less than $13,000/S_y$, the calculated stress shall be governed by the provisions of (e) below.

(e) *Slender Compression Elements*

(1) *General Requirements.* Axially loaded members and flexural members, containing elements subject to compression and having a width-thickness ratio in excess of the applicable limit given in (d)(1) and (d)(2) above, shall be proportioned to meet the requirements of the following subparagraphs.

⁹ Webs of flexural members are covered by the provisions of NF-3322.6(a) and NF-3322.6(e)(2) and are not subject to the provisions of this paragraph.

¹⁰ Assumes net area of plate at widest hole as basis for computing compression stresses.

(2) *Unstiffened Compression Elements.* Except as provided herein, stress on unstiffened compression elements, the width-thickness ratio of which exceeds the applicable limit given in (d)(1) above, shall be subject to a reduction of factor Q_s . The value of Q_s shall be determined by Eqs. (27) to (32), as applicable, where b is the width of the unstiffened element as defined in (d)(1) above. When such elements comprise the compression flange of a flexural member, the maximum allowable bending stress shall not exceed $0.6S_y Q_s$, nor the applicable value as provided in (d)(5) or (6) above. The allowable stress of axially loaded compression members shall be modified by the appropriate reduction factor Q_s as provided in (e)(5) below.

(a) For single angles, when

$$76/\sqrt{S_y} < b/t < 155/\sqrt{S_y}$$

then

$$(27) Q_s = 1.340 - 0.00447 (b/t) \sqrt{S_y}$$

when

$$b/t \geq 155/\sqrt{S_y}$$

then

$$(28) Q_s = 15,500/[S_y(b/t)]$$

(b) For angles or plates projecting from columns or other compression members and for projecting elements of compression flanges of girders, when

$$95/\sqrt{S_y/k_c} < b/t < 195/\sqrt{S_y/k_c}$$

then

$$(29) Q_s = 1.293 - 0.00309 (b/t)\sqrt{S_y/k_c}$$

when

$$b/t > 195/\sqrt{S_y/k_c}$$

then

$$(30) Q_s = 26,200 k_c/[S_y(b/t)^2]$$

$$k_c = \frac{4.05}{(h/t)^{0.46}} \text{ if } \frac{h}{t} > 70, \text{ otherwise } k_c = 1.0.$$

(c) For stems of tees, when

$$127/\sqrt{S_y} < b/t < 176/\sqrt{S_y}$$

then

$$(31) Q_s = 1.908 - 0.00715 (b/t) \sqrt{S_y}$$

**TABLE NF-3322.2(e)(2)-1
LIMITING PROPORTIONS FOR CHANNELS AND TEES**

Shape	Ratio of Flange Width to Profile Depth	Ratio of Flange Thickness to Web or Stem Thickness
Built-up or	≤ 0.25	≤ 3.0
rolled channels } Built-up tees	≤ 0.50	≤ 2.0
	≥ 0.50	≥ 1.25
Rolled tees	≥ 0.50	≥ 1.10

TABLE NF-3322.2(e)(2)-1 LIMITING PROPORTIONS FOR CHANNELS AND TEES

when

$$b/t \geq 176/\sqrt{S_y}$$

then

$$(32) Q_s = 20,000/[S_y(b/t)^2]$$

(d) However, unstiffened elements of channels and tees whose proportions exceed the limits of (d)(1) above shall conform to the limits given in Table NF-3322.2(e)(2)-1.

(3) Stiffened Compression Elements

(a) When the width-thickness ratio of uniformly compressed stiffened elements, except for perforated cover plates, exceeds the applicable limit given in (d)(2) above, a reduced effective width b_e shall be used in computing the flexural design properties of the section containing the element and the permissible axial stress, except that the ratio b/t need not be taken as less than the applicable value permitted in (d)(2) above.

(1) For the flanges of square and rectangular sections of uniform thickness:

$$b_e = \frac{253t}{\sqrt{f}} \left[1 - \left(\frac{50.3}{(b/t) \sqrt{f}} \right) \right] \leq b \quad (33)$$

(33)

(2) For other uniformly compressed elements:

$$b_e = \frac{253t}{\sqrt{f}} \left[1 - \left(\frac{44.3}{(b/t) \sqrt{f}} \right) \right] \leq b \quad (34)$$

(34)

where

b

= the actual width, in., of a stiffened compression element as defined in (d)(2) above

f

= computed compressive stress, ksi, in the stiffened elements based on the design properties as specified in (e)(4) below. If unstiffened elements are included in the total cross section for the stiffened element, f must be such that the maximum compressive stress in the unstiffened element does not exceed $F_a Q_s$ or $F_b Q_s$, as applicable.

(b) The allowable stress for axially loaded circular tubular members not meeting the requirements of NF-3322.1(e) above, but having a diameter-to-thickness ratio of less than $13,000/S_y$, shall not exceed either the smaller value determined by NF-3322.1(e) above or:

$$F_a = \left[\frac{662}{D/t} + 0.4S_y \right]$$

(c) When the allowable stresses are increased for Level C Conditions, the effective width b_e shall be determined on the basis of 0.75 times the stress caused by Level C Conditions.

(4) *Design Properties.* Properties of sections shall be determined in accordance with conventional methods, using the full cross section of the member, except as required in (e)(4)(a) and (b) below.

(a) In computing the moment of inertia and section modulus of flexural members with respect to the axis of bending under consideration, the effective width of stiffened compression elements parallel to the axis of bending and having a width-thickness ratio in excess of the applicable limit given in (d)(2) above, rather than the actual width, shall be used, and the axis of bending shall be located accordingly, except that for sections otherwise symmetrical, the properties may conservatively and more easily be computed using a corresponding effective area on the tension side

of the neutral axis as well. That portion of the area which is neglected in arriving at the effective area shall be located at and symmetrical about the center line of the stiffened element to which it applies.

(b) The stress f_a due to axial loading, and the radius of gyration r , shall be computed on the basis of actual cross-sectional area. However, the allowable axial stress F_a as provided in (e)(5) below shall be subject to the form factor:

$$Q_a = \frac{\text{effective area}}{\text{actual area}}$$

where the effective area is equal to the actual area less $\Sigma (b-b_e) t$.

(5) *Axially Loaded Compression Members.* The allowable stress for axially loaded compression members containing unstiffened or stiffened elements shall not exceed:

Page 69

$$F_a = \frac{Q_s Q_a \left[1 - \frac{(Kl/r)^2}{2(C'_c)^2} \right] S_y}{\frac{5}{3} + \frac{3(Kl/r)}{8C'_c} - \frac{(Kl/r)^3}{8(C'_c)^3}} \quad (35)$$

(35)

where

$$C'_c = \sqrt{\frac{2\pi^2 E}{Q_s Q_a S_y}}$$

and

$$Q = Q_s Q_a$$

(a) Cross sections composed entirely of unstiffened elements,

$$Q = Q_s \text{ (i.e., } Q_a = 1.0\text{)}$$

(b) Cross sections composed entirely of stiffened elements,

$$Q = Q_a \text{ (i.e., } Q_s = 1.0\text{)}$$

(c) Cross sections composed of both stiffened and unstiffened elements,

$$Q = Q_s Q_a$$

when the largest effective slenderness ratio of any unbraced segment of the member is neither less than C'_c nor the value given by Eq. (5) when Kl/r exceeds C'_c .

(6) *Combined Axial and Flexural Stress.* In applying the provisions of NF-3322.1(e) to members subject to combined axial and flexural stress and containing stiffened elements whose width-thickness ratio exceeds the applicable limit given in (d)(2) above, the stresses F_a , f_{bx} , and f_{by} shall be calculated on the basis of the section properties as provided in (e)(4) and (5) above, as applicable. The allowable bending stress F_b for members containing unstiffened elements whose width-thickness ratio exceeds the applicable limit given in (d)(1) above shall be the smaller value $0.6S_y Q_s$ or that provided in NF-3322.1(d)(5).

NF-3322.3 Plate Girders, Rolled Beams, and Built-Up Members

(a) *Girders and Rolled Beams.* Rolled or welded shapes, plate girders, and cover-plated beams shall, in general, be proportioned by the moment of inertia of the gross section. No deduction shall be made for shop or field bolt or rivet holes in either flange provided that

$$(35a) 0.5S_u A_{fn} \geq 0.6S_y A_{fg}$$

where A_{fg} is the gross flange area and A_{fn} is the net flange area, calculated in accordance with the provisions of NF-3322.8.

If

$$(35b) \ 0.5S_u A_{fn} < 0.6S_y A_{fg}$$

the member flexural properties shall be based on an effective tension flange area A_{fe}

$$A_{fe} = \frac{5}{6} \frac{S_u}{S_y} A_{fn} \quad (35c)$$

(35c)

(b) *Hybrid Girders.* Hybrid girders may be proportioned by the moment of inertia of their gross section, provided that they are not required to resist an axial force greater than $0.15S_y$ times the area of the gross section, where S_y is the yield stress of the flange material. To qualify as hybrid girders, the flanges at any given section shall have the same cross-sectional area and be made of the same grade of steel.

(c) *Open Box-Type Beams and Grillages.* When two or more rolled beams or channels are used side by side to form a flexural member, they shall be connected together at intervals of not more than 5 ft. Through-bolts and separators may be used, provided that in beams having a depth of 12 in. or more, no fewer than two bolts shall be used at each separator location. When concentrated loads are carried from one beam to the other or distributed between the beams, diaphragms having sufficient stiffness to distribute the load shall be bolted or welded between the beams.

NF-3322.4 Compression Members

(a) Requirements for Fasteners

(1) *Transverse Spacing of Fasteners.* All parts of built-up compression members and the transverse spacing of their lines of fasteners shall meet the requirements of NF-3322.2.

(2) *End Fasteners.* At the ends of built-up compression members bearing on base plates or milled surfaces, all components in contact with one another shall be connected by bolts, spaced longitudinally not more than four diameters apart for a distance equal to $1\frac{1}{2}$ times the maximum width of the member, or by continuous welds having a length not less than the maximum width of the member.

(3) *Intermediate Fasteners.* The longitudinal spacing for intermediate bolts or intermittent welds in built-up members shall be adequate to provide for the transfer

Page 70

of calculated stress. The maximum longitudinal spacing of bolts or intermittent welds connecting two rolled shapes in contact with one another shall not exceed 24 in. In addition, for painted members and unpainted members not subject to corrosion where the outside component consists of a plate, the maximum longitudinal spacing shall not exceed:

(a) $127/\sqrt{S_y}$ times the thickness of the outside plate nor 12 in. when fasteners are not staggered along adjacent gage lines;

(b) $190/\sqrt{S_y}$ times the thickness of the outside plate nor 18 in. when fasteners are staggered along adjacent gage lines.

(b) *Local Slenderness Ratio.* Compression members composed of two or more rolled shapes separated by intermittent fillers shall be connected at these fillers at intervals such that the slenderness ratio Kl/r of either shape, between the

fasteners, does not exceed $\frac{3}{4}$ times the governing slenderness ratio of the built-up member. The least radius of gyration r shall be used in computing the slenderness ratio of each component part. At least two intermediate connectors shall be used along the length of the built-up member.

(c) *Tie Plates.* Open sides of compression members built up from plates or shapes shall be provided with lacing having tie plates at each end and at intermediate points if the lacing is interrupted. Tie plates shall be as near to the ends as practicable. In main members carrying calculated stress, the end tie plates shall have a length of not less than the distance between the lines of bolts or welds connecting them to the elements of the member. Intermediate tie plates shall have a length not less than one-half of this distance. The thickness of tie plates shall be not less than one-fiftieth of the distance between the lines of bolts or welds connecting them to the segments of the members. In bolted construction, the spacing in the direction of stress in tie plates shall be not more than six diameters and the tie plates shall be connected to each segment by at least three fasteners. In welded construction, the welding on each line connecting a tie plate shall aggregate not less than one-third of the length of the plate.

(d) *Lacing.* Lacing, including flat bars, angles, channels, or other shapes employed as lacing, shall be so spaced that the ratio l/r of the flange included between their connections shall not exceed $\frac{3}{4}$ times the governing ratio for the member as a whole. Lacing shall be proportioned to resist a shearing stress normal to the axis of the member equal to 2% of the total compressive stress in the member. The ratio l/r for lacing bars arranged in single systems shall not exceed 140. For double lacing this ratio shall not exceed 200. Double lacing bars shall be joined at their intersections. For lacing bars in compression, the unsupported length of the lacing bar shall be taken as the distance between fasteners or welds connecting it to the components of the built-up member for single lacing, and 70% of that distance for double lacing. The inclination of lacing bars to the axis of the member shall preferably be not less than 60 deg. for single lacing and 45 deg. for double lacing. When the distance between the lines of fasteners or welds in the flanges is more than 15 in. (381 mm), the lacing preferably shall be double or be made of angles.

(e) *Perforated Cover Plates.* The function of tie plates and lacing may be performed by continuous cover plates perforated with a succession of access holes. The unsupported width of such plates at access holes, as defined in NF-3322.2(d)(2), is assumed to be available to resist axial stress, provided that:

- (1) the width-thickness ratio conforms to the limitations of NF-3322.2(d)(2);
- (2) the ratio of length in direction of stress to width of hole shall not exceed 2;
- (3) the clear distance between holes in the direction of stress shall be not less than the transverse distance between nearest lines of connection bolts or welds; and
- (4) the periphery of the holes at all points connecting shall have a minimum radius of $1\frac{1}{2}$ in. (38 mm).

NF-3322.5 Tension Members

(a) *Longitudinal Spacing of Connectors.* The longitudinal spacing of connectors between elements in continuous contact consisting of a plate and a shape or two plates shall not exceed:

- (1) 24 times the thickness of the thinner plate, or 12 in. for painted members or unpainted members not subject to corrosion;
- (2) 14 times the thickness of the thinner plate, or 7 in. for unpainted members of weathering steel subject to atmospheric corrosion.

In a tension member the longitudinal spacing of fasteners and intermittent welds connecting two or more shapes in contact shall not exceed 24 in. (610 mm). Tension members composed of two or more shapes or plates separated by intermittent fillers shall be connected to one another at these fillers at intervals such that the slenderness ratio of either component between the fasteners does not exceed 300.

(b) *Perforated Cover and Tie Plates.* Either perforated cover plates or tie plates without lacing may be used on the open sides of built-up tension members. Tie plates shall have a length not less than two-thirds the distance between the lines of bolts or welds connecting them to the elements of the member. The

thickness of such tie plates shall not be less than one-fiftieth of the distance between these lines. The longitudinal spacing of bolts or intermittent welds at tie plates shall not exceed 6 in. (152 mm). The spacing of tie plates shall be such that the slenderness ratio of any component in the length between tie plates shall not exceed 240.

NF-3322.6 Webs, Flanges, and Stiffeners

(a) *Webs*. The ratio of the clear distance between flanges to the web thickness shall not exceed:

$$(36) \ 14,000/\sqrt{S_y(S_y + 16.5)}$$

except that when transverse stiffeners are provided, spaced not more than $1\frac{1}{2}$ times the girder depth, the limiting ratio may be $2000/\sqrt{S_y}$, where S_y is the yield stress of the compression flange.

(1) *Combined Shear and Tension Stress*. Plate girder webs which depend upon tension field action, as provided in Eq. (45), shall be so proportioned that bending tensile stress due to moment in the plane of the girder web shall not exceed $0.6S_y$, or

$$\left(0.825 - 0.375 \frac{f_v}{F_v}\right) S_y \quad (37)$$

(37)

where

F_v = allowable web shear stress, ksi, according to Eq. (45)

The allowable shear stress in the webs of girders having flanges and webs with yield values greater than 68 ksi shall not exceed the values given by Eq. (44) if the flexural stress in the flange f_b exceeds $0.75F_b$

(2) *Web Crippling*

(a) *Local Web Yielding*. Webs of beams and welded plate girders shall be so proportioned that the compressive stress at the web toe of the fillets, resulting from concentrated loads not supported by bearing stiffeners, shall not exceed the value of $0.75S_y$; otherwise, bearing stiffeners shall be provided. The governing equations shall be:

(1) for interior loads:

$$\frac{R}{t(N + 5k)} \leq 0.66S_y \quad (38)$$

(38)

(2) for end reactions:

$$\frac{R}{t(N + 2.5k)} \leq 0.66S_y \quad (39)$$

(39)

where N is greater than or equal to k for end reactions.

(b) *Stress on Compression Edge of Web Plate.* Bearing stiffeners shall be provided in the webs of members under concentrated loads, when the compressive force exceeds the following limits:

when the concentrated load is applied at a distance not less than $d/2$ from the end of the member:

$$R = 67.5t_w^2 \left[1 + 3 \left(\frac{N}{d} \right) \left(\frac{t_w}{t_f} \right)^{1.5} \right] \sqrt{S_y t_f / t_w} \quad (40)$$

(40)

when the concentrated load is applied less than a distance $d/2$ from the end of the member:

$$R = 34 t_w^2 \left[1 + 3 \left(\frac{N}{d} \right) \left(\frac{t_w}{t_f} \right)^{1.5} \right] \sqrt{S_y t_f / t_w} \quad (41)$$

(41)

where

S_y	= specified minimum yield stress of beam web, ksi
d	= overall depth of the member, in.
t_f	= flange thickness, in.

If stiffeners are provided and extend at least one-half the web depth, Eqs. (40) and (41) need not be checked.

Bearing stiffeners shall be provided in the webs of members with flanges not restrained against relative movement by stiffeners or lateral bracing and subject to concentrated compressive loads, when the compressive force exceeds the following limits:

If the loaded flange is restrained against rotation and $(d_c/t_w)/(l/b_f)$ is less than 2.3:

$$R = \frac{6,800 t_w^3}{h} \left[1 + 0.4 \left(\frac{d_c/t_w}{l/b_f} \right)^3 \right] \quad (41a)$$

(41a)

If the loaded flange is not restrained against rotation and $(d_c/t_w)/(l/b_f)$ is less than 1.7:

$$R = \frac{6,800 t_w^3}{h} \left[0.4 \left(\frac{d_c/t_w}{l/b_f} \right)^3 \right] \quad (41b)$$

(41b)

where

l	= largest laterally unbraced length along either flange at the point of load, in.
b_f	= flange width, in.
d_c	= $d - 2k$ = web depth clear of fillets, in.

Page 72

Equations (41a) and (41b) need not be checked providing $(d_c/t_w)/(l/b_f)$ exceeds 2.3 or 1.7, respectively, or for webs subject to uniformly distributed load.

These stresses shall be computed as required by (a)(2)(b)(1) and (2) below.

(1) Concentrated loads shall be divided by the product of the web thickness and the girder depth or the length of panel in which the load is placed, whichever is the lesser panel dimension.

(2) Distributed loads, kips/linear in. of length, shall be divided by the web thickness.

(b) Flanges

(1) The thickness of outstanding parts of flanges shall conform to the requirements of NF-3322.2(d)(1).

(2) Flanges of welded plate girders may be varied in thickness or width by splicing a series of plates or by the use of cover plates.

(3) The total cross-sectional area of cover plates of bolted girders shall not exceed 70% of the total flange area.

(c) Flange Development

(1) High strength bolts or welds connecting flange to web or cover plate to flange shall be proportioned to resist the total horizontal shear resulting from the bending forces on the girder. The longitudinal distribution of these bolts or intermittent welds shall be in proportion to the intensity of the shear, but the longitudinal spacing shall not exceed the maximum permitted, respectively, for compression or tension members in NF-3322.4(a)(3) or NF-3322.5(a). Additionally, bolts or welds connecting flange to web shall be proportioned so as to transmit to the web any loads applied directly to the flange unless provision is made to transmit such loads by direct bearing.

(2) Partial length cover plates shall be extended beyond the theoretical cut-off point and the extended portion shall be attached to the beam or girder by high strength bolts for friction-type joints or fillet welds adequate at the applicable stresses allowed in NF-3324.6(a), NF-3324.5(d), or NF-3324.4, to develop the cover plate portion of the flexural stresses in the beam or girder at the theoretical cut-off point. In addition, for welded cover plates, the welds connecting

the cover plate termination to the beam or girder in the length d' , defined in (c)(1)(a) through (c) below, shall be adequate at the allowed stresses to develop the cover plate portion of the flexural stresses in the beam or girder at the distance d' from the end of the cover plate. The length d' measured from the end of the cover plate, shall be:

(a) a distance equal to the width of the cover plate when there is a continuous weld equal to or larger than three-fourths of the plate thickness across the end of the plate and continuous welds along both edges of the cover plate in the length d' ;

(b) a distance equal to $1\frac{1}{2}$ times the width of the cover plate when there is a continuous weld smaller than three-fourths of the plate thickness across the end of the plate and continuous welds along both edges of the cover plate in the length d' ;

(c) a distance equal to two times the width of the cover plate when there is no weld across the end of the plate, but continuous welds along both edges of the cover plate in the length d' ;

(d) *Reduction in Flange Stress.* When the web depth-thickness ratio exceeds $760/\sqrt{F_b}$, the maximum stress in the compression flange shall not exceed:

$$F'_b \leq F_b \left[1.0 - 0.0005 \frac{A_w}{A_f} \left(\frac{h}{t} - \frac{760}{\sqrt{F_b}} \right) \right] \quad (42)$$

(42)

where F_b is the applicable bending stress, ksi, given in NF-3322.1(d). The maximum stress in either flange of a hybrid girder shall not exceed the value given in Eq. (42) or:

$$F'_b \leq F_b \left[\frac{12 + (A_w/A_f)(3\alpha - \alpha^3)}{12 + 2(A_w/A_f)} \right] \quad (43)$$

(43)

(e) *Stiffeners*

(1) *Bearing.* Bearing stiffeners shall be placed in pairs at unframed ends on the webs of plate girders and, where required by (a)(2) above, at points of concentrated loads. Such stiffeners, when the load normal to the flange is tensile, shall be welded to the loaded flange and when the load normal to the flange is compressive may be welded or bear on the loaded flange. They shall be designed as columns subject to the provisions of NF-3322.1, assuming the column section to comprise the pair of stiffeners and a centrally located strip of the web whose width is equal to not more than 25 times its thickness at interior stiffeners, or a width equal to not more than 12 times its thickness when the stiffeners are located at the end of the web. The effective length shall be taken as not less than three-fourths of the length of the stiffeners in computing the ratio l/r . Only that portion of the stiffener outside of the flange angle fillet or the flange to

web welds shall be considered effective in bearing.

(2) *Average Web Shear.* Except as provided herein, the largest average web shear f_v , ksi, computed for any condition of complete or partial loading, shall not exceed the value given by Eq. (44):

Page 73

$$F_v = (S_y / 2.89) C_v \leq 0.4 S_y \quad (44)$$

(44)

where

$$\begin{aligned} C_v &= (45,000k) / [S_y(h/t)^2], \text{ when } C_v \text{ is less than } 0.8 \\ &= [190/(h/t)] \sqrt{k/S_y}, \text{ when } C_v \text{ is more than } 0.8 \\ k &= 4.00 + [5.34/(a/h)^2], \text{ when } a/h \text{ is less than } 1.0 \\ &= 5.34 + [4.00/(a/h)^2], \text{ when } a/h \text{ is more than } 1.0 \end{aligned}$$

Alternatively, for girders other than hybrid girders and tapered members, if intermediate stiffeners are provided and spaced to satisfy the provisions of (e)(3) below and if $C_v \leq 1$, the allowable shear given by Eq. (45)¹¹ may be used in lieu of the value given in Eq. (44):

$$F_v = \frac{S_y}{2.89} \left[C_v + \frac{1 - C_v}{1.15 \sqrt{1 + (a/h)^2}} \right] \leq 0.4 S_y \quad (45)$$

(45)

(3) Intermediate Stiffeners

(a) Subject to the limitations of NF-3322.6(a), intermediate stiffeners are not required when the ratio h/t is less than 260 and the maximum web shear stress f_v is less than that permitted for F_v by Eq. (44).

(b) The spacing of intermediate stiffeners, when stiffeners are required, shall be such that the web shear stress will not exceed the value for F_v given by Eq. (44) or (45), as applicable, and the ratio a/h shall not exceed $[260/(h/t)]^2$ or 3.0.

(c) In girders designed on the basis of tension field action, the spacing between stiffeners at end panels, at panels containing large holes, and at panels adjacent to panels containing large holes shall be such that f_v does not exceed the

value for F_v given by Eq. (44).

(4) *Moment of Inertia and Gross Area*

(a) The moment of inertia, in.⁴, of a pair of intermediate stiffeners or a single intermediate stiffener, with reference to an axis in the plane of the web, shall not be less than $(h/50)^4$.

(b) The gross area, sq in., of intermediate stiffeners spaced as required for Eq. (45) (total area, when stiffeners are furnished in pairs), shall be not less than that computed by Eq. (46):

$$A_{st} = \frac{1 - C_v}{2} \left[\frac{a}{h} - \frac{(a/h)^2}{\sqrt{1 + (a/h)^2}} \right] Y D h t \quad (46)$$

(46)

where

D	$= 1.0$ for stiffeners furnished in pairs $= 1.8$ for single angle stiffeners $= 2.4$ for single plate stiffeners
-----	---

11 Equation (45) recognizes the contribution of tension field action.

(c) When the greatest shear stress f_v in a panel is less than that permitted by Eq. (45), this gross area requirement may be reduced proportionately.

(d) Intermediate stiffeners required by Eq. (45) shall be connected for a total shear transfer, kips/linear in. of single stiffener or pair of stiffeners, not less than that computed by Eq. (47):

$$f_{vs} = h \left(\frac{S_y}{340} \right)^{2/3} \quad (47)$$

(47)

This shear transfer may be reduced in the same proportion that the largest computed shear stress f_v in the adjacent panels is less than that permitted by Eq. (45). However, bolts and welds in intermediate stiffeners which are required to transmit to the web an applied concentrated load or reaction shall be proportioned for not less than the applied load or reaction.

(e) Intermediate stiffness may be stopped short of the tension flange, provided bracing is not needed to transmit a concentrated load or reaction; the weld by which intermediate stiffeners are attached to the web shall be terminated not closer than four times nor more than six times the web thickness from the near toe of the web to flange welds. When single stiffeners are used, they shall be attached to the compression flange, if it consists of a rectangular plate, to resist any uplift tendency due to torsion in the plate. When lateral bracing is attached to a stiffener or a pair of stiffeners, these, in turn, shall be connected to the compression flange to transmit 1% of the total flange stress, unless the flange is composed only of angles.

(f) Bolts connecting stiffeners to the girder web shall be spaced not more than 12 in. (305 mm) on center. If intermittent fillet welds are used, the clear distance between welds shall not be more than 16 times the web thickness, or more than 10 in. (254 mm).

(f) *Splices.* Groove welded splices in the plate girders and beams shall develop the full strength of the smaller spliced section; other types of splices in cross sections of plate girders and in beams shall develop the strength required by the stresses at the point of splice.

(g) *Rotational Restraint at Points of Support.* Beams, girders, and trusses shall be restrained against rotation about their longitudinal axis at points of support.

NF-3322.7 Simple and Continuous Spans, and Provision for Expansion

(a) Design Requirements for Spans

(1) *Simple Spans.* Beams, girders, and trusses shall ordinarily be designed on the basis of simple spans whose effective length is equal to the distance between

Page 74

centers of gravity of the members to which they deliver their end reactions.

(2) *Continuous Spans.* When designed on the assumption of full or partial end restraint, due to continuous, semi-continuous, or cantilever action, the beams, girders, and trusses, as well as the sections of the members to which they connect, shall be designed to carry the shears and moments so introduced, as well as all other forces, without exceeding at any point the unit stresses prescribed in NF-3321.1, except that some nonelastic but self-limiting deformation of a part of the connection may be permitted when this is essential to the avoidance of overstressing of fasteners.

(3) *Provision for Expansion.* Adequate provision shall be made for expansion and contraction appropriate to the function of the support structure.

NF-3322.8 Gross and Net Areas

(a) *Determination of Gross and Net Areas.* The gross area of a member at any point shall be determined by summing the products of the thickness and the gross width of each element as measured normal to the axis of the member. The net area shall be determined by substituting the net width, computed in accordance with (c) below, for the gross width.

(b) *Net Area and Effective Net Area.* Unless otherwise specified, tension members shall be designed on the basis of net area. Compression members shall be designed on the basis of gross area. Beams and girders shall be designed in accordance with NF-3322.3(a).

(c) Calculation of Net Area

(1) Parts With Holes

(a) In the case of a chain of holes extending across a part in any diagonal or zigzag line, the net width of the part shall be obtained by deducting from the gross width the sum of the diameters of all the holes in the chain and adding, for each gage space in the chain, the quantity $s^2/4g$.

(b) The critical net area A_n of the part is obtained from that chain which gives the least net width.

(c) In determining the net area across plug or slot welds, the weld metal shall not be considered as adding to the net

area.

(d) The effective net area A_e of axially loaded tension members, where the load is transmitted by bolts through some but not all of the cross-sectional elements of the member, shall be computed from the formula:

$$A_e = C_t A_n$$

Unless a larger coefficient can be justified by tests or other recognized criteria, the following values of C_t shall be used in computations:

When the load is transmitted by welds through some but not all of the cross-sectional elements of the member, the effective net area A_e shall be computed as:

$$A_e = U A_g$$

where

$$A_g = \text{gross area of member, in.}^2$$

When load is transmitted by transverse welds to some but not all of the cross-sectional elements of W, M, or S shapes and structural tees cut from these shapes, A_e shall be taken as the area of the directly connected elements.

When the load is transmitted to a plate by longitudinal welds along both edges at the end of the plate, the length of the welds shall not be less than the width of the plate. The effective net area A_e shall be computed as above.

Unless a larger coefficient can be justified by tests or other criteria, the following values of U shall be used: when $l > 2w$, $U = 1.0$; when $2w > l > 1.5w$, $U = 0.87$; when $1.5w > l > w$, $U = 0.75$

where

$$l = \text{weld length, in.}$$

$$w = \text{plate width (distance between welds), in.}$$

(1) W, M, or S shapes with flange widths not less than two-thirds of the depth, and structural tees cut from these shapes, provided the connection is to the flanges and has no fewer than three fasteners per line in the direction of applied stress:

$$C_t = 0.90$$

(2) W, M, or S shapes not meeting the conditions of (c)(1)(d)(1) above, structural tees cut from these shapes, and all other shapes, including built-up cross sections, provided the connection has not less than three fasteners per line in the direction of applied stress:

$$C_t = 0.85$$

(3) all members whose connections have only two fasteners per line in the direction of applied stress:

$$C_t = 0.75$$

(e) Bolted splice and gusset plates, and other connection fittings subject to tensile force shall be designed in accordance with the provisions of NF-3322.1(a) where the effective net area shall be taken

Page 75

as the actual net area, except that for the purpose of design calculations it shall not be taken as greater than 85% of the gross area.

(2) *Size of Bolt Holes.* In computing net area, the diameter of a bolt hole shall be taken as $1/16$ in. greater than the nominal dimension of the hole normal to the direction of applied stress.

(3) *Angles.* For angles, the gross width shall be the sum of the widths of the legs less the thickness. The gage for holes in opposite legs shall be the sum of the gages from the back of angles less the thickness.

(4) *Pin-Connected Members*

(a) Eyebars shall be of uniform thickness without reinforcement at the pinholes.¹² They shall have circular heads in

which the periphery of the head beyond the pinhole is concentric with the pinhole. The radius of transition between the circular head and the body of the eyebar shall be equal to or greater than the diameter of the head. The width of the body of the eyebar shall not exceed eight times its thickness and the thickness shall not be less than $\frac{1}{2}$ in. (13 mm). The minimum net area beyond the pin hole, parallel to the axis of the member, shall not be less than $\frac{2}{3}$ of the net area across the pin hole. The thickness may be less than $\frac{1}{2}$ in. (13 mm) only if external nuts are provided to tighten pin plates and filler plates into snug contact. The diameter of the pin shall not be less than seven-eighths of the width of the body of the eyebar. The diameter of the pinhole shall not be more than $\frac{1}{32}$ in. (0.8 mm) greater than the diameter of the pin. For steels having a yield stress greater than 70.0 ksi (480 MPa), the diameter of the pinhole shall not exceed five times the plate thickness.

(b) In pin-connected plates other than eyebars, the tensile stress on the net area transverse to the axis of the member shall not exceed the stress allowed in NF-3322.1(a), and the bearing stress on the projected area of the pin shall not exceed the stress allowed in NF-3322.1(f)(1). The minimum net area beyond the pinhole, parallel to the axis of the member, shall not be less than two-thirds of the net area across the pinhole.

12 Members having a different thickness at the pinhole location are termed built-up.

(c) The distance used in calculations, transverse to the axis of pin-connected plates or any individual element of a built-up member, from the edge of the pinhole to the edge of the member or element shall not exceed 4 times the thickness at the pinhole. For calculation purposes, the distance from the edge of the pinhole to the edge of the plate or to the edge of a separated element of a built-up member at the pinhole, shall not be assumed to be more than 0.8 times the diameter of the pinhole.

(d) The corners beyond the pinhole may be cut at 45 deg. to the axis of the member, provided the net area beyond the pinhole, on a plane perpendicular to the cut, is not less than that required beyond the pinhole parallel to the axis of the member.

(e) Thickness limitations on both eyebars and pin-connected plates may be waived whenever external nuts are provided so as to tighten pin plates and filler plates into snug contact. When the plates are thus contained, the allowable stress in bearing shall be no greater than as specified in NF-3322.1(f)(1).

NF-3323 Design Requirements for Steel Castings and Forgings

NF-3323.1 Allowable Stresses.

Allowable stresses for steel castings and forgings shall be the same as those provided in NF-3322 with the applicable values for yield strength of Table Y-1, Section II, Part D, Subpart 1.

NF-3324 Design Requirements for Connections and Joints

NF-3324.1 General Requirements

(a) *Types of Connections Permitted.* Structural Connections of a welded, bolted, or welded and bolted type shall be used.

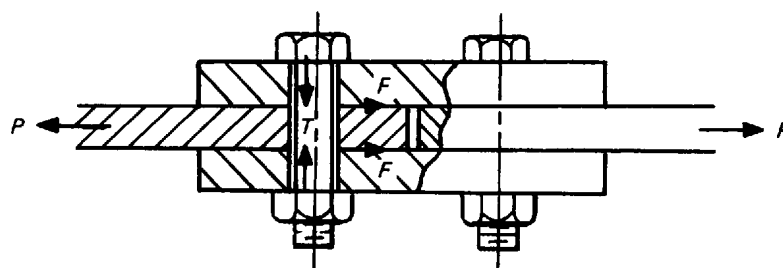
Types of bolted connections include:

(1) Friction-type connections that are mechanically fastened structural connections that use high strength bolts (such as SA-325 and SA-490) and are sufficiently tightened to reliably produce a high clamping force that prevents slip between faying surfaces. Load is transferred at the faying surfaces by friction [Fig. NF-3324.1(a)(1)].

(2) Bearing-type connections that are mechanically fastened structural connections that depend on direct shear of the fastener to transfer the load from one connected part to another.

(3) Other connections that are not covered by (1) and (2) above, such as clamps and U-bolts shown in Fig. NF-1214-1, are not friction-type connections and shall meet the requirements of NF-3380, unless otherwise indicated in the design documents.

(b) *Provision for Eccentric Connections.* Axially stressed members meeting at a point shall have their gravity axes



GENERAL NOTES:

T = clamping force

P = applied load

F = friction force

FIG. NF-3324.1(a)(1) TYPICAL FRICTION-TYPE CONNECTIONS USING HIGH STRENGTH BOLTS

FIG. NF-3324.1(a)(1) TYPICAL FRICTION-TYPE CONNECTIONS USING HIGH STRENGTH BOLTS

(c) *Placement of Bolts and Welds.* Except as otherwise provided, groups of bolts or welds at the ends of any member transmitting axial stress into that member shall have their centers of gravity on the gravity axis of the member, unless provision is made for the effect of the resulting eccentricity. Except in members subject to repeated variation in stress, as stipulated in NF-3330, disposition of fillet welds to balance the forces about the neutral axes for end connections of single angle, double angle, and similar type members is not required. Eccentricity between the gravity axes of such members and the gage lines for their bolted end connections may be neglected in statically loaded members, but should be considered in members subjected to fatigue loading.

NF-3324.2 Connection Design

(a) *Connections for Unrestrained Members*

(1) Except as otherwise indicated by the Designer, connections of beams, girders, or trusses shall be designed as flexible and may ordinarily be proportioned for the reaction shears only.

(2) Flexible beam connections shall accommodate end rotations of unrestrained (simple) beams. To accomplish this, inelastic action in the connection is permitted.

(b) *Connections for Restrained Members*

(1) Fasteners or welds for end connections of beams, girders, and trusses shall be designed for the combined effect of forces resulting from moment and shear induced by the rigidity of the connections.

(2) When flanges or moment connection plates for end connections of beams and girders are welded to the flange of an I or H shaped column, a pair of column web stiffeners having a combined cross-sectional area A_{st} not less than that computed from Eq. (48) shall be provided whenever the calculated value of A_{st} is positive:

$$A_{st} = \frac{P_{bf} - F_{yc}t(t_b + 5k)}{F_{yst}} \quad (48)$$

(48)

(3) Notwithstanding the requirements of (b)(2) above, a stiffener or a pair of stiffeners shall be provided opposite the compression flange when the column web depth clear of fillets d_c is greater than:

$$\frac{4100t^3 \times \sqrt{F_{yc}}}{P_{bf}}$$

and a pair of stiffeners shall be provided opposite the tension flange when the thickness of the column flange t_f is less than:

$$0.4 \sqrt{(P_{bf}/F_{yc})}$$

(4) Stiffeners required by the provisions of (b)(2) and (3) above shall comply with the following criteria:

(a) The width of each stiffener plus one-half the thickness of the column web shall not be less than one-third the width of the flange or moment connection plate delivering the concentrated force.

(b) The thickness of stiffeners shall not be less than $t_b/2$.

(c) When the concentrated force delivered occurs on only one column flange, the stiffener length need not exceed one-half the column depth.

(d) The weld joining stiffeners to the column web shall be sized to carry the force in the stiffener caused by unbalanced moments on opposite sides of the column.

(5) The thickness of column webs within the boundaries of rigid connections of two or more members whose webs lie in a common plane shall not be less than

$$t_{\min} = \frac{32M}{d_b \cdot d_c \cdot S_y}$$

where

M	= the algebraic sum of clockwise and counter-clockwise moments, kip-ft, applied on opposite sides of the connection boundary
d_b	= the beam depth, in.
d_c	= the column depth, in.
$t_{\min}$	= the web thickness, in.

When the web thickness is less than $t_{\min}$ doubler plates or longitudinal stiffeners may be provided to reinforce the column web.

(c) Connections of Tension and Compression Members in Trusses. The connections at ends of the tension or compression member in trusses shall develop the force due to the Design Load but not less than 50% of the effective strength of the member, based upon the kind of stress that governs the selection of the member.

(d) Connections for Compression Members With Bearing Joints

(1) For members subjected to compression forces only, which bear on bearing plates, sufficient bolts or welds shall be provided to hold all parts securely in place.

(2) For members subjected to compression forces only, which are finished to bear at splices, the splice material and its bolting or welding shall be arranged to hold all parts in line and shall be proportioned for 50% of the computed stress.

(3) All of the foregoing joints shall be proportioned to resist any tension that would be developed by design moments acting in conjunction with 75% of the axial compression forces.

NF-3324.3 Design of Lap Joints and Fillers

(a) Lap Joint Design. The minimum amount of lap on lap joints shall be five times the thickness of the thinner part joined but not less than 1 in. (25 mm). Lap joints subjected to axial stress shall be fillet welded along the end of both lapped parts, except where the deflection of the lapped parts is sufficiently restrained to prevent opening of the joint under maximum loading.

(b) Filler Design

(1) Bolted Construction. When bolts carrying computed stress pass through fillers thicker than $\frac{1}{4}$ in., except in friction-type connections assembled with high strength bolts, the fillers shall be extended beyond the splice material and the filler extension shall be secured by enough bolts to distribute the total stress in the member uniformly over the combined section of the member and the filler or an equivalent number of fasteners shall be included in the connection. Fillers between $\frac{1}{4}$ in. (6 mm) and $\frac{3}{4}$ in. (19 mm) thick, inclusive, need not be extended and developed, provided the allowable shear stress in the bolts is reduced by the factor, $0.4(t - 0.25)$, where t is the total thickness of the fillers, up to $\frac{3}{4}$ in. (19 mm).

(2) Welded Construction. In welded construction, any filler $\frac{1}{4}$ in. (6 mm) or more in thickness shall extend beyond the edges of the splice plate and shall be welded to the part on which it is fitted with sufficient weld to transmit the splice plate stress, applied at the surface of the filler as an eccentric load. The welds joining the splice plate to the filler shall be sufficient to transmit the splice plate stress and shall be long enough to avoid overstressing the filler along the toe of the weld. Any filler less than $\frac{1}{4}$ in. (6 mm) thick shall have its edges made flush with the edges of the splice plate, and the weld size shall be the sum of the size necessary to carry the splice plate stress plus the thickness of the filler plate.

NF-3324.4 Joint Combinations

(a) Combinations of Welds. If two or more of the general types of weld (groove, fillet, plug, or slot) are combined in a single joint, the effective capacity of each shall be separately computed with reference to the axis of the group, in order to determine the allowable capacity of the combination.

(b) Bolts in Combination With Welds. SA-307 bolts or high strength bolts used in bearing-type connections shall not be considered as sharing the stress in combination with welds. Welds, if used, shall be provided to carry the entire stress in the connection. High strength bolts installed as a friction-type connection prior to welding may be considered as sharing the stress with the welds.

NF-3324.5 Design of Welded Joints

(a) Permissible Types of Welded Joints in Linear Supports. All welded joints in Linear Supports shall be as described in NF-3256.1 except that intermittent or lap joints using fillet welds may not be used for the support of Class 1 Components or Class 2 vessels designed to NC-3200. The allowable stress limits shall be as defined in (b) and (c) below.

(b) Design Limits. The allowable stress limits which must be satisfied for welds for Design Loadings stated in the Design Specification shall be as follows.

(1) Full Penetration Groove Welds. The stress limits for full penetration groove welds shall not exceed the applicable stress value for the base metal being joined, as specified in NF-3321.1 and Table NF-3324.5(a)-1.

(2) Partial Penetration Groove Welds

**TABLE NF-3324.5(a)-1
ALLOWABLE STRESS LIMITS FOR CLASS 1 LINEAR-TYPE SUPPORT WELDS**

Kind of Stress	Base Metal TS Range, ksi	Weld Metal Min. TS, ksi [Note (1)]	Stress Limits, ksi
Tension and compression parallel to axis of any full penetration groove weld	...	...	Same as for base metal
Tension normal to effective throat of full penetration groove weld	...	...	Same as allowable tensile stress for base metal
Compression normal to effective throat of full penetration groove weld and partial penetration groove weld	...	...	Same as allowable compressive stress for base metal
Shear stress on effective throat of fillet weld, regardless of direction of application of load; tension normal to the axis on the effective throat of a partial penetration groove weld and shear stress on effective area of a plug or slot weld. The given stresses shall also apply to such welds made with the specified electrode on steel having a yield stress greater than that of the matching base metal.	45–60	60	0.30 × minimum tensile strength of weld metal (ksi), except shear stress on base metal shall not exceed 0.40 × yield stress of base metal
	61–70	70	
	71–80	80	
	81–90	90	
	91–100	100	
	101–120	120	

NOTE:

(1) Weld metal one nominal strength level stronger than shown will be permitted (e.g., E70xx for E60xx applications).

TABLE NF-3324.5(a)-1 ALLOWABLE STRESS LIMITS FOR CLASS 1 LINEAR-TYPE SUPPORT WELDS

(a) *Compression Normal to Effective Throat or Shear on Effective Throat.* The stress limits shall be the same as those for the base metal, as required by NF-3321.1.

(b) *Tension Normal to the Axis on the Effective Throat.* The stress limits shall be as specified in Table NF-3324.5(a)-1.

(3) *Fillet Welds.* The allowable stress limits for fillet welds shall be as specified in Table NF-3324.5(a)-1.

(c) *Service Limits, Level A Through D, and Test.* The rules and stress limits which must be satisfied for welds for any Level A through D Service and Test Loading stated in the Design Specification are those given in NF-3324.5(b) multiplied by the appropriate base material stress limit factor given in Table NF-3623(b)-1 for piping supports and Table NF-3523(b)-1 for component supports.

(d) *Fillet Welds*

(1) *Minimum Size of Fillet Welds and Partial Penetration Welds.* Fillet and partial penetration welds shall not be specified less than $\frac{1}{8}$ in. (3.2 mm) (NF-4427). When fillet or partial penetration welds less than $\frac{1}{4}$ in. (6 mm) are used to join heavy section members, the designer shall consider specifying preheat and special requirements for fit-up of members to ensure adequate weld deposition.

(2) *Maximum Effective Size of Fillet Welds.* The maximum size of a fillet weld that may be assumed in the design of a connection shall be such that the stresses in the adjacent base material do not exceed the values allowed in Table NF-3324.5(a)-1 and NF.3321.1. The maximum size that may be used along edges of connected parts shall be as stipulated in (d)(2)(a) and (b) below:

(a) along edges of material less than $\frac{1}{4}$ in. (6 mm) thick, the maximum size may be equal to the thickness of the material;

(b) along edges of material $\frac{1}{4}$ in. (6 mm) or more in thickness, the maximum size shall be $\frac{1}{16}$ in. (1.6 mm) less than the thickness of the material, unless the weld is especially designated on the drawings to be built up to obtain full throat thickness.

(3) Length of Fillet Welds

Page 79

(a) The effective length of a fillet weld shall be the overall length of a full-size fillet, including returns.

(b) The minimum effective length of a strength fillet weld shall be not less than four times the nominal size, or else the size of the weld shall be considered not to exceed one-fourth of its effective length.

(c) If longitudinal fillet welds are used alone in end connections of tension members, the length of each fillet weld shall be not less than the perpendicular distance between them. The transverse spacing of longitudinal fillet welds used in end connections shall not exceed 8 in., unless the design otherwise prevents excessive transverse bending in the connection.

(4) *Effective Throat Thickness of Fillet Welds.* The effective throat thickness of a fillet weld joining members at angles between 60 deg. and 135 deg., inclusive (Fig. NF-4427-1), shall be the shortest distance from the root to the face of the diagrammatic weld, except that for fillet welds made by the submerged arc process the effective throat thickness shall be taken equal to the leg size for $\frac{3}{8}$ in. (10 mm) and smaller fillet welds, and equal to the theoretical throat plus 0.11 in. for fillet welds over $\frac{3}{8}$ in. (10 mm). For fillet welds joining members at angles less than 60 deg. use the rules for partial penetration groove welds, NF-3324.5(f)(3).

(5) *Effective Area of Fillet Welds.* The effective area of fillet welds shall be considered as the effective length of the weld times the effective throat thickness.

(6) *Effective Area of Fillet Welds in Holes and Slots.* The effective area of fillet welds in holes and slots shall be computed as specified in (d)(5) above for fillet welds using for effective length the length of center line of the weld through the center of the plane through the throat. However, in the case of overlapping fillets the effective area shall not exceed the nominal cross-sectional area of the hole or slot in the plane of the faying surface.

(7) *Intermittent Fillet Welds.* Intermittent fillet welds may be used to transfer calculated stresses across a joint or faying surface, when the strength required is less than that developed by a continuous fillet weld of the smallest permitted size, and to join elements of built-up members. The effective length of any segment of intermittent fillet welding shall not be less than four times the weld size with a minimum of $1\frac{1}{2}$ in. (38 mm).

(8) *End Returns to Fillet Welds.* Side or end fillet welds terminating at ends or sides, respectively, of parts or members shall, when required by the designer, be returned continuously around the corners for a distance not less than twice the nominal size of the weld. This provision shall apply to side and top fillet welds connecting brackets, beam seats, and similar connections, on the plane about which bending moments are computed. For framing angles and simple end-plate connections which depend upon flexibility of the outstanding legs for connection flexibility, end returns shall not exceed four times the nominal size of the weld. Fillet welds which occur on opposite sides of a common plane shall be interrupted at the corner common to both welds. End returns, when required by the designer, shall be indicated on the drawings.

(9) *Fillet Welds in Holes and Slots.* Fillet welds in holes or slots may be used to transmit shear in lap joints or to prevent the buckling or separation of lapped parts and to join elements of built-up members. Such fillet welds may overlap, subject to the provisions of (d)(6) above. Fillet welds in holes or slots are not to be considered plug or slot welds.

(e) Plug and Slot Welds

(1) *Use of Plug and Slot Welds.* Plug and slot welds may be used to transmit shear in a lap joint or to prevent buckling of lapped parts and to join component parts of built-up members.

(2) *Diameter of Holes for Plug Welds.* The diameter of the holes for a plug weld shall be not less than the thickness of the part containing it plus $\frac{5}{16}$ in. (8 mm), rounded to the next greater odd $\frac{1}{16}$ in. (1.6 mm), nor greater than the minimum diameter plus $\frac{1}{8}$ in. (3.2 mm) or $2\frac{1}{4}$ times the thickness of the weld metal.

(3) *Spacing of Plug Welds.* The minimum center-to-center spacing of plug welds shall be four times the diameter of the hole.

(4) *Length of Slot Welds.* The length of slot for a slot weld shall not exceed 10 times the thickness of the weld. The width of the slot shall be not less than the thickness of the part containing it plus $\frac{5}{16}$ in. (8 mm), rounded to the next greater odd $\frac{1}{16}$ in. (1.6 mm), nor shall it be greater than $2\frac{1}{4}$ times the thickness of the weld. The ends of the slot shall be semicircular or shall have the corners rounded to a radius not less than the thickness of the part containing it, except for those ends which extend to the edge of the part.

(5) *Spacing of Slot Welds.* The minimum spacing of lines of slot welds in a direction transverse to their length shall be four times the width of the slot. The minimum center to center spacing in a longitudinal direction on any line shall be two times the length of the slot.

(6) *Thickness of Plug and Slot Welds.* The thickness of plug and slot welds in material $\frac{5}{8}$ in. (16 mm) or less in thickness shall be equal to the thickness of the material. In material over $\frac{5}{8}$ in. (16 mm) in thickness, it shall be at least one-half the thickness of the material but not less than $\frac{5}{8}$ in. (16 mm).

Page 80

(7) *Effective Shearing Area of Plug and Slot Welds.* The effective shearing area of plug and slot welds shall be considered as the nominal cross-sectional area of the hole or slot in the plane of the faying surface.

(f) *Full Penetration and Partial Penetration Joints.* The effective area shall be the effective weld length multiplied by the effective throat thickness.

(1) The effective weld length for any groove weld, square or skewed, shall be the length of weld throughout which the correct proportioned cross section exists. In a curved weld it shall be its true length measured along its curvature.

(2) The effective throat thickness of a full penetration groove weld which shall conform to the requirements of NF-4000 shall be the thickness of the thinner part joined. No increase is permitted for weld reinforcement.

(3) The effective throat of partial penetration groove welds is dependent upon the type of groove.

(a) For square, U, and J groove welds, the effective throat is equal to the depth of preparations.

(b) For V and bevel groove welds with an included angle at the root equal to or greater than 60 deg., the effective throat shall be the minimum distance from the root to the face of the weld.

(c) For V and bevel groove welds with an included angle at the root less than 60 deg. but equal to or greater than 45 deg., the effective throat shall be the minimum distance from the root to the face of the weld less $\frac{1}{8}$ in. (3.2 mm).

(d) For V and bevel groove welds, with an included angle at the root less than 45 deg. but equal to or greater than 30 deg., the effective throat shall be the minimum distance from the root to the face of the weld less $\frac{1}{8}$ in. (3.2 mm) and multiplied by 0.75. The required effective throat must be specified on the drawing.

(e) For V and bevel groove welds, angles less than 30 deg. at the root are not allowed.

(f) For flare bevel groove welds, when filled flush to the surface, the effective throat shall be 0.31 times the outside radius of the curved section forming the groove. For formed rectangular tubing, the outside radius may be considered as two times the wall thickness.

(g) For flare V groove welds, when filled flush to the surface, the effective throat shall be 0.5 (except use 0.375 for GMAW when $R \geq \frac{1}{2}$ in. (13 mm) times the outside radius when the outside radius is less than 1 in. For flare bevel groove welds, the effective throat shall be 0.312 times the outside radius.

NF-3324.6 Design Requirements for Bolted Joints.

The rules and stress limits for bolting shall be as given in this paragraph. The stress limits which must be satisfied for

any Design, Level A through D, and Test Loadings, shall be those given in this paragraph, multiplied by the appropriate stress limit factors given in Table NF-3225.2-1 for the particular Loading specified in the Design Specification (NCA-3250). This product shall not exceed the yield strength of the material at temperature.

(a) *Allowable Stresses.* Allowable tensile, shearing, and bearing stresses in bolts and threaded parts shall be as given in the paragraphs below. All allowables are expressed in ksi acting on the actual bolt area available in the shear planes of the connected parts. All are expressed in terms of the ultimate tensile strength at temperature (Table Y-1, Section II, Part D, Subpart 2). The shear capacity of bolts is directly proportional to the shear area available in the shear planes. Shear strength is unaffected by shear plane location.

(1) *Tensile Stress Only.* Bolts loaded in direct tension shall be so proportioned that their average tensile stress F_{tb} , computed on the basis of the actual tensile stress area available (independent of any initial tightening force), shall not exceed:

For ferritic steels:

$$F_{tb} = \frac{S_u}{2}$$

For austenitic steels:

$$F_{tb} = \frac{S_u}{3.33}$$

The applied load shall be the sum of the external load and any tension resulting from prying action produced by

deformation of the connected parts.

(2) *Shearing Stress Only*

(a) *Bearing-Type Joints*

(1) *Threads Excluded From Shear Planes.* The allowable shear F_{vb} in bolts and threaded parts loaded in direct shear, expressed in ksi of actual shear stress area available (applicable to the total nominal bolt area in the shear planes in this case), shall not exceed:

Page 81

For ferritic steels:

$$F_{vb} = \frac{0.62S_u}{3}$$

For austenitic steels:

$$F_{vb} = \frac{0.62S_u}{5}$$

(2) *Threads Not Excluded From Shear Planes.* The allowable shear stress F_{vb} in bolts and threaded parts loaded in direct shear, expressed in ksi of actual shear stress area available (applicable to the total bolt root area in the shear planes in this case), shall not exceed:

For ferritic steels:

$$F_{vb} = \frac{0.62S_u}{3}$$

For austenitic steels:

$$F_{vb} = \frac{0.62S_u}{5}$$

(3) Combined Tensile and Shear Stresses

(a) Bearing-Type Joints. Bolts subjected to combined shear and tension shall be so proportioned that either the shear or the tensile stress, kips/sq in. of actual cross-sectional area, shall not exceed the value derived from the ellipse equation below when the corresponding computed tensile or shearing stress is substituted:

$$\frac{f_i^2}{F_{ib}^2} + \frac{f_v^2}{F_{vb}^2} = 1$$

The allowable tensile and shear stress values shall be those derived from the equations given in (a)(1) and (2) above.

(b) *Friction-Type Joints.* A bolt in a connection designed as a friction-type joint is not subjected to shear (provided the joint does not slip into bearing); it experiences tension only. Friction-type joints shall be designed as given in (a)(4) below.

(4) *Slip Resistance - Friction-Type Joints.* The maximum slip resistance to which a friction-type joint may be designed shall not exceed the value of P_s , calculated in the following equation [see Table NF-3324.6(a)(4)-1]:

$$P_s = mnT_i k_s$$

**TABLE NF-3324.6(a)(4)-1
EFFECTIVE SLIP COEFFICIENT VS
SURFACE CONDITION**

Surface Condition	Slip Coefficient, k_s
Clean mill scale	0.25
Grit-blasted carbon and low alloy high strength steel	0.41
Grit-blasted heat treated steel	0.25
Hot dip galvanized wire, brushed, scored, or blasted	0.31
Blast cleaned, zinc rich paint	0.31
Blast cleaned, zinc silicate paint	0.45

TABLE NF-3324.6(a)(4)-1 EFFECTIVE SLIP COEFFICIENT VS SURFACE CONDITION

If the joint clamping force will be reduced by any direct tension load on the joint, the T_i value shall be reduced by an equivalent amount before substituting in the above equation. SA-307 and austenitic steel bolting shall not be used for friction-type joints.

(5) *Bearing Stress.* Allowable bearing stress on the projected area of bolts in bearing type connections shall be:

$$F_p = \frac{LS_u}{2d} \leq 1.5S_u$$

(b) Minimum Edge Distance

(1) Minimum Edge Distance in Line of Load. In both bearing- and friction-type joints the minimum distance from the center of the end bolt in a connection to that edge of the connected part toward which the load is directed shall be determined in accordance with either (b)(1)(a) or (b) below.

(a) The edge distance shall satisfy all of the following:

(1) $L/d \geq 0.5 + 1.43 (f_p/S_u)$

(2) $L/d \geq 1.2$

(3) $f_p/S_u \leq 1.5$

where

$$f_p = P/dt$$

(b) The edge distance shall be as shown in Table NF-3324.6(b)(1)-1.

(c) Maximum Edge Distance. The maximum distance from the center of any rivet or bolt to the nearest edge of parts in contact shall be 12 times the thickness of the connected part under consideration, but shall not exceed 6 in. Bolted joints in unpainted steel exposed

to atmospheric corrosion require special limitations on pitch and edge distance.

**TABLE NF-3324.6(b)(1)-1
MINIMUM EDGE DISTANCES**

Minimum Edge Distance for Punched, Reamed, or Drilled Holes, in.		
Bolt Diameter, in.	At Sheared Edges	At Rolled Edges of Plates, Shapes, or Bars, or Gas Cut Edges [Note (1)]
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{3}{4}$
$\frac{5}{8}$	$1\frac{1}{8}$	$\frac{7}{8}$
$\frac{3}{4}$	$1\frac{1}{4}$	1
$\frac{7}{8}$	$1\frac{1}{2}$ [Note (2)]	$1\frac{1}{8}$
1	$1\frac{3}{4}$ [Note (2)]	$1\frac{1}{4}$
$1\frac{1}{8}$	2	$1\frac{1}{2}$
$1\frac{1}{4}$	$2\frac{1}{4}$	$1\frac{5}{8}$
$>1\frac{1}{4}$	$1\frac{3}{4} \times \text{diam.}$	$1\frac{1}{4} \times \text{diam.}$

NOTES:

- (1) All edge distances in this column may be reduced $\frac{1}{8}$ in. when the hole is at the point where stress does not exceed 25% of the maximum allowed stress in the element.
- (2) These may be $1\frac{1}{4}$ in. at the ends of beam connection angles.

TABLE NF-3324.6(b)(1)-1 MINIMUM EDGE DISTANCES

For unpainted, built-up members made of weathering steel which will be exposed to atmospheric corrosion, the spacing of fasteners connecting a plate and a shape or two-plate components in contact shall not exceed 14 times the thickness of the thinnest part nor 7 in. (178 mm), and the maximum edge distance shall not exceed eight times the thickness of the thinnest part, or 5 in. (127 mm).

(d) *Minimum Spacing.* The distance between centers of standard, oversized, or slotted fastener holes shall be not less than three times the nominal diameter of the bolt. Along a line of transmitted force, the distance between centers of holes shall be not less than the following:

$$\text{Standard Holes: } 2P/S_u t + d/2$$

(e) *Effective Bearing Area.* The effective bearing area of bolts shall be the diameter multiplied by the length in bearing,

except that for countersunk bolts one-half the depth of the countersink shall be deducted.

(f) *Long Grips.* SA-307 bolts, which carry calculated stress and the grip of which exceeds five diameters, shall have their number increased 1% for each additional $\frac{1}{16}$ in. (1.6 mm) in the grip.

(g) *Anchor Bolts.* Anchor bolts shall be designed to provide resistance to all conditions of tension and shear at the bases of columns, including the net tensile components of any bending moments which may result from fixation or partial fixation of columns.

NF-3324.7 Design Requirements for Column Bases.

Proper provision shall be made to transfer the column loads and moments, if any, to the footings and foundations.

NF-3330 HIGH CYCLE FATIGUE DESIGN FOR CLASS 1

NF-3331 Introduction

NF-3331.1 Scope.

Members and their connections, subject to a number of cycles (>20,000) of fatigue loading resulting in damage as defined in NF-3331.2, shall be proportioned to satisfy the stress range limitations provided therein.

NF-3331.2 Definitions.

High cycle fatigue, as used in this Subsubarticle, is defined as the damage that may result in fracture after a sufficient number of fluctuations of stress. *Stress range* is defined as the numerical sum of maximum repeated tensile and compressive stresses or the sum of maximum shearing stresses of opposite direction at a given point, resulting from differing arrangements of live load.

NF-3332 Design Requirements

NF-3332.1 Design Considerations.

In the design of members and connections subject to repeated variation of live load stress, consideration shall be given to the number of stress cycles, the expected range of stress, and the type and location of member or detail.

NF-3332.2 Classification of Loading Conditions.

Loading conditions shall be classified as shown in Table NF-3332.2-1.

NF-3332.3 Stress Categories.

Stress categories for use in establishing the maximum range of stress in relation to the type of member or part, material, and location shall be as stipulated in Table NF-3332.3-1. For illustrations of the members and parts, see Fig. NF-3332.3-1.

NF-3332.4 Allowable Stresses.

The maximum stress shall not exceed the basic allowable stress permitted by NF-3322 and the maximum range of stress shall not exceed that given in Table NF-3332.4-1.

NF-3332.5 Provisions for Mechanical Fasteners.

Range in tensile stress in properly tightened ASTM A325 or ASTM A490 bolts need not be considered, but the maximum computed stress, including prying action, shall not exceed the values given in NF-3332.4 subject to the following stipulations.

TABLE NF-3332.2-1
CLASSIFICATION OF LOADING CONDITIONS

Loading Condition	Number of Loading Cycles	
	From	To
1	20,000 [Note (1)]	100,000 [Note (2)]
2	100,000	500,000 [Note (3)]
3	500,000	2,000,000 [Note (4)]
4	> 2,000,000	

NOTES:

- (1) Approximately equivalent to 2 applications every day for 25 years.
- (2) Approximately equivalent to 10 applications every day for 25 years.
- (3) Approximately equivalent to 50 applications every day for 25 years.
- (4) Approximately equivalent to 200 applications every day for 25 years.

TABLE NF-3332.2-1 CLASSIFICATION OF LOADING CONDITIONS

(a) Connections subject to more than 20,000 cycles, but not more than 500,000 cycles of direct tension may be designed for the stress produced by the sum of applied and prying loads if the prying load does not exceed 10% of the externally applied load. If the prying force exceeds 10%, the allowable tensile stress given in NF-3324.6(a)(1) shall be reduced 40%, applicable to the external load alone.

(b) Connections subject to more than 500,000 cycles of direct tension may be designed for the stress produced by the sum of applied and prying loads if the prying load does not exceed 5% of the externally applied load. If the prying force exceeds 5%, the allowable tensile stress given in NF-3324.6(a)(1) shall be reduced 50%, applicable to the external load alone. The use of other bolts and threaded parts subject to tensile fatigue loading is not recommended. Bolts and threaded parts subjected to cyclic loading in shear may be designed for the bearing-type shear stresses given in NF-3324.6(a)(2) insofar as the fatigue strength of the fasteners is concerned.

NF-3340 LIMIT ANALYSIS DESIGN FOR CLASS 1

NF-3341 Introduction

NF-3341.1 Scope

(a) Subject to the limitation of this Subsubarticle, simple or continuous beams, rigid frames, and similar portions of structures rigidly constructed so as to be continuous over at least one interior support¹³ may be proportioned on the basis of plastic design, namely, on the basis of low bound collapse load. This strength, as determined by rational analysis, shall not be less than that required to support a factored load equal to 1.7 times those of the level A and Level B Service Limits or 1.3 times that of the Level C Service Limits.

(b) Connections joining a portion of a structure designed on the basis of plastic behavior with a portion not so designed need be no more rigid than ordinary seat and cap angle or ordinary web connections.

(c) When plastic design is used as the basis for proportioning continuous beams and structural frames, the provisions relating to allowable working stress contained in NF-3320 are waived. Except as modified by these rules, all other provisions of NF-3320 shall govern.

NF-3342 Design Requirements

NF-3342.1 General Design Requirements

(a) *Shear.* Unless reinforced by diagonal stiffeners or a doubler plate, the webs of column, beams, and girders, including areas within the boundaries of the connections, shall be so proportioned that:

$$(1) V_u \leq 0.555 S_y t d$$

where V_u is the shear, kips, that would be produced by the required factored loading.

(b) *Combined Loads.* When the interaction method of calculation (Section III, Division 1, Appendices, A-9000) is used, members shall be so proportioned that the interaction of factored loads at a section shall satisfy the interaction equations of Table A-9210(d)-1 (Section III, Division 1, Appendices), except that columns subjected to combined bending and compression shall be governed by the requirements of NF-3342.2(b)(3).

(c) *Depth-Thickness Ratio of Webs.* The depth-thickness ratio of webs of members subjected to plastic bending shall not exceed the value given by Eqs. (2) and (3), as applicable:

¹³ As used here, interior support may be taken to include a rigid frame knee formed by the junction of a column and a sloping or horizontal beam or girder.

**TABLE NF-3332.3-1
STRESS CATEGORIES**

General Condition	Situation	Kind of Stress [Note (1)]	Stress Category (See Table NF-3332.4-1)	Illustrative Example [Note (2)] Sketch Nos. (See Fig. NF-3332.3-1)
Plain material	Base metal with rolled or cleaned surfaces	T or Rev.	A	(1), (2)
Built-up members	Base metal and weld metal in members, without attachments, built up plates or shapes connected by continuous full or partial penetration groove welds, or continuous fillet welds parallel to the direction of applied stress	T or Rev.	B	(3), (4), (5), (6)
	Base metal in members without attachments, built-up plates or shapes connected by continuous full-penetration groove welds or by continuous fillet welds parallel to the direction of applied stress	T or Rev.	B	(3), (4), (5), (6)
	Calculated flexural stress f_b in base metal at toe of welds on girder webs or flanges adjacent to welded transverse stiffeners	T or Rev.	C	(7)
	Base metal at ends of partial length welded cover plates narrower than the flange having square or tapered ends, with or without welds across the ends or wider than flange with welds across the ends Flange thickness ≤ 0.8 in. Flange thickness > 0.8 in.	T or Rev. T or Rev.	E E'	(5) (5)
	Base metal at end of partial length welded cover plates wider than the flange without welds across the ends		E'	(5)
Mechanically fastened connections	Base metal at gross section of high-strength bolted slip-critical connections, except axially loaded joints which induce out-of-plane bending in connected material	T or Rev.	B	(8)
	Base metal at net section of other mechanically fastened joints [Note (3)]	T or Rev.	D	(8), (9)
	Base metal at net section of fully tensioned high-strength, bolted-bearing connections	T or Rev.	B	(8), (9)
Fillet welded connections	Base metal at intermittent fillet welds	T or Rev.	E	
	Base metal at junction of axially loaded members with fillet-welded end connections. Welds shall be disposed about the axis of the member so as to balance weld stresses $b \leq 1$ in. $b > 1$ in.	T or Rev. T or Rev.	E E'	(17), (18) (17), (18)

(Table NF-3332.3-1 continues on next page)

TABLE NF-3332.3-1 STRESS CATEGORIES

**TABLE NF-3332.3-1 (CONT'D)
STRESS CATEGORIES**

General Condition	Situation	Kind of Stress [Note (1)]	Stress Category (See Table NF-3332.4-1)	Illustrative Example [Note (2)] Sketch Nos. (See Fig. NF-3332.3-1)
Fillet welded connections (cont'd)	Base metal at members connected with transverse fillet welds $b \leq \frac{1}{2}$ in. $b > \frac{1}{2}$ in.	T or Rev.	C See Note (4)	(20), (21)
Fillet welds	Weld metal of continuous or intermittent longitudinal or transverse fillet welds	S	F See Note (4)	(15), (17), (18), (20), (21)
Groove welds	Base metal and weld metal at full penetration groove welded splices of parts of similar cross section ground flush, with grinding in the direction of applied stress and with weld soundness established by radiographic or ultrasonic inspection in accordance with the requirements of Table 9.25.3 of AWS D1.1-77	T or Rev.	B	(10)
	Base metal and weld metal at full penetration groove welded splices at transitions in width or thickness, with welds ground to provide slopes no steeper than 1 to $2\frac{1}{2}$, with grinding in the direction of applied stress, and with weld soundness established by radiographic or ultrasonic inspection in accordance with the requirements of Table 9.25.3 of AWS D1.1-77	T or Rev.	B	(12), (13)
	Base metal and weld metal at full penetration groove welded splices, with or without transitions having slopes no greater than 1 to $2\frac{1}{2}$, when reinforcement is not removed and with weld soundness established by radiographic or ultrasonic inspection in accordance with the requirements of Table 9.25.3 of AWS D1.1-77	T or Rev.	C	(10), (11), (12), (13)
Partial penetration groove welds	Weld metal of partial penetration transverse groove welds, based on effective throat area of the weld or welds	T or Rev.	F [Note (4)]	(16)
Plug or slot welds	Base metal at plug or slot welds	T or Rev.	E	(27)
	Shear on plug or slot welds	S	F	(27)

(Table NF-3332.3-1 continues on next page)

TABLE NF-3332.3-1 (CONT'D) STRESS CATEGORIES

**TABLE NF-3332.3-1 (CONT'D)
STRESS CATEGORIES**

General Condition	Situation	Kind of Stress [Note (1)]	Stress Category (See Table NF-3332.4-1)	Illustrative Example [Note (2)] Sketch Nos. (See Fig. NF-3332.3-1)
Attachments	Base metal at details attached by full-penetration groove welds subject to longitudinal and/or transverse loading when the detail embodies a transition radius R with the weld termination ground smooth and for transverse loading, the weld soundness established by radiographic or ultrasonic inspection in accordance with 9.25.2 or 9.25.3 of AWS D1.1			
	Longitudinal loading			
	$R > 24$ in.	T or Rev.	B	(14)
	24 in. $> R > 6$ in.	T or Rev.	C	(14)
	6 in. $> R > 2$ in.	T or Rev.	D	(14)
	2 in. $> R$	T or Rev.	E	(14)
	Detail base metal for transverse loading: equal thickness and reinforcement removed			
	$R > 24$ in.	T or Rev.	B	(14)
	24 in. $> R > 6$ in.	T or Rev.	C	(14)
	6 in. $> R > 2$ in.	T or Rev.	D	(14)
	2 in. $> R$	T or Rev.	E	(14), (15)
	Detail base metal for transverse loading: equal thickness and reinforcement not removed			
	$R > 24$ in.	T or Rev.	C	(14)
	24 in. $> R > 6$ in.	T or Rev.	C	(14)
	6 in. $> R > 2$ in.	T or Rev.	D	(14)
	2 in. $> R$	T or Rev.	E	(14), (15)
	Detail base metal for transverse loading: unequal thickness and reinforcement removed			
	$R > 2$ in.	T or Rev.	D	(14)
	2 in. $> R$	T or Rev.	E	(14), (15)
	Detail base metal for transverse loading: unequal thickness and reinforcement not removed			
	all R	T or Rev.	E	(14), (15)
	Detail base metal for transverse loading			
	$R > 6$ in.	T or Rev.	C	(19)
	6 in. $> R > 2$ in.	T or Rev.	D	(19)
	2 in. $> R$	T or Rev.	E	(19)
	Base metal at detail attached by full-penetration groove welds subject to longitudinal loading			
	$2 < a < 12b$ or 4 in.	T or Rev.	D	(15)
	$a > 12b$ or 4 in. when $b \leq 1$ in.	T or Rev.	E	(15)
	$a > 12b$ or 4 in. when $b > 1$ in.	T or Rev.	E'	(15)

(Table NF-3332.3-1 continues on next page)

TABLE NF-3332.3-1 (CONT'D) STRESS CATEGORIES

**TABLE NF-3332.3-1 (CONT'D)
STRESS CATEGORIES**

General Condition	Situation	Kind of Stress [Note (1)]	Stress Category (See Table NF-3332.4-1)	Illustrative Example [Note (2)] Sketch Nos. (See Fig. NF-3332.3-1)
Attachments (cont'd)	Base metal at detail attached by fillet welds or partial-penetration groove welds subject to longitudinal loading $a \leq 2$ in. $2 \text{ in.} < a \leq 12b \text{ or } 4 \text{ in.}$ $a > 12b \text{ or } 4 \text{ in. when } b \leq 1 \text{ in.}$ $a > 12b \text{ or } 4 \text{ in. when } b > 1 \text{ in.}$	T or Rev. T or Rev. T or Rev. T or Rev.	C D E E'	(15), (23), (24), (25), (26) (15), (23), (24), (26) (15), (23), (24), (26) (15), (23), (24), (26)
	Base metal attached by fillet welds or partial-penetration groove welds subjected to longitudinal loading when the weld termination embodies a transition radius with the weld termination ground smooth: $R > 2$ in. $R \leq 2$ in.	T or Rev. T or Rev.	D E	(19) (19)
	Fillet-welded attachments where the weld termination embodies a transition radius, weld termination ground smooth, and main material subject to longitudinal loading: Detail base metal for transverse loading: $R > 2$ in. $R \leq 2$ in.	T or Rev. T or Rev.	D E	(19) (19)
	Base metal at stud-type shear connector attached by fillet weld or automatic end weld	T or Rev.	C	(22)
	Shear stress on nominal area of stud-type shear connectors	S	F	

NOTES:

- (1) T signifies range in tensile stress only; Rev. signifies a range involving reversal of tensile or compressive stress; S signifies range in shear, including shear stress reversal.
- (2) These examples are provided as guidelines and are not intended to exclude other reasonably similar situations.
- (3) When stress reversal is involved, use of SA-307 bolts is not recommended.
- (4) Allowable fatigue stress range for transverse partial penetration and transverse fillet welds is a function of the effective throat, depth of penetration and plate thickness. See Frank and Fisher, "Fatigue Strength of Fillet Welded Cruciform Joints," Journal of the Structural Division, ASCE, Vol. 105, No. 519, 1979.

TABLE NF-3332.3-1 (CONT'D) STRESS CATEGORIES

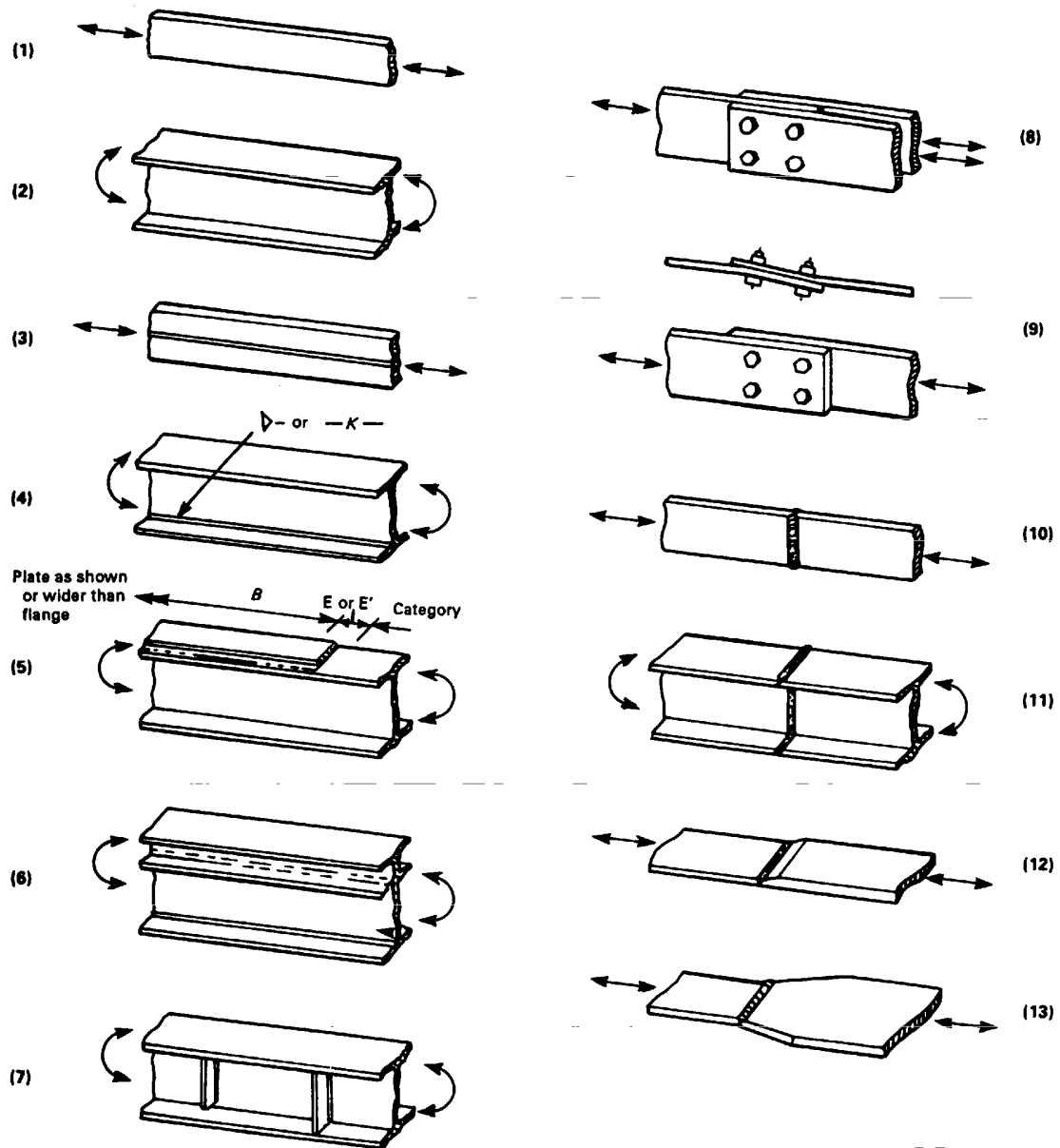


FIG. NF-3332.3-1 ILLUSTRATIVE EXAMPLES

FIG. NF-3332.3-1 ILLUSTRATIVE EXAMPLES

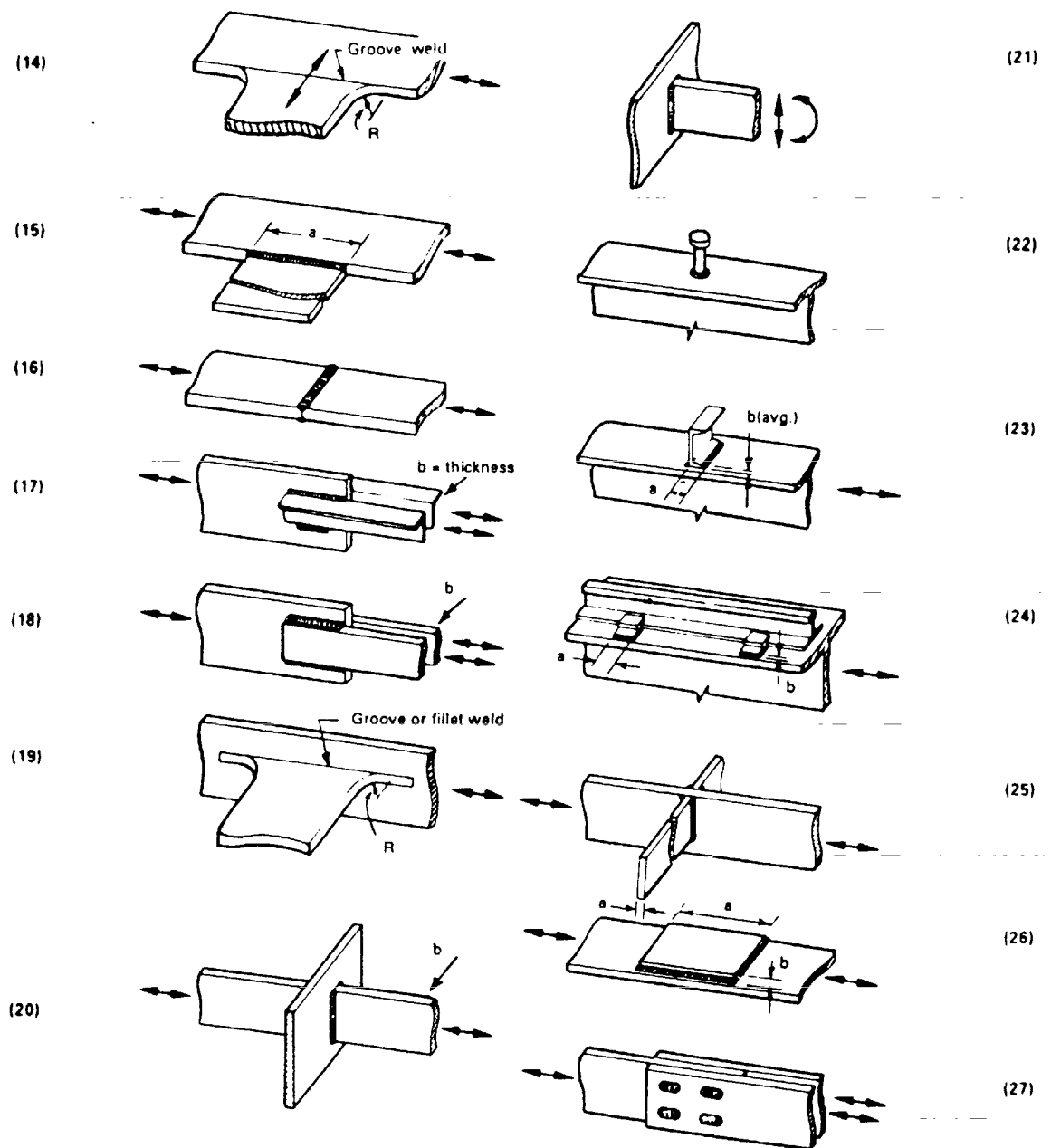


FIG. NF-3332.3-1 ILLUSTRATIVE EXAMPLES (CONT'D)

FIG. NF-3332.3-1 ILLUSTRATIVE EXAMPLES (CONT'D)

$$\frac{d}{t} = \frac{412}{\sqrt{S_y}} \left[1 - \left(1.4 \frac{P}{P_y} \right) \right] \text{ when } \frac{P}{P_y} \leq 0.27 \quad (2)$$

$$\frac{d}{t} = \frac{257}{\sqrt{S_y}} \text{ when } \frac{P}{P_y} > 0.27 \quad (3)$$

(2)-(3)

TABLE NF-3332.4-1
ALLOWABLE STRESS RANGES

Stress Category Used in Table NF-3332.3-1	Allowable Range of Stress F_{sr} , ksi			
	Loading Condition 1 F_{sr1}	Loading Condition 2 F_{sr2}	Loading Condition 3 F_{sr3}	Loading Condition 4 F_{sr4}
A	63	37	24	24
B	49	29	18	16
B'	39	23	15	12
C	35	21	13	10 ¹
D	28	16	10	7
E	22	13	8	5
E'	16	9	6	3
F	15	12	9	8

NOTE:

(1) Flexural stress range of 12 ksi permitted at toe of stiffener welds on webs or flanges.

TABLE NF-3332.4-1 ALLOWABLE STRESS RANGES

(d) *Web Crippling.* Web stiffeners are required on a member at a point of load application where a plastic hinge would form. At points on a member where the concentrated load delivered by the flanges of a member framing into it would produce web crippling opposite the compression flange or high tensile stress in the tension flange, web stiffeners are required in accordance with the provisions of NF-3324.2(b).

(e) *Width-Thickness Ratios of Flanges*

(1) The width-thickness ratio for flanges of rolled W shapes and similar built-up single web shapes that would be subjected to compression involving hinge rotation under ultimate loading shall not exceed the following values:

$$S_y \quad b_f / 2t_f$$

	8.5
42	8.0
45	7.4
50	7.0
55	6.6
60	6.3
65	6.0

The thickness of sloping flanges may be taken as their average thickness.

(2) The width-thickness ratio of similarly compressed flange plates in box sections and cover plates shall not exceed $190/\sqrt{S_y}$. For this purpose the width of a cover plate shall be taken as the distance between longitudinal lines of connecting high strength bolts or welds.

NF-3342.2 Specific Design Requirements

(a) *Beams*. The maximum bending strength of a flexural member shall be:

$$(4) M_p = S_y Z_x$$

(b) *Columns*

(1) In the plane of bending of columns which would develop a plastic hinge at ultimate loading, the slenderness ratio l/r shall not exceed C_c defined in NF-3322.1(c).

(2) The maximum strength of an axially loaded compression member shall be taken as:

$$(5) P_{cr} = 1.7AF_a$$

where A is the gross area of the member, and F_a as defined by Eq. (4) in NF-3322.1(c)(1), is based upon the applicable slenderness ratio.

(3) Members subject to combined axial load and bending moment, including moment resulting in secondary stress, shall be proportioned so as to satisfy the following interaction formulas:

Page 91

$$\frac{P}{P_{cr}} + \frac{C_m M}{[1 - (P/P_e)] M_m} \leq 1.0 \quad (6)$$

$$\frac{P}{P_y} + \frac{M}{1.18 M_p} \leq 1.0; M \leq M_p \quad (7)$$

(6 - 7)

where

$$P_e = 1.92AF_e' \text{ where } F_e' \text{ is defined in NF-3322.1(e)}$$

$$C_m = \text{coefficient defined in NF-3322.1(e)}$$

The right-hand side of Eq. (7) may be replaced by 1.5 when it can be shown that the bending moment results only in secondary stress.

(4) For columns braced in the weak direction:

$$M_m = M_p$$

(5) For columns unbraced in the weak direction:

$$M_m = M_p \left[1.07 - \frac{(l/r_y) \sqrt{S_y}}{3160} \right] \leq M_p \quad (8)$$

(8)

(c) *Basis for Maximum Strength Determination.* For one or two story frames, the maximum strength may be determined by a routine plastic analysis procedure, and the frame instability effect $P\Delta$ may be ignored. For braced multistory frames, provisions should be made to include the frame instability effect in the design of the bracing system and frame members. For unbraced multistory frames, the frame instability effect should be included directly in the calculations for maximum strength. The vertical bracing system for a plastically designed braced multistory frame shall be shown to be adequate, as determined by a rational analysis, to prevent buckling of the structure under factored gravity load, and maintain the lateral stability of the structure, including consideration of the overturning effects of drift, under factored horizontal and gravity loads.

(1) *Stability of Braced Frames.* The vertical bracing system may be considered to function together with in-plane shear-resisting exterior and interior walls, floor slabs, and roof decks, if these walls, slabs, and decks are secured to the structural frames. The columns, girders, beams, and diagonal members, when used as the vertical bracing systems, may be considered to comprise a cantilever, simply connected truss in the analysis for frame buckling and lateral stability. Axial deformation of all members in the vertical bracing system shall be included in the lateral stability analysis. The axial force in these members, caused by factored horizontal and gravity loads, shall not exceed $0.85P_y$, where P_y is the product of yield stress times area of the member. Girders and beams included in the vertical bracing system of a braced multistory frame shall be proportioned for axial force and moment caused by the concurrent factored horizontal and gravity loads, in accordance with Eq. (5) with P_{cr} taken as the maximum axial strength of the beam, based on the actual slenderness ratio between braced points in the plane of bending.

(2) *Stability of Unbraced Frames.* The strength of an unbraced multistory frame shall be determined by a rational analysis which includes the effects of frame instability and column axial deformation. Such a frame shall be designed to be stable under the following conditions:

(a) factored gravity loads;

(b) factored gravity plus factored horizontal loads.

The axial force in the column at factored load levels shall not exceed $0.75P_y$.

(d) *Lateral Bracing*

(1) Members shall be adequately braced to resist lateral and torsional displacements at the plastic hinge locations

associated with the failure mechanism. The laterally unsupported distance l_{cr} from such braced hinge locations to similarly braced adjacent points on the member or frame shall not exceed the value determined from Eq. (9) or (10), as applicable:

$$(9) l_{cr}/r_y = 1375/S_y + 25$$

when

$$+1.0 > M'/M_p > -0.5$$

or

$$(10) l_{cr}/r_y = 1375/S_y$$

when

$$-0.5 \geq M'/M_p > -1.0$$

where

M'/M_p = the end moment ratio, positive when the segment is bent in reverse curvature and negative when bent in single curvature

(2) The provisions of (d)(1) above need not apply in the region of the last hinge to form, in the failure mechanism assumed as the basis for proportioning a given member, nor in members oriented with their weak axis normal to the plane of bending. However,

Page 92

in the region of the last hinge to form and in regions not adjacent to a plastic hinge, the maximum distance between points of lateral support shall be such as to satisfy the requirements of Eq. (17), (18), or (19) of NF-3322.1(d)(5), or Eq. (20) or (21) of NF-3322.1(e)(1). For this case, the value of f_a and f_b shall be computed from the moment and axial force at factored loading, divided by the applicable load factor.

(3) Members built into a masonry wall and having their web perpendicular to this wall can be assumed to be laterally supported with respect to their weak axis of bending.

(e) Connections

(1) *General Requirements.* All connections, the rigidity of which is essential to the continuity assumed as the basis for the analysis, shall be capable of resisting the moments, shears, and axial loads to which they would be subjected by the full factored loading, or any probable partial distribution thereof.

(2) *Corner Connections.* Corner connections (haunches) that are tapered or curved for architectural reasons shall be so proportioned that the full plastic bending strength of the section adjacent to the connection can be developed, if required.

(3) *Stiffeners.* Stiffeners shall be used, as required, to preserve the flange continuity of interrupted members at their junction with other members in a continuous frame. Such stiffeners shall be placed in pairs on opposite sides of the web of the member which extends continuously through the joint.

(4) *Stress in Bolts and Welds.* High strength bolts, SA-307 bolts, and welds shall be proportioned to resist the forces produced at factored load, using stresses equal to 1.7 times those given in NF-3324.6(a) for bolts and Table NF-3324.5(a)-1 for welds. In general, groove welds are preferable to fillet welds, but their use is not mandatory.

(5) *Joints With Painted Contact Surfaces.* High strength bolts may be used in joints having painted contact surfaces when these joints are of such size that the slip required to produce bearing would not interfere with the formation, at factored loading, of the plastic hinges assumed in the design.

NF-3350 DESIGN BY ANALYSIS FOR CLASS 2 AND MC

The design by analysis of Class 2 and MC supports shall be in accordance with NF-3320, NF-3330, and NF-3340.

NF-3360 DESIGN BY ANALYSIS FOR CLASS 3

The design by analysis of Class 3 supports shall be in accordance with NF-3320, NF-3330, and NF-3340.

NF-3370 EXPERIMENTAL STRESS ANALYSIS

Supports of all types may be designed by experimental stress analysis in accordance with Appendix II of Section III, Division 1, Appendices.

NF-3380 DESIGN BY LOAD RATING

NF-3381 Procedure for Load Rating

The procedure for load rating shall consist of imposing a total load on one or more duplicate full-size samples for a support equal to or less than the load under which the support fails to perform its required function. Full-size samples composed of various parts may have each part or a number of parts load rated provided that all parts in the load path are either load rated or otherwise qualified per NF-3300 or by experimental stress analysis. When parts are connected by bolting or welding, the connection shall be either load rated or qualified per NF-3225 or NF-3226. Should more than one part be load rated in a single load test, then the load rating equations of NF-3380 shall be evaluated for each part using the part's $S_{y(act)}$ and $S_{u(act)}$ values. The part having the lowest load rating shall establish the load rating for the combination of parts. A single test sample is permitted, but in that case, the load ratings shall be decreased by 10%. Otherwise, tests shall be run on a statistically significant number of samples. The permissible types of welded joints shall be as permitted for the specific class of construction in NF-3226.1, NF-3256.1, NF-3266, and NF-3324. The requirements of NF-3324.5(b) for size of fillet and partial penetration welds do not apply, provided the full-size sample is fabricated for testing using the minimum weld stipulated in the Design Drawings. Bolted joints in the test sample shall be made up using the lowest strength bolt material and minimum edge distance allowed by the specification.

NF-3382 Load Ratings in Relation to Design Service and Test Loadings

The load rating for Design Loadings shall be determined in accordance with the requirements for Service Level A limits. The load ratings for Service Loadings

Page 93

for which Level A, B, or C Limits have been designated shall be determined by means of the equations in the following subparagraphs. For Level D Limits, see Appendix F of Section III, Division 1, Appendices. The load rating for Test Loadings shall be determined in accordance with the requirements for Service Level B limits.

NF-3382.1 Nomenclature.

The symbols used in this paragraph are defined as follows:

TL_y	= support test load at or below yield
TL_u	= support test load at which a substantial increase in load displacement results in zero or negative increase in actual support load
F_{all}	= allowable value for the type of stress in NF-3310, ksi
$S_{u(act)}$	= actual tensile strength of the material used in the part or support which had reached ultimate capacity during the test
$S_{y(act)}$	= actual yield strength of the material used in the part or support which yielded during the test
KI	= load rating coefficient for supports in compression

NF-3382.2 Linear-Type Supports.

The load ratings for Linear-Type Supports for the Service Loadings shall be determined by the following equations:

Design and Level A Limits (lower of the two values)

$$\text{load rating}_{(\text{yield})} = TL_y \times 1.0 \frac{F_{\text{all}}}{S_{y(\text{act})}} \quad (1)$$

$$\text{load rating}_{(\text{ult.})} = TL_u \times 1.0 \frac{F_{\text{all}}}{S_{u(\text{act})}}$$

(1)

Test and Level B Limits (lower of the two values)

$$\text{load rating}_{(\text{yield})} = TL_y \times 1.33 \frac{F_{\text{all}}}{S_{y(\text{act})}} \quad (2)$$

$$\text{load rating}_{(\text{ult.})} = TL_u \times 1.33 \frac{F_{\text{all}}}{S_{u(\text{act})}}$$

(2)

Level C Limits (lower of the two values)

$$\text{load rating}_{(\text{yield})} = TL_y \times 1.5 \frac{F_{\text{all}}}{S_{y(\text{act})}} \quad (3)$$

$$\text{load rating}_{(\text{ult.})} = TL_u \times 1.5 \frac{F_{\text{all}}}{S_{u(\text{act})}}$$

(3)

NF-3382.3 Supports Loaded in Compression.

The load rating for the supports loaded in compression shall be determined for Service Level A, B, and C by the methods of NF-3382.2. In addition, for cases where buckling governs, TL_u shall be corrected for the ratio of Young's Modulus at the Design Temperature to Young's Modulus at the test temperature. The load rating shall be determined by the following equations:

Design and Level A Limits

$$\text{load rating} = 0.52 Kl \times TL_u$$

Test and Level B Limits

$$\text{load rating} = 0.67 Kl \times TL_u$$

Level C limits

$$\text{Load rating} = 0.67 Kl \times TL_u$$

Kl

= 1.0 for elastic buckling

$$Kl = \frac{S_y}{S_{y(\text{act})}} \text{ for inelastic buckling}$$

TERM

NF-3382.4 Alternate Load Rating Method Using TL_y or TL_u Test Results Only.

Either TL_y or TL_u test results may be used to establish a support load rating provided the load rating as determined by the method of NF-3382.2 or NF-3382.3 is modified as follows:

(a) For load rating based on TL test results only:

(1) for supports constructed of materials having definitely determinable yield points and specified minimum S_y/S_u ratios not greater than 0.625, the load rating shall be multiplied by 0.83. If $S_{y(akt)}$ of the material is not known, 150% of the material specified minimum yield strength shall be assumed as the $S_y/S_{y(akt)}$ in place of multiplier 0.83;

(2) for supports constructed of carbon steel with specified minimum tensile strengths of not over 70,000 psi (480 MPa), $S_{y(akt)}$ shall be increased by 5000 psi (34 MPa) prior to determining the load rating;

(3) for all other materials the determined load rating shall be multiplied by 0.67.

For supports loaded in compression, a TL_u test shall be performed with the compressive load rating determined in accordance with NF-3382.3.

(b) For load rating based on TL_u test results, the determined load rating shall be multiplied by 0.50.

Page 94

NF-3400 DESIGN RULES FOR STANDARD SUPPORTS

NF-3410 GENERAL REQUIREMENTS

The following requirements apply in addition to the requirements of NF-3100, NF-3200, and NF-3300.

NF-3411 General Design Requirements

Standard Supports (NF-1214) shall conform to the design considerations of NF-3120, the design rules of NF-3200 or NF-3300, and the following additional requirements.

NF-3411.1 Standard Supports Used as Component Supports.

Standard Supports may be used as component supports, as defined in NF-3500.

NF-3411.2 Standard Supports Used as Piping Supports.

Standard Supports may be used as piping supports, as defined in NF-3600.

NF-3411.3 Loads

(a) Standard Supports shall be capable of carrying all concurrently acting loads listed in NF-3111 and stipulated in the Design Specification. The supports shall be designed to provide the required supporting effort and to permit the designed piping or component movement.

(b) Spring supports shall be capable of exerting a supporting force equal to the load, as determined by weight-balance calculations, plus the weight of all hanger parts such as clamps and rods that will be supported by a spring at the point of attachment to a pressure retaining component or to an integral attachment.

(1) The design shall be such as to prevent complete release of the piping or component load in the event of spring failure or misalignment.

(2) When springs are to be enclosed in spaces where high ambient temperatures occur, the spring material shall be such that the spring constants will not be significantly changed at the temperature to be experienced.

(c) Snubbers shall meet the requirements of (a) above and (1) and (2) below.

(1) The following occasional loads shall be considered:

(a) seismic inertial;

(b) seismic anchor displacement;

(c) hydraulic transient loads resulting from, but not limited to, water hammer, steam hammer, pump startup, pump shutdown, safety and safety relief valve discharges, as specified in the Design Specification.

(2) *Thermal Expansion and Thermal Anchor Displacement.* The snubber shall not resist the effects of thermal growth of the component, the piping system, or the anchorage to the degree where it imposes a significant load or stress on the piping or component.

NF-3412 Standard Support Items

NF-3412.1 Constant Support Spring Hangers.

Constant support spring hangers may be used to support piping or components at those locations requiring a substantially uniform supporting force throughout the travel range but which, while subject to thermal movement, cannot tolerate appreciable variability of the supporting force. They shall have a mean variability (deviation), including friction, of no more than 6% throughout the travel range. Deviation is the sum of kinematic friction and manufacturing tolerance factors. Determination of deviation is by load test machine and is calculated as follows:

deviation = (maximum reading moving down

- minimum reading moving up)

÷ (maximum reading moving down

+ minimum reading moving up)

NF-3412.2 Variable Support Spring Hangers.

Variable support spring hangers may be used to support piping or components at those locations subject to vertical movement due to temperature differences, where a variability of the supporting force up to a factor of 0.25, as calculated by the following equation, can be tolerated:

$$\text{variability factor} = (\text{travel} \times \text{spring rate}) / \text{load}$$

(a) The variability of the supporting force resulting from movement of the piping or component shall be considered in the loadings used in the stress analysis of the piping or component.

(b) Variable support spring hangers shall be provided with means to limit misalignment, buckling, and eccentric loading and to prevent overstressing of the spring.

(c) It is recommended that all hangers employing springs be provided with means to indicate at all times the compression of the spring with respect to the appropriate hot and cold positions of the piping or component.

NF-3412.3 Hanger Rods.

Design loads for threaded hanger rods shall be based on the root area of the threads. In no case shall hanger rods less than $\frac{3}{8}$ in. (10 mm) diameter be used for supporting pipe 2 in.

Page 95

(DN 50) and smaller, or less than $\frac{1}{2}$ in. (13 mm) diameter rod for supporting pipe $2\frac{1}{2}$ in. (DN 65) and larger. Pipe, structural shapes, or bars may be used instead of hanger rods. Hanger rods, structural shapes, etc., shall be designed to permit the free movement of piping as indicated in the thermal stress analysis. The possibility of moment loading of hanger rods or shapes as a result of pipe motion shall be considered and avoided unless the support is specifically designed for such loading.

NF-3412.4 Snubbers

(a) Snubbers may be incorporated in the system design to accommodate Design Mechanical Loads or conditions of a vibratory or dynamic nature. Snubbers may be attached to a piping or component to protect it against dynamic type loading. Snubbers shall allow essentially free movement of the piping or component to which they are attached during nondynamic application of load such as that imposed by expansion and contraction.

(b) Snubbers shall be carefully applied to ensure that they will perform their intended function without placing unacceptable loads on the piping system or other components.

(c) The Design Specification shall contain, as a minimum, the following:

(1) the Design Loadings for loading conditions and transients, and combinations of loadings for which the snubber is designed to accommodate;

(2) required force, time, and displacement relationship;

(3) the environmental conditions that the snubber will be exposed to, such as:

(a) temperature

(b) irradiation

(c) corrosive atmosphere

(d) moisture

(e) airborne particles

(4) consideration of material characteristics, such as:

(a) compatibility

(b) stability

(c) fire resistance

(d) wear

(e) aging

(5) tests which are required prior to installation.

(d) Design of functional members such as interconnections, tubing and fittings reservoirs, and flow distributors shall consider the effect of internal pressure, thermal expansion, and vibration loading.

NF-3420 DESIGN BY ANALYSIS FOR CLASS 1

NF-3421 General Design Requirements

The design of Class 1 Standard Supports shall be in accordance with the requirements of NF-3420 using one of the design procedures indicated in Table NF-3131(a)-1 for Class 1 construction.

NF-3422 Design of Plate- and Shell-Type Standard Supports

The requirements of NF-3200 shall be met.

NF-3423 Design of Linear-Type Standard Supports

The requirements of NF-3300 shall be met.

NF-3425 Design of Bolting

The requirements of NF-3225 and NF-3324.6 shall be met.

NF-3426 Design of Welded Joints

NF-3426.1 Permissible Types.

The permissible types of welded joints for Standard Supports are described in paragraphs NF-3226.1 and NF-3256.1. Additional types of joints are as follows. Typical examples of the types are shown in Fig. NF-3426.1-1.

(a) *Tee Joints*. Tee joints shall be one of the following:

(1) fillet, double welded, sketch (a-1);

(2) fillet, single welded, when double members are used, sketch (a-2);

(3) fillet, single welded, between a flat surface and the end surface of a closed tubular section or a closed formed section, sketch (f). Partially closed tubular sections or partially closed formed sections and the total length of their respective welds shall encompass a minimum of 270 deg. of the circumference and provide symmetrical loadings on closure plates.

(b) *Corner Joints.* Corner joints shall be one of the following.

(1) Partial penetration, without a fillet weld between the edge of a plate and the end surface of a closed tubular section or partially closed formed section, sketch (e). Partially closed tubular sections or partially closed formed sections as well as the total length of their respective welds shall encompass a minimum of 270 deg. of the circumference and provide symmetrical loadings on closure plates;

Page 96

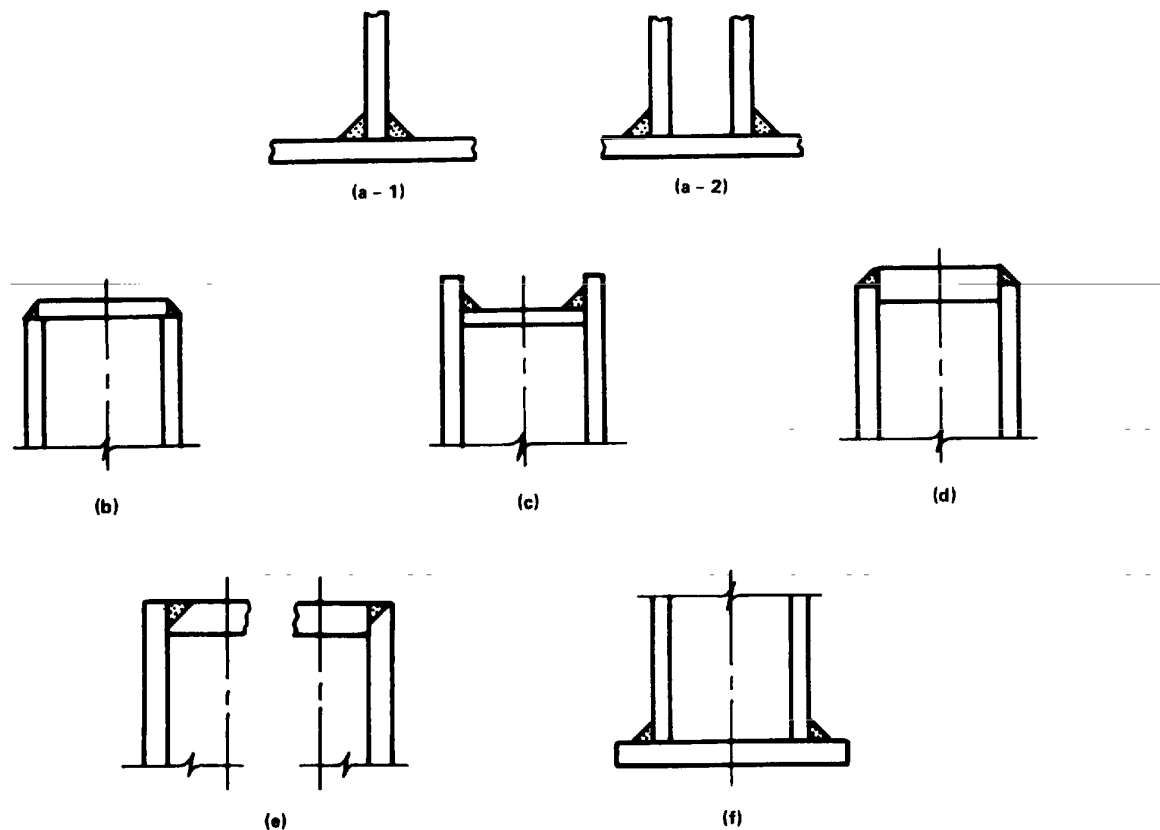


FIG. NF-3426.1-1 ADDITIONAL PERMISSIBLE WELDED JOINTS FOR CLASS 1 STANDARD SUPPORTS

FIG. NF-3426.1-1 ADDITIONAL PERMISSIBLE WELDED JOINTS FOR CLASS 1 STANDARD SUPPORTS

(2) Fillet welds between the edge of a plate and the end surface of a closed tubular section or partially closed tubular section or partially closed formed section, sketches (b), (c), and (d). In addition, weld joints (b) and (d) may be used only if the lengths of the respective legs of the fillet weld are equal to the exposed thickness of the plate and shell elements. Partially closed tubular sections or partially closed formed sections as well as the total length of their

respective welds shall encompass a minimum of 270 deg. of the circumference and provide symmetrical loadings on closure plates.

(3) The use of welded joints permitted by (a)(3) and (b) above is limited to housings for spring encapsulation of standard supports.

NF-3426.2 Design Stress Intensity and Allowable Stress Limits for Welded Joints.

The limit of design stress intensity or of allowable stress for welded joints for Standard Supports shall not exceed the applicable design stress intensity value or allowable stress value for the base metal being joined.

NF-3450 DESIGN BY ANALYSIS FOR CLASS 2 AND MC

NF-3451 General Design Requirements

The design of Class 2 and MC Standard Supports shall be in accordance with the requirements of NF-3450

Page 97

using one of the design procedures indicated in Table NF-3131(a)-1.

NF-3452 Design of Plate- and Shell-Type Standard Supports

The requirements of NF-3200 shall be met.

NF-3453 Design of Linear-Type Standard Supports

The requirements of NF-3300 shall be met.

NF-3455 Design of Bolting

The requirements of NF-3225 and NF-3324.6 shall be met.

NF-3456 Design of Welded Joints

The requirements of NF-3426 shall be met, except that for groove welded and fillet welded T-joints, the welds may be intermittent instead of continuous.

NF-3460 DESIGN BY ANALYSIS FOR CLASS 3

The design of Class 3 Standard Supports shall be in accordance with the requirements of NF-3450, using one of the design procedures indicated in Table NF-3131(a)-1.

NF-3470 DESIGN BY EXPERIMENTAL STRESS ANALYSIS

Standard Supports may be designed by experimental stress analysis in accordance with the requirements of NF-3270 for Plate- and Shell-Type Standard Supports and NF-3370 for Linear-Type Standard Supports.

NF-3480 PROCEDURE FOR LOAD RATING

Standard Supports may be designed by the procedure for load rating in accordance with the requirements of NF-3280 for Plate- and Shell-Type Standard Supports and NF-3380 for Linear-Type Standard Supports.

NF-3500 DESIGN RULES FOR COMPONENT SUPPORTS

NF-3510 GENERAL REQUIREMENTS

The design of component supports shall be in accordance with this Subarticle and the applicable general requirements of NF-3110, NF-3210, NF-3310, and NF-3410.

NF-3520 DESIGN BY ANALYSIS FOR CLASS 1

NF-3521 General Design Requirements

This Subsubarticle provides stress limits for elements of Class 1 component supports. For general requirements as to stress determinations, definitions, derivations of stress intensities, and classification of stresses, refer to NF-3120.

NF-3522 Design of Plate- and Shell-Type Component Supports

(a) The design rules and stress intensity limits which must be satisfied for the Design and Service Loadings are given in NF-3220.

(b) When design by analysis is used, the stress limit factors for each loading and stress category are specified in Table NF-3522(b)-1.

NF-3523 Design of Linear-Type Component Supports

(a) The design rules and stress limits which must be satisfied for the Design and Service Loadings are given in NF-3320.

(b) When design by analysis is used, the stress limit factors for each loading and stress category are specified in Table NF-3523(b)-1.

NF-3524 Design of Standard Component Supports

(a) The design rules and stress limits which must be satisfied for the Design and Service Loadings are given in NF-3420.

(b) When design by analysis is used, the stress limit factors for each loading and stress category are specified

Page 98

in Table NF-3522(b)-1 or Table NF-3523(b)-1, as applicable.

TABLE NF-3522(b)-1
ELASTIC ANALYSIS STRESS CATEGORIES AND STRESS LIMIT FACTORS FOR CLASS 1 PLATE- AND SHELL-
TYPE SUPPORTS DESIGNED BY ANALYSIS — COMPONENT SUPPORTS

Stress Limit Factors for Loading Categories [Note (1)]						
Stress Category	Design	Service Level A	Service Level B [Note (2)]	Service Level C [Note (3)]	Service Level D	Test Loadings
Primary stresses [Notes (4), (5)]	$K_m = 1.0$	$K_m = 1.0$	$K_m = 1.33$	$K_m = 1.5$		$K_m = 1.33$
	$K_v = 1.0$	$K_v = 1.0$	$K_v = 1.33$	$K_v = 1.5$		$K_v = 1.33$
	$K_{bk} = 1.0$	$K_{bk} = 1.0$	$K_{bk} = 1.33$	$K_{bk} = 1.5$	Use Appendix F	$K_{bk} = 1.33$
	but stress $\leq \frac{1}{2}$ of critical buckling stress	but stress $\leq \frac{1}{2}$ of critical buckling stress	but stress $\leq \frac{1}{2}$ of critical buckling stress	but stress $\leq \frac{1}{2}$ of critical buckling stress		but stress $\leq \frac{1}{2}$ of critical buckling stress
Primary plus secondary stresses [Note (5)]	Evaluation is required for critical buckling for all loading categories. The requirements of this Subarticle shall be met for this evaluation.					
Peak stresses	Evaluation not required.					

GENERAL NOTES:

K_m = stress limit factor applicable to the Design allowable membrane stress intensity or membrane plus bending stress intensity (see NF-3221.1 and NF-3221.2).

K_v = stress limit factor applicable to the Design allowable shear stress (see NF-3223.2)

K_{bk} = stress limit factor applicable to the Design allowable membrane stress intensity or membrane plus bending stress intensity (compression only)

NOTES:

(1) Control of deformation is not assured by these stress limit factors. When required by Design Specification, deformation control must be considered separately.

(2) K_m , K_v , and $K_{bk} = 1.0$ for design of snubbers.

(3) Stress shall not exceed $0.7 S_u$.

(4) For Service Levels A, B, C, and D, stresses induced on the supports by restraint of free-end displacement and anchor motions of piping shall be considered as primary stresses.

(5) Thermal stresses within the support as defined by NF-3121.11 need not be evaluated. For Service Levels A and B, primary plus secondary stresses shall be limited to a range of $2 S_y$ or S_u at temperature, whichever is less.

TABLE NF-3522(b)-1 ELASTIC ANALYSIS STRESS CATEGORIES AND STRESS LIMIT FACTORS FOR CLASS 1 PLATE- AND SHELL-TYPE SUPPORTS DESIGNED BY ANALYSIS - COMPONENT SUPPORTS

NF-3525 Design of Bolting

The number and cross-sectional area of bolts required for the Design Loadings of NF-3112 shall be determined in accordance with the procedures of NF-3324.6.

NF-3526 Design of Welded Joints

- (a) Welded joints in Plate- and Shell-Type Component Supports shall be as stipulated in NF-3226.
 (b) Welded joints used in Linear-Type Component Supports shall be as stipulated in NF-3324.5.

NF-3550 DESIGN BY ANALYSIS FOR CLASS 2, 3, AND MC

NF-3552 Design of Plate- and Shell-Type Component Supports

- (a) The design rules and stress limits which must be satisfied for the Design and Service Loadings are given in NF-3250 and NF-3260.
 (b) When design by analysis is used, the stress limit factors for each loading and stress category are specified in Table NF-3552(b)-1.

NF-3553 Design of Linear-Type Component Supports

The design rules and stress limits which must be satisfied for the Design and Service Loadings are given in NF-3523.

Page 99

TABLE NF-3523(b)-1
ELASTIC ANALYSIS STRESS CATEGORIES AND STRESS LIMIT FACTORS FOR CLASS 1, 2, 3, AND MC LINEAR-TYPE SUPPORTS DESIGNED BY ANALYSIS — COMPONENT SUPPORTS

Stress Limit Factors for Loading Categories [Note (1)]						
Stress Category	Design	Service Level A	Service Level B [Note (2)]	Service Level C [Note (3)]	Service Level D	Test Loadings
Primary stresses [Notes (4), (6)]	$K_s = 1.0$	$K_s = 1.0$	$K_s = 1.33$	$K_s = 1.5$		$K_s = 1.33$
	$K_v = 1.0$	$K_v = 1.0$	$K_v = 1.33$ [Note (5)]	$K_v = 1.5$ [Note (5)]	Use Appendix F	$K_v = 1.33$ [Note (5)]
	$K_{bk} = 1.0$	$K_{bk} = 1.0$	$K_{bk} = 1.33$ but stress $\leq \frac{2}{3}$ of critical buckling stress	$K_{bk} = 1.5$ but stress $\leq \frac{2}{3}$ of critical buckling stress		$K_{bk} = 1.33$ but stress $\leq \frac{2}{3}$ of critical buckling stress
Primary plus secondary stresses [Note (6)]	Evaluation is required for critical buckling for all loading categories. The requirements of this Subarticle shall be met for this evaluation.					
Peak stresses	Evaluation not required.					

GENERAL NOTES:

K_s = stress limit factor applicable to the Design allowable tensile and bending stresses (see NF-3321.1, NF-3322.1, NF-3350, and NF-3360)
 K_v = stress limit factor applicable to the Design allowable shear stresses (see NF-3321.1, NF-3322.1, NF-3350, and NF-3360)
 K_{bk} = stress limit factor applicable to the Design allowable compressive axial and bending stresses to determine buckling limit

NOTES:

- (1) Control of deformation is not assured by these stress limit factors. When required by Design Specification, deformation control must be considered separately.
- (2) K_s , K_v , and $K_{bk} = 1.0$ for design of snubbers.
- (3) Stress shall not exceed $0.7 S_u$.
- (4) For Service Levels A, B, C, and D, stresses induced on the supports by restraint of free-end displacement and anchor motions of piping shall be considered as primary stresses.
- (5) Shear stress shall not exceed $0.42 S_u$.
- (6) Thermal stresses within the support as defined by NF-3121.11 need not be evaluated. For Service Levels A and B, primary plus secondary stresses shall be limited to a range of $2 S_y$ or S_u at temperature, whichever is less.

TABLE NF-3523(b)-1 ELASTIC ANALYSIS STRESS CATEGORIES AND STRESS LIMIT FACTORS FOR CLASS 1, 2, 3, AND MC LINEAR-TYPE SUPPORTS DESIGNED BY ANALYSIS - COMPONENT SUPPORTS

NF-3554 Design of Standard Component Supports

The design of Standard Component Supports shall be in accordance with NF-3524.

NF-3555 Design of Bolting

The provision of NF-3525 shall be met.

NF-3556 Design of Welded Joints

(a) Welded joints in Plate- and Shell-Type Component Supports shall be as stipulated in NF-3256 for Class 2 and MC and NF-3266 for Class 3.

(b) Welded joints in Linear-Type Component Supports shall be as stipulated in NF-3324.5.

NF-3570 EXPERIMENTAL STRESS ANALYSIS

Component supports of all types may be designed by experimental stress analysis in accordance with Appendix II of Section III, Division 1, Appendices.

NF-3580 DESIGN BY LOAD RATING

Component supports of all types may be designed by load rating in accordance with the requirements of NF-3280 for Plate- and Shell-Type, NF-3380 for Linear-Type, and the applicable Subsubarticle for Standard Component Supports.

Page 100

TABLE NF-3552(b)-1
ELASTIC ANALYSIS STRESS CATEGORIES AND STRESS LIMIT FACTORS FOR CLASS 2, 3, AND MC PLATE- AND SHELL-TYPE SUPPORTS DESIGNED BY ANALYSIS — COMPONENT SUPPORTS

Stress Limit Factors for Loading Categories [Note (1)]						
Stress Category	Design	Service Limit A	Service Limit B [Note (2)]	Service Limit C [Note (6)]	Service Limit D	Test Loadings
Primary stresses [Notes (3), (5)]	$K_m = 1.0$	$K_m = 1.0$	$K_m = 1.33$	$K_m = 1.5$		$K_m = 1.33$
	$K_v = 1.0$	$K_v = 1.0$	$K_v = 1.33$ [Note (4)]	$K_v = 1.5$ [Note (4)]	Use Appendix F	$K_v = 1.33$ [Note (4)]
	$K_{bk} = 1.0$	$K_{bk} = 1.0$	$K_{bk} = 1.33$	$K_{bk} = 1.5$		$K_{bk} = 1.33$
	but stress $\leq \frac{1}{2}$ of critical buckling stress	but stress $\leq \frac{1}{2}$ of critical buckling stress	but stress $\leq \frac{1}{2}$ of critical buckling stress	but stress $\leq \frac{1}{2}$ of critical buckling stress		but stress $\leq \frac{1}{2}$ of critical buckling stress

GENERAL NOTES:

K_m = stress limit factor applicable to the Design allowable membrane stress or membrane plus bending stress (see NF-3251.1 and NF-3261)

K_v = stress limit factor applicable to the Design allowable shear stress (see NF-3252.2 and NF-3261)

K_{bk} = stress limit factor applicable to the Design allowable membrane stress or membrane plus bending stress (compression only)

NOTES:

(1) Control of deformation is not assured by these stress limit factors. When required by Design Specification, deformation control must be considered separately.

(2) K_m and $K_{bk} = 1.0$ for design of snubbers.

(3) For Service Levels A, B, C, and D, stresses induced on the supports by restraint of free-end displacement and anchor motions of piping shall be considered as primary stresses.

(4) Shear stress shall not exceed $0.42 S_u$.

(5) Thermal stresses within the support as defined by NF-3121.11 need not be evaluated.

(6) Stress shall not exceed $0.7 S_u$.

TABLE NF-3552(b)-1 ELASTIC ANALYSIS STRESS CATEGORIES AND STRESS LIMIT FACTORS FOR CLASS 2, 3, AND MC PLATE- AND SHELL-TYPE SUPPORTS DESIGNED BY ANALYSIS - COMPONENT SUPPORTS

NF-3600 DESIGN RULES FOR PIPING SUPPORTS

NF-3610 GENERAL REQUIREMENTS

The design of piping supports shall be in accordance with this Subarticle and the applicable general requirements of NF-3110, NF-3210, NF-3310, and NF-3410.

NF-3611 Spacing of Piping Supports

Supports for piping with a longitudinal axis in approximately a horizontal position shall be spaced to prevent excessive shear stresses resulting from sag and bending in the piping, with special consideration given when components such as pumps and valves impose concentrated loads. The suggested maximum spans for spacing of weight supports for standard weight and heavier piping are given in Table NF-3611-1.

NF-3612 Vibration

Piping shall be arranged and supported so that vibration will be minimized.

NF-3613 Anchors, Guides, Pivots, and Restraints

Anchors, guides, pivots, and restraints shall be designed to secure the desired points of piping in a relatively fixed position. They shall permit the piping to expand and contract freely as directed from the anchored or guided point and shall be structurally capable of withstanding the thrusts, moments, and other imposed loads.

NF-3614 Support Adjustments

(a) Screwed adjustments shall have threaded parts to conform to ANSI B1.1 coarse threaded series, Class 2 fit. Alternatively, other thread forms, series, and fits may be used which permit adjustment after erection, and are designed to withstand the forces, moments, and other imposed loads acting on the support, considering the worst combination of thread tolerances.

(b) Turnbuckles and adjusting nuts shall have the full length of thread in engagement. Means shall be provided for determining that full thread length is

Page 101

engaged. All screw and equivalent adjustments shall be provided with suitable locking devices.

**TABLE NF-3611-1
SUGGESTED PIPING SUPPORT SPACING**

Nominal Pipe Size, in.	Suggested Maximum Span, ft	
	Water Service	Steam, Gas, or Air Service
1	7	9
2	10	13
3	12	15
4	14	17
6	17	21
8	19	24
12	23	30
16	27	35
20	30	39
24	32	42

GENERAL NOTES:

- (a) Suggested maximum spacing between piping supports for horizontal straight runs of standard and heavier piping with a maximum operating temperature of 750°F.
- (b) Does not apply where span calculations are made or where there are concentrated loads between supports such as flanges, valves, specialties, etc.
- (c) The spacing is based on a maximum combined bending and shear stress of 1.5 ksi and insulated piping filled with water or the equivalent weight of steel pipe for steam, gas, or air service, and the pitch of the line is such that a sag of 0.1 in. between supports is permissible.

TABLE NF-3611-1 SUGGESTED PIPING SUPPORT SPACING

NF-3615 Piping Clamps

(a) When clamps are used to support vertical piping lines, it is recommended that shear lugs be welded to the piping to prevent slippage.

(b) In addition to the provision of (a) above, clamps to support vertical piping lines shall be designed to support the total load on either arm in the event the load shifts because of piping or hanger movement, or both.

NF-3616 Hanger Rods

The provisions for hanger rods of NF-3412.3 apply.

NF-3620 DESIGN BY ANALYSIS FOR CLASS 1

NF-3622 Design of Plate- and Shell-Type Piping Supports

(a) The design rules and stress intensity limits which must be satisfied for the Design and Service Loadings are given in NF-3220.

(b) When design by analysis is used, the stress intensity limit factors for each loading and stress category are specified in Table NF-3622(b)-1.

NF-3623 Design of Linear-Type Piping Supports

(a) The design rules and stress limits which must be satisfied for the Design and Service Loadings are given in NF-3320.

(b) When design by analysis is used, the stress limit factors for each loading and stress category are specified in Table NF-3623(b)-1.

NF-3624 Design of Standard Piping Supports

(a) The design rules and stress limits which must be satisfied for the Design and Service Loadings are given in NF-3420.

(b) When design by analysis is used, the stress limit factors for each loading and stress category are specified in Table NF-3622(b)-1 or Table NF-3623(b)-1, as applicable.

NF-3625 Design of Bolting

The number and cross-sectional area of bolts required for the Design Loadings of NF-3112 shall be determined in accordance with the procedures of NF-3324.6. The allowable bolt design stress value shall be determined in accordance with NF-3324.6.

NF-3626 Design of Welded Joints

(a) Welded joints in Plate- and Shell-Type Piping Supports shall be as stipulated in NF-3226. In addition, tee joints, double fillet welded, sketch (a) [Fig. NF-3626(a)-1] and single welded, when double members, sketch (b), are permitted.

(b) Welded joints used in Linear-Type Piping Supports shall be as stipulated in NF-3324.5.

**TABLE NF-3622(b)-1
ELASTIC ANALYSIS STRESS CATEGORIES AND STRESS LIMIT FACTORS
FOR CLASS 1 PLATE- AND SHELL-TYPE SUPPORTS DESIGNED BY ANALYSIS — PIPING SUPPORTS**

Stress Limit Factors for Loading Categories [Note (1)]						
Stress Category	Design	Service Level A	Service Level B [Note (2)]	Service Level C [Note (3)]	Service Level D	Test Loadings
Primary stresses [Notes (4), (5)]	$K_m = 1.0$	$K_m = 1.0$	$K_m = 1.33$	$K_m = 1.5$		$K_m = 1.33$
	$K_v = 1.0$	$K_v = 1.0$	$K_v = 1.33$	$K_v = 1.5$		$K_v = 1.33$
	$K_{bk} = 1.0$	$K_{bk} = 1.0$	$K_{bk} = 1.33$	$K_{bk} = 1.5$	Use Appendix F	$K_{bk} = 1.33$
	but stress $\leq \frac{1}{2}$ of critical buckling stress	but stress $\leq \frac{1}{2}$ of critical buckling stress	but stress $\leq \frac{1}{2}$ of critical buckling stress	but stress $\leq \frac{1}{2}$ of critical buckling stress		but stress $\leq \frac{1}{2}$ of critical buckling stress
Primary plus secondary stresses [Note (5)]	Evaluation is required for critical buckling for all loading categories. The requirements of this Subarticle shall be met for this evaluation.					
Peak stresses	Evaluation not required.					

GENERAL NOTES:

K_m = stress limit factor applicable to the Design allowable membrane stress intensity or membrane plus bending stress intensity (see NF-3221.1 and NF-3221.2)

K_v = stress limit factor applicable to the Design allowable shear stress (see NF-3223.2)

K_{bk} = stress limit factor applicable to the Design allowable membrane stress intensity or membrane plus bending stress intensity (compression only)

NOTES:

(1) Control of deformation is not insured by these stress limit factors. When required by Design Specification, deformation control must be considered separately.

(2) K_m , K_v , and $K_{bk} = 1.0$ for design of snubbers.

(3) Stress shall not exceed $0.7 S_u$.

(4) For Service Levels A, B, C, and D, stresses induced on the supports by restraint of free-end displacement and anchor motions of piping shall be considered as primary stresses.

(5) Thermal stresses within the support as defined by NF-3121.11 need not be evaluated.

TABLE NF-3622(b)-1 ELASTIC ANALYSIS STRESS CATEGORIES AND STRESS LIMIT FACTORS FOR CLASS 1 PLATE- AND SHELL-TYPE SUPPORTS DESIGNED BY ANALYSIS - PIPING SUPPORTS

NF-3650 DESIGN BY ANALYSIS FOR CLASS 2, 3, AND MC

NF-3652 Design of Plate- and Shell-Type Piping Supports

(a) The design rules and stress limits which must be satisfied for the Design and Service Loadings are given in NF-3250 and NF-3260.

(b) When design by analysis is used, the stress limit factors for each loading and stress category are specified in Table NF-3652(b)-1.

NF-3653 Design of Linear-Type Piping Supports

The design rules and stress limits which must be satisfied for the Design and Service Loadings are given in NF-3623.

NF-3654 Design of Standard Piping Supports

The design of Standard Piping Supports shall be in accordance with NF-3624.

NF-3655

The provisions of NF-3625 shall be met.

NF-3656 Design of Welded Joints

(a) Welded joints in Plate- and Shell-Type Piping Supports shall be as stipulated in NF-3256 for Class 2 and MC and NF-3266 for Class 3.

(b) Welded joints used in Linear-Type Piping Supports shall be as stipulated in NF-3324.5.

Page 103

**TABLE NF-3623(b)-1
ELASTIC ANALYSIS STRESS CATEGORIES AND STRESS LIMIT FACTORS
FOR CLASS 1, 2, 3, AND MC LINEAR-TYPE SUPPORTS DESIGNED BY ANALYSIS — PIPING SUPPORTS**

Stress Limit Factors for Loading Categories [Note (1)]						
Stress Category	Design	Service Level A	Service Level B [Note (2)]	Service Level C [Note (3)]	Service Level D	Test Loadings
Primary stresses [Notes (4), (6)]	$K_s = 1.0$	$K_s = 1.0$	$K_s = 1.33$	$K_s = 1.5$		$K_s = 1.33$
	$K_v = 1.0$	$K_v = 1.0$	$K_v = 1.33$ [Note (5)]	$K_v = 1.5$ [Note (5)]	Use Appendix F	$K_v = 1.33$ [Note (5)]
	$K_{bk} = 1.0$	$K_{bk} = 1.0$	$K_{bk} = 1.33$ but stress $\leq \frac{2}{3}$ of critical buckling stress	$K_{bk} = 1.5$ but stress $\leq \frac{2}{3}$ of critical buckling stress		$K_{bk} = 1.33$ but stress $\leq \frac{2}{3}$ of critical buckling stress
Primary plus secondary stresses [Note (6)]	Evaluation is required for critical buckling for all loading categories. The requirements of this Subarticle shall be met for this evaluation.					
Peak stresses	Evaluation not required.					

GENERAL NOTES:

K_s = stress limit factor applicable to the Design allowable tensile and bending stresses (see NF-3623 and NF-3653)

K_v = stress limit factor applicable to the Design allowable shear stresses (see NF-3623 and NF-3653)

K_{bk} = stress limit factor applicable to the Design allowable compressive axial and bending stresses to determine buckling limit

NOTES:

(1) Control of deformation is not assured by these stress limit factors. When required by Design Specification, deformation control must be considered separately.

(2) K_s , K_v , and $K_{bk} = 1.0$ for design of snubbers.

(3) Stress shall not exceed $0.7 S_y$.

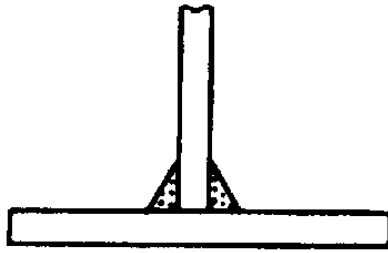
(4) For Service Levels A, B, C, and D, stresses induced on the supports by restraint of free-end displacement and anchor motions of piping shall be considered as primary stresses.

(5) Shear stress shall not exceed $0.42 S_y$.

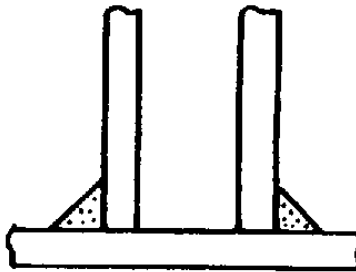
(6) Thermal stresses within the support as defined by NF-3121.11 need not be evaluated.

TABLE NF-3623(b)-1 ELASTIC ANALYSIS STRESS CATEGORIES AND STRESS LIMIT FACTORS FOR CLASS 1, 2, 3, AND MC LINEAR-TYPE SUPPORTS DESIGNED BY ANALYSIS - PIPING SUPPORTS

Page 104



(a)



(b)

**FIG. NF-3626(a)-1 ADDITIONAL PERMISSIBLE
WELDED JOINTS FOR CLASS 1 PIPING SUPPORTS**

FIG. NF-3626(a)-1 ADDITIONAL PERMISSIBLE WELDED JOINTS FOR CLASS 1 PIPING SUPPORTS

TABLE NF-3652(b)-1
ELASTIC ANALYSIS STRESS CATEGORIES AND STRESS LIMIT FACTORS FOR CLASS 2, 3, AND MC PLATE- AND SHELL-TYPE SUPPORTS DESIGNED BY ANALYSIS — PIPING SUPPORTS

Stress Limit Factor for Loading Categories [Note (1)]													
Stress Category		Design		Service Limit A		Service Limit B [Note (2)]		Service Limit C [Note (6)]		Service Limit D		Test Loadings	
Primary stresses [Notes (4), (5)]		K_m	= 1.0	K_m	= 1.0	K_m	= 1.33	K_m	= 1.50	Use Appendix F		K_m	= 1.33
		K_v	= 1.0	K_v	= 1.0	K_v	= 1.33 [Note (4)]	K_v	= 1.50 [Note (4)]			K_v	= 1.33 [Note (4)]
		K_{bk}	= 1.0	K_{bk}	= 1.0	K_{bk}	= 1.33	K_{bk}	= 1.50			K_{bk}	= 1.33
		but stress $\leq \frac{1}{2}$ of critical buckling stress		but stress $\leq \frac{1}{2}$ of critical buckling stress		but stress $\leq \frac{1}{2}$ of critical buckling stress		but stress $\leq \frac{1}{2}$ of critical buckling stress		but stress $\leq \frac{1}{2}$ of critical buckling stress			

GENERAL NOTES:

K_m = stress limit factor applicable to the Design allowable membrane stress or membrane plus bending stresses (see NF-3251.1 and NF-3261)

K_v = stress limit factor applicable to the Design allowable shear stress (see NF-3252.2 and NF-3261)

K_{bk} = stress limit factor applicable to the Design allowable membrane stress or membrane plus bending stress (compression only)

NOTES:

(1) Control of deformation is not assured by these stress limit factors. When required by Design Specification, deformation control must be considered separately.

(2) K_m and K_{bk} = 1.0 for design of snubbers.

(3) For Service Limits A, B, C, and D, stresses induced on the supports by restraint of free-end displacement and anchor motions of piping shall be considered as primary stresses.

(4) Shear stress shall not exceed $0.42 S_u$.

(5) Thermal stresses within the support as defined by NF-3121.11 need not be evaluated.

(6) Stress shall not exceed $0.7 S_u$.

TABLE NF-3652(b)-1 ELASTIC ANALYSIS STRESS CATEGORIES AND STRESS LIMIT FACTORS FOR CLASS 2, 3, AND MC PLATE- AND SHELL-TYPE SUPPORTS DESIGNED BY ANALYSIS - PIPING SUPPORTS

NF-3670 EXPERIMENTAL STRESS ANALYSIS

Piping supports of all types may be designed by experimental stress analysis in accordance with Appendix II of Section III, Division 1, Appendices.

NF-3680 DESIGN BY LOAD RATING

Piping supports of all types may be designed by load rating in accordance with the requirements of NF-3280 for Plate- and Shell-Type, NF-3380 for Linear-Type, and the applicable Subsubarticle for Standard Piping Supports.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NF-4000

ARTICLE NF-4000 FABRICATION AND INSTALLATION

Page 105

NF-4100 GENERAL REQUIREMENTS

NF-4110 INTRODUCTION

NF-4111 Fabrication and Installation

Supports shall be fabricated and installed in accordance with the requirements of this Article and shall be manufactured from material which meets the requirements of NF-2000.

NF-4112 Reassembly of Subsection NF Supports

The Certificate Holder may reassemble supports from completed supports that have not been in operating service or from parts and material of disassembled supports that have not been in operating service, provided all required documentation is available and the applicable Code requirements are met.

The program for maintaining identification of material and parts, including disposition of nameplate and stamping and material documentation or Data Reports, as applicable, shall be described in a written procedure that shall be submitted to the cognizant Authorized Nuclear Inspector for review and acceptance.

NF-4120 CERTIFICATION OF MATERIALS AND FABRICATION BY SUPPORT CERTIFICATE HOLDER

NF-4121 Means of Certification

The Certificate Holder for an item shall certify, by application of the appropriate Code symbol and completion of the appropriate Data Report in accordance with NCA-8000, that the materials used comply with all the requirements of NF-2000 and that the fabrication or installation complies with the requirements of NF-4000.

NF-4121.1 Certification of Treatments, Tests, and Examinations.

If the Certificate Holder performs treatments, tests, repairs, or examinations required by other Articles of this Section, he shall certify that he has fulfilled that requirement [NCA-3861(c)]. Reports of all required treatments and the results of all required tests, repairs, and examinations performed shall be available to the Inspector.

NF-4121.2 Repetition of Tensile or Impact Tests.

If during the fabrication or installation of the support the material is subjected to heat treatment that has not been covered by treatment of the test coupons (NF-2200) and that may reduce either the tensile or impact properties below the required values, the tensile and impact tests shall be repeated by the Certificate Holder on test specimens taken from test coupons which have been taken and treated in accordance with the requirements of NF-2000.

NF-4122 Material Identification

Material for supports shall carry identification markings which will remain distinguishable until the support is fabricated or installed. If the original identification markings are cut off or the material is divided, the marks shall be accurately transferred to the parts or a coded marking shall be used to assure identification of each piece of material during subsequent fabrication or installation, unless otherwise provided by NF-2150. Material supplied with a Certificate of Compliance and welding and brazing material shall be identified and controlled so that they can be traced to each support, or else a control procedure shall be employed which ensures that the specified material is used.

NF-4123 Examinations

Visual examination activities that are not referenced for examination by other specific Code paragraphs, and are performed solely to verify compliance with

Page 110

requirements of NF-4000, may be performed by the persons who perform or supervise the work. These visual examinations are not required to be performed by personnel and procedures qualified to NF-5500 and NF-5100, respectively, unless so specified.

NF-4125 Testing of Welding and Brazing Materials

All welding and brazing materials shall meet the requirements of NF-2400.

NF-4130 REPAIR OF MATERIAL

NF-4131 Elimination and Repair of Defects

Material originally accepted on delivery in which defects exceeding the limits of NF-2500 are known or discovered during the process of fabrication or installation is unacceptable. The material may be used provided the condition is corrected in accordance with the requirements of NF-2500 for the applicable product form, except:

(a) weld repair is not required if the defect is removed by mechanical means and does not reduce the section below the minimum thickness required by NF-3000;

(b) when weld repair is performed,

(1) the weld repair restores the section to the minimum thickness required by NF-3000;

(2) the limitation on the depth of weld repair does not apply;

(3) the time of examination of weld repairs to weld edge preparations and to material shall be in accordance with NF-5120; and

(4) the provisions of NF-2610(e) for weld repair of structural material apply.

NF-4200 FORMING, FITTING, AND ALIGNING

NF-4210 CUTTING, FORMING, AND BENDING

NF-4211 Cutting

Material may be cut to shape and size by mechanical means such as machining, shearing, or chipping, or by grinding or thermal cutting. Thermally cut edges that are to be welded shall be smooth and free of all loose scale and slag accumulations.

NF-4211.1 Preheating Before Thermal Cutting.

When thermal cutting is performed to prepare weld joints or edges, to remove attachments or defective material, or for any other purpose, consideration shall be given to preheating the material using preheat schedules, such as suggested in Appendix D (Section III, Division 1, Appendices).

NF-4212 Forming and Bending Processes

Any process may be used to hot or cold form or bend materials, including weld metal, provided the required dimensions are attained (see NF-4214 and NF-4220), and provided the specified impact properties of the material, when required, are not reduced below the minimum specified values or they are effectively restored by heat treatment following the forming operation. *Hot forming* is defined as forming with the material temperature higher than 100°F (56°C) below the lower transformation temperature of the material. When required, the process shall be qualified for impact properties as outlined in NF-4213.

NF-4213 Qualification of Forming Processes for Impact Property Requirements

When impact testing is required by the Design Specifications, a procedure qualification test shall be conducted using specimens taken from material of the same material specification, grade or class, heat treatment, and with similar impact properties as required for the material in the support. These specimens shall be subjected to the equivalent forming or bending process and heat treatment as the material in the support. Applicable tests shall be conducted to determine that the required impact properties of NF-2300 are met after straining.

NF-4213.1 Exemptions.

Procedure qualification tests are not required for material listed in (a) through (f) below:

(a) hot formed material, such as forgings, in which the hot forming is completed by the Material Organization prior to removal of the impact test specimens;

(b) hot formed material represented by test coupons which has been subjected to heat treatment representing the hot forming procedure and the heat treatments to be applied to the parts;

(c) material which does not require impact tests in accordance with NF-2300;

(d) material which has final strain less than 0.5%;

(e) material where the final strain is less than that of a previously qualified procedure for that material;

(f) material from which the impact testing required by NF-2300 is performed on each heat and lot, as applicable, after forming.

Page 111

NF-4213.2 Procedure Qualification Test.

The procedure qualification test shall be performed in the manner stipulated in (a) through (f) below.

(a) The tests shall be performed on three different heats of material both before and after straining to establish the effects of the forming and subsequent heat treatment operations.

(b) Specimens shall be taken in accordance with the requirements of NF-2000 and shall be taken from the tension side of the strained material.

(c) The percent strain shall be established by the following formulas:

For cylinders:

$$\% \text{ strain} = 50t/R_f[1 - (R_f/R_o)]$$

For spherical or dished surfaces:

$$\% \text{ strain} = 75t/R_f[1 - (R_f/R_o)]$$

For pipe:

$$\% \text{ strain} = 100r/R$$

where

t = nominal thickness, in.

R_f = final radius to center line of shell, in.

R_o = original radius (equal to infinity for a flat part), in.

R = nominal bending radius to the center line of the pipe, in.

r = nominal radius of the pipe, in.

(d) The procedure qualification shall simulate the maximum percent surface strain, employing a bending process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient Charpy V-notch specimens shall be taken from each of three heats of material to establish a transition curve showing in both the upper and lower shelves. On each of these three heats, tests consisting of three impact specimens shall be conducted at a minimum of five different temperatures distributed throughout the transition region. The upper and lower shelves may be established by the use of one test specimen each, depending on the product form.

(f) Using the results of the impact test data from each of three heats, taken both before and after straining, determine either:

(1) the maximum change in NDT temperature along with:

- (a) the maximum change of lateral expansion and energy of the temperature under consideration, or
- (b) the maximum change of temperature at the lateral expansion and energy levels under consideration; or
- (2) when lateral expansion is the acceptance criterion (NF-2300), either the maximum change in temperature or the maximum change in lateral expansion.

NF-4213.3 Acceptance Criteria for Formed Material.

To be acceptable, the formed material used in the support shall have impact properties before forming sufficient to compensate for the maximum loss of impact properties due to the qualified forming procedure used.

NF-4213.4 Requalification.

A new procedure qualification test is required when any of the following changes are made:

- (a) the actual postweld heat treatment time at temperature is greater than previously qualified considering NF-2211; if the material is not postweld heat treated, the procedure must be qualified without postweld heat treatment;
- (b) the maximum calculated strain of the material exceeds the previously qualified strain by more than 0.5%;
- (c) where preheat over 250°F is used in the forming or bending operation but not followed by a subsequent postweld heat treatment.

NF-4214 Minimum Thickness of Fabricated Material

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of NF-3000, the material may be repaired in accordance with NF-4130.

NF-4220 FORMING TOLERANCES

NF-4221 Tolerances for Plate- and Shell-Type Supports

(a) The outer surface of a Plate- and Shell-Type Support shall not deviate from the specified shape by more than the greater of $1\frac{1}{4}\%$ of the overall design dimension or those tolerances permitted by NF-4222 or NF-4223. Such deviations shall not include abrupt changes.

(b) For Plate- and Shell-Type Supports which are skirts, the difference between the maximum and minimum outside diameters shall not exceed 1% of the nominal outside diameter.

Page 112

NF-4222 Tolerances for Linear-Type Supports

Tolerances for Linear-Type Supports fabricated from built-up members may be as recommended in Nonmandatory Appendix K (Section III, Division 1, Appendices), unless otherwise specified in the Design Specifications.

NF-4223 Tolerances for Standard Supports

Tolerances for Standard Supports may be as recommended in Appendix K (Section III, Division 1, Appendices), unless otherwise specified in the Design Specifications.

NF-4230 FITTING AND ALIGNING

NF-4231 Fitting and Aligning Methods

Parts that are to be joined may be fitted, aligned, and retained in position during the joining operation by the use of bars, jacks, clamps, drift pins, tack welds, or temporary attachments. Mechanical devices shall be carefully used to avoid damage to surfaces of the parts and to avoid enlargement of bolt holes.

NF-4231.1 Tack Welds.

Tack welds used to secure alignment shall either be removed completely, when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified welders using qualified welding procedures. When tack welds are to become part of the finished weld, they shall be visually examined and defective tack welds removed.

NF-4231.2 Column Bases

(a) Column bases shall be set level and to correct elevation with full bearing on the masonry.

(b) Column bases shall be finished in accordance with the requirements of (b)(1) through (3) below.

(1) Rolled steel bearing plates 2 in. or less in thickness may be used without milling, provided a satisfactory contact bearing is obtained. Rolled steel bearing plates over 2 in. but not over 4 in. (102 mm) in thickness may be straightened by pressing or, if presses are not available, by milling for all bearing surfaces except those noted in (b)(3) below to obtain satisfactory contact bearing. Rolled steel bearing plates over 4 in. (102 mm) in thickness shall be milled for all bearing surfaces except as noted in (b)(3) below.

**TABLE NF-4232-1
MAXIMUM ALLOWABLE OFFSET IN
FINAL BUTT WELDED JOINTS**

Section Thickness, in.	Maximum Allowable Offset
Up to $\frac{3}{4}$, incl.	$\frac{1}{4}t$
Over $\frac{3}{4}$ to $1\frac{1}{2}$, incl.	$\frac{3}{16}$ in.
Over $1\frac{1}{2}$ to 2, incl.	$\frac{1}{8}t$
Over 2	Lesser of $\frac{1}{8}t$ or $\frac{3}{4}$ in.

TABLE NF-4232-1 MAXIMUM ALLOWABLE OFFSET IN FINAL BUTT WELDED JOINTS

(2) Column bases other than rolled steel bearing plates shall be planed for all bearing surfaces, except as noted in (b)(3) below.

(3) The bottom surfaces of bearing plates and column bases which are grouted to ensure full bearing contact on foundation need not be planed.

NF-4232 Maximum Offset of Aligned Sections

Alignment of butt joints shall be such that the maximum offset of the finished weld will not be greater than the applicable amount listed in Table NF-4232-1, where t is the nominal thickness of the thinner section of the joint.

NF-4232.1 Fairing of Offsets.

Any offset within the allowable tolerance of Table NF-4232-1 shall be blended uniformly over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld.

NF-4240 REQUIREMENTS FOR WELDED JOINTS

Butt welds may be made with or without backing or consumable insert rings. When the use of permanent backing rings is undesirable [NF-3226.1(a) or NF-3256.1(a)]:

- (a) the backing ring shall be removed and the inside of the joint ground smooth; or
- (b) the joint shall be welded without backing rings; or
- (c) consumable insert rings shall be used.

NF-4300 WELDING QUALIFICATIONS

NF-4310 GENERAL REQUIREMENTS

NF-4311 Types of Processes Permitted

Only those welding processes which are capable of producing welds in accordance with the welding procedure

Page 113

qualification requirements of Section IX and this Subsection shall be used for welding support material or attachments thereto. Any process used shall be such that the records required by NF-4320 can be prepared except that records for stud welds shall be traceable to the welders and welding operators, and not necessarily to each specific weld.

NF-4311.1 Stud Welding Restrictions.

Stud welding is acceptable for insulation supports, nameplates, and locating lugs. Studs shall be limited to 1 in. (25 mm) maximum diameter for round studs or an equivalent cross-sectional area for studs of other shapes when welding in the flat position and $\frac{3}{4}$ in. (19 mm) diameter for all other welding positions. When studs are $\frac{1}{2}$ in. (13 mm) in diameter or less, postweld heat treatment, qualified welding procedures, and certified welding materials are not required.

NF-4311.2 Capacitor Discharge Welding.

Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments provided:

- (a) temporary attachments are removed in accordance with the provisions of NF-4435(b); and
- (b) the energy output for permanent nonstructural attachments such as strain gages and thermocouples is limited to 125 W-sec and the minimum thickness of the material to which the attachment is made is greater than 0.09 in.; and
- (c) a Welding Procedure Specification is prepared describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required.

NF-4311.4 Inertia and Continuous Drive Friction Welding

- (a) Inertia and continuous drive friction welding shall not be used for fabrication of Class 1 Plate- and Shell-Type Component Supports.
- (b) The weld between the two members shall be a full penetration weld.

NF-4320 WELDING QUALIFICATION AND RECORDS

NF-4321 Required Qualifications

- (a) Each Certificate Holder is responsible for the welding done by his organization and shall establish the procedure and conduct the tests required by this Article and Section IX in order to qualify both the welding procedures and the

performance of welders and welding operators who apply these procedures.

(b) Procedures, welders, and welding operators used to join permanent or temporary attachments to support elements and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Article.

(c) When making procedure test plates for butt welds, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. This applies particularly to material and weld metal of 80.0 ksi (552 MPa) tensile strength or higher and heavy sections of both low and high tensile strength material. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

(d) NCA-3131 provides specific additional requirements when welding services are subcontracted to or through organizations not holding an appropriate Certificate of Accreditation.

NF-4322 Maintenance and Certification of Records

The Certificate Holder shall maintain a record of his qualified welding procedures and of the welders and welding operators qualified by him, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and signed by any authorized individual assigned by the Certificate Holder, and they shall be accessible to the Owner and to the Inspector.

NF-4322.1 Identification of Joints for Class 1 Component Supports

(a) For Class 1 Plate- and Shell-Type, and Linear-Type Component Supports, the welder or welding operator shall apply the identification mark assigned to him by the Certificate Holder on or adjacent to all permanent welds, including fillet welds, at 3 ft (0.9 m) intervals or less, except as noted in (b) below. The marking shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps. As an alternative, the Certificate Holder shall keep a record of permanent welded joints in a component support, and of the welders and welding operators used in making each of the joints.

(b) For partial penetration welds with a depth less than 1 in. and fillet welds with a throat dimension less than 1 in. in primary members, and for all welds in secondary members, the Certificate Holder need not identify the welder or welding operator who welded each joint provided:

Page 114

(1) the Certificate Holder maintains a system that will identify the welders or welding operators who made such welds on each item so that the Inspector can verify that the welders or welding operators were all properly qualified;

(2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification.

NF-4322.2 Identification of Other Joints.

For all types of Class 2, 3, and MC component supports and for all classes of piping supports and Standard Supports, the Certificate Holder shall certify that only welders and welding operators qualified in accordance with NF-4321 were used in making all welds.

NF-4322.3 Identification of Tack Welds.

The identification of welder or welding operator is not required for tack welds.

NF-4323 Welding Prior to Qualification

No welding shall be undertaken until after the welding procedures which are to be used have been qualified. Only welders and welding operators who are qualified in accordance with NF-4320 and Section IX shall be used.

NF-4324 Transferring Qualifications

The welding procedure qualifications and the performance qualification tests for welders and welding operators conducted by one Certificate Holder shall not qualify welding procedures and shall not qualify welders or welding operators to weld for any other Certificate Holder, except as provided in Section IX, QW-201 and QW-300.2.

NF-4330 GENERAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION TESTS

NF-4331 Conformance to Section IX Requirements

All welding procedure qualification tests shall be in accordance with the requirements of Section IX as supplemented by the requirements of this Article.

NF-4334 Preparation of Test Coupons and Specimens

(a) Removal of test coupons from the test weld and the dimensions of specimens made from them shall conform to the requirements of Section IX, except that the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with (b) below.

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test specimens. When each process cannot be included in the full-size impact test specimen at the $\frac{1}{4}t$ location required by this Section, additional full-size specimens shall be obtained from locations in the test weld that will ensure that at least a portion of each process has been included in full-size test specimens. As an alternative, additional test welds can be made with each process so that full-size specimens can be tested for each process.

NF-4334.1 Coupons Representing the Weld Deposits.

Impact test specimen and testing methods shall conform to NF-2321. The impact specimen shall be located so that the longitudinal axis of the specimen is at least $\frac{1}{4}t$, and where the thickness of the test assembly permits, not less than $\frac{3}{8}$ in. (10 mm) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified in NF-4620, and the test assembly is cooled at an accelerated rate, the longitudinal axis of the specimen shall be a minimum of t from the edge of the test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the weld. The length of the notch of the Charpy V-notch specimen shall be normal to the surface of the weld.

NF-4334.2 Coupons Representing the Heat Affected Zone.

Where impact tests of the heat affected zone are required by NF-4335.2, specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through (c) below.

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented either parallel to or perpendicular to the principal direction of rolling or forging.

(b) The heat affected zone impact test specimens and testing methods shall conform to NF-2321. The specimens shall be removed from a location as near as practical to a depth midway between the surface and center thickness. The coupons for heat affected zone impact specimens shall be taken transverse to the axis of the weld and etched to define the heat affected zone. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much heat affected zone as possible in the resulting fracture. Where the material thickness permits, the axis of a specimen may

Page 115

be inclined to allow the root of the notch to align parallel to the fusion line. When a grain refining heat treatment is not performed on welds made by the electroslag or electrogas welding process, the notch for the impact specimens shall be located in the grain coarsened region.

(c) For the comparison of heat affected zone values with base material values [NF-4335.2(b)], Charpy V-notch specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the heat affected zone specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the heat affected zone specimens, and the axis of the notch shall be normal to the surface of the base material.

NF-4335 Impact Test Requirements

When materials are required to be impact tested per NF-2300, impact tests of the weld metal and heat affected zone shall be performed in accordance with the following subparagraphs. Exemptions from impact testing under NF-2311(b)(9) and (10) do not apply to weld metal unless the specific weld metal used is included in Table NF-2311(b)-1 (weld metal exemptions are being developed). Exemption from impact testing of the heat affected zone of those base materials which are exempted by NF-2311(b)(9) and (10) is not permitted. The welding procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of NF-2330 and NF-4334. Retests in accordance with the provisions of NF-2350 are permitted.

NF-4335.1 Impact Tests of Weld Metal

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding $\frac{5}{8}$ in. (16 mm) in thickness when the weld is made on the surface or penetrates the base material that requires impact testing in accordance with NF-2310. In addition, such testing of the weld metal is required for the welding procedure qualification tests for any weld repair to base material that requires impact testing in accordance with NF-2310, regardless of the depth of the repair. Exemption from impact testing under NF-2311(b)(9) and (10) does not apply to weld metal of the welding procedure qualification test for either production weld joints or base material repairs unless the specific weld metal used is included in Table NF-2311(b)-1 (weld metal exemptions are being developed).

(b) The impact test requirements and acceptance standards for welding procedure qualification weld metal shall be the same as specified in NF-2330 for the base material to be welded or repaired. Where two materials which have different fracture toughness requirements are to be joined by welding, the test requirements and acceptance standards of either material may be used for the weld metal, except where otherwise specified by NCA-1280 or other parts of this Section.

(c) A Welding Procedure Specification (WPS) qualified to the impact testing requirements of Subsection NB, NC, or NE may be accepted as an alternative to the WPS impact testing requirements of this Subsection.

NF-4335.2 Impact Tests of Heat Affected Zone

(a) Charpy V-notch tests of the heat affected zone of the welding procedure qualification test assembly are required whenever the thickness of the weld exceeds $\frac{5}{8}$ in. (16 mm), and either of the base materials requires impact testing in accordance with the rules of NF-2310. Exemption of base materials by NF-2311(b)(9) or (10) does not apply to the welding procedure qualification of the heat affected zone or unaffected base material for such materials. The only exceptions to the requirements are the following:

(1) the qualification for welds in P-Nos. 1 and 3 and SA-336 F12 materials that are postweld heat treated and are made by any process other than electroslag, electrogas, or thermit.

(2) the qualification for weld deposit cladding or hard-facing on any base material.

(b) Impact testing of the procedure qualification test heat affected zone, where required by NF-4335, shall be conducted in accordance with (b)(1) through (3) and (c) below, if applicable.

(1) For tests of welding procedure qualifications for materials that require testing in accordance with NF-2331, the three Charpy V-notch heat affected zone and three Charpy V-notch unaffected base material specimens shall be tested at a temperature in accordance with NF-2331. The Charpy V-notch impact test of the unaffected base material shall meet the toughness requirements of Table NF-2331(a)-1, Table NF-2331(a)-2, Table NF-2331(a)-3, Table NF-2331(a)-4, Fig. NF-2331(a)-1, or Fig. NF-2331(a)-2 as applicable. If the average toughness value of the three heat affected zone specimens is equal to or greater than the average value of the unaffected base material Charpy V-notch specimens, the test shall be considered acceptable and the values and testing temperature shall be recorded on the Welding Procedure Qualification Record.

(2) If the heat affected zone Charpy V-notch average toughness values of (b)(1) above are less than the unaffected base material and the qualification test meets the other criteria of acceptance, the Charpy V-notch

in (b)(3) below to provide an additive temperature for the adjustment of the lowest service temperature (LST) of the base material that is to be welded in production with the welding procedure being qualified. Alternatively, the welding procedure qualification may be rewelded and retested.

(3) The data for use in (b)(2) above shall be developed by performing additional Charpy V-notch tests on either the welding procedure qualification test heat affected zone or the unaffected base material, or both, at temperatures which provide toughness values that meet or exceed those required for the thickness of the material to be welded in production. The average toughness data for the heat affected zone and unaffected base material shall be plotted on a property temperature chart. The temperature at which these two sets of data exhibit a common acceptable value of toughness for the production thickness involved shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the heat affected zone. This difference, if a positive number, shall be used in (b)(2) above as the adjustment temperature. The welding procedure adjustment temperature shall be added to the highest LST established by the tests of NF-2331 for all of the base material to be welded by this procedure in production. If the temperature difference is zero or a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by the tests for NF-2331 will still apply as stated in (b)(2) above. Where the actual LST is not required for the production material to be welded [for example, where the testing temperature is established by the Design Specification to determine that the material has adequate toughness to meet the toughness requirements of Table NF-2331(a)-1, Table NF-2331(a)-2, Table NF-2331(a)-3, Table NF- 2331(a)-4, Fig. NF-2331(a)-1, or Fig. NF-2331(a)-2 as applicable, at the specified test temperature], the adjustment temperature determined by the curves shall be used to establish a reduction in the specified testing temperature for the production material. The adjustment temperature shall be used to lower the specified testing temperature for any production material on which the procedure will be used.

(c) Should the unaffected base material Charpy V-notch impact test results fail to meet the applicable requirements referenced in (b)(1) above, additional unaffected base material Charpy V-notch impact tests shall be tested at higher temperatures until the applicable requirements are met. Charpy V-notch impact tests of the heat affected zone shall be tested at the same temperature at which acceptable unaffected base material properties were achieved. The rules governing the average toughness of the heat affected zone relative to the average toughness of the unaffected base material shall be followed as in (b)(1) through (3) above to determine the data which are to be recorded on the Welding Procedure Qualification Record.

(d) A Welding Procedure Specification (WPS) qualified to the impact testing requirements of Subsection NB, NC, or NE may be accepted as an alternative to the WPS impact testing requirements of this Subsection.

NF-4400 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS

NF-4410 PRECAUTIONS TO BE TAKEN BEFORE WELDING

NF-4411 Identification, Storage, and Handling of Welding Materials

Each Certificate Holder is responsible for control of the welding electrodes and other materials which are used in the fabrication and installation of supports (NF-4120). Suitable identification, storage, and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by electrodes and flux.

NF-4412 Cleanliness and Protection of Weld Surfaces

The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

NF-4420 RULES FOR MAKING WELDED JOINTS

NF-4421 Backing Strips

The materials for backing strips, when used, shall be compatible with the base metal.

NF-4422 Peening

The weld metal may be peened when it is deemed necessary or helpful to control distortion.

NF-4423 Double Welded Joints

Before applying weld metal on the second side to be welded, the root of full penetration double welded joints shall be prepared by suitable methods, such as chipping, grinding, or thermal gouging, except for those processes of welding by which proper fusion and penetration are otherwise obtained and demonstrated to be satisfactory by welding procedure qualification.

NF-4424 Surfaces of Welds

(a) The surface condition of the finished weld shall be sufficiently free from coarse ripples, grooves, overlaps, abrupt ridges, and valleys for the proper interpretation of radiographic and other required nondestructive examinations of the welds. In those cases where there is a question regarding the surface condition on the interpretation of a radiographic film, the film shall be compared to the actual weld surface for interpretation and determination of acceptability.

(b) Concavity on the root side of a single welded circumferential butt weld is permitted when the resulting thickness of the weld meets the requirements of NF-3000.

(c) Fusion shall exist between adjacent layers of weld metal and between weld metal and base metal except as provided in NF-5360(c).

(d) For inertia and continuous drive friction welding, the weld upset shall meet the specified amount within $\pm 10\%$. Flash shall be removed to sound metal.

NF-4427 Shape and Size of Welds

(a) Fillet welds may vary from convex to concave. The shape and size of the weld shall be in accordance with the requirements of Fig. NF-4427-1. Convexity of fillet welds is not a criteria for acceptance and need not be measured.

(b) The faces of groove welds may be flat or convex. The thickness of groove welds shall be no less than $\frac{1}{32}$ in. (0.8 mm) less than the thickness of the thinner of the members joined.

(c) On web-to-flange welds on girders, no underrun as permitted at the ends for a length equal to twice the width of the flange.

NF-4429 Plug Welds

When plug welds are used on supports, a fillet weld shall first be deposited around the circumference at the bottom of the hole.

NF-4430 WELDING OF ATTACHMENTS**NF-4435 Welding of Nonstructural and Temporary Attachments, and Their Removal**

(a) Nonstructural attachments such as insulation supports, nameplates, locating lugs, and temporary attachments may be noncertified material and may be welded to the support or parts thereof with continuous or intermittent fillet or partial penetration welds, provided the requirements of (1) through (5) below are met:

- (1) the welding procedure and the welders have been qualified in accordance with NF-4321;
- (2) the material is identified and is suitable for welding;
- (3) the material is compatible with the material to which it is attached;
- (4) the welding material is identified and compatible with the materials joined;

(5) the welds are postweld heat treated when required by NF-4620.

(b) Removal of temporary attachments shall be accomplished as follows:

- (1) the temporary attachment shall be completely removed in accordance with the procedures of NF-4211;
- (2) as an alternative to (a)(5) above, postweld heat treatment may be deferred until after removal of the attachment;
- (3) the surface of the support shall be visually examined after removal of the temporary attachment.

NF-4440 SPECIAL REQUIREMENTS FOR WELDING

NF-4441 General Requirements

When a primary member of a component support, consists of a plate or a rolled shape and transmits loads in the through thickness direction, one of the following requirements shall be met if the primary member subjected to through thickness loading is 1 in. (25 mm) and greater in thickness.

(a) After completion of welding, the base material directly underneath the attachment shall be ultrasonically examined in accordance with the requirements of NF-5214,

Page 118

NF-5224, or NF-5234, as appropriate to the component support class.

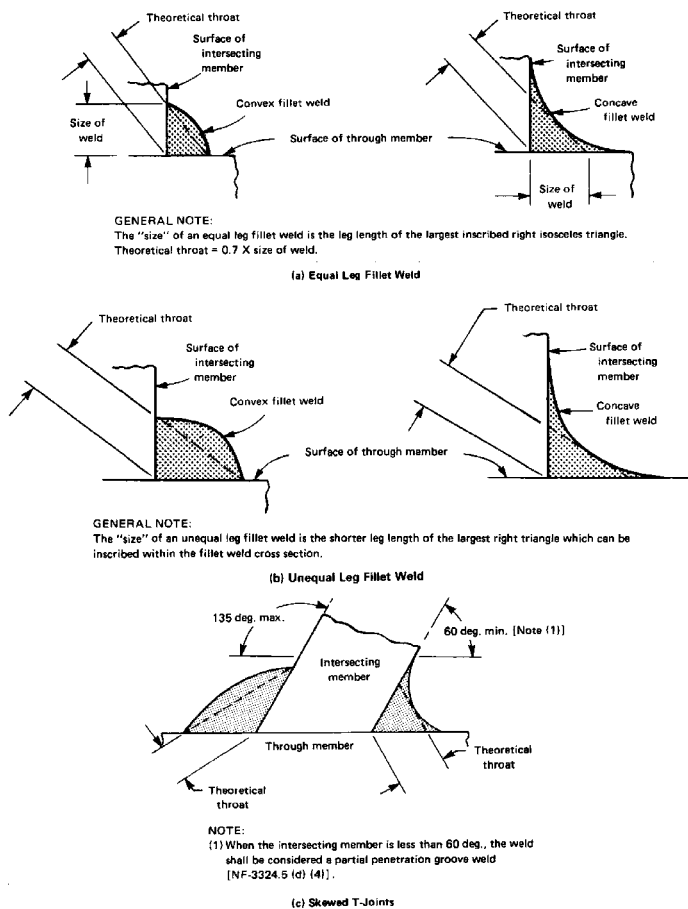


FIG. NF-4427-1 FILLET WELD DIMENSIONS

FIG. NF-4427-1 FILLET WELD DIMENSIONS

(b) A weld metal inlay or overlay shall be made in accordance with Fig. NF-4441-1 and ultrasonically examined in accordance with NF-5214, NF-5224, or NF-5234, prior to making the weld joining the attachment member to the inlay or overlay.

(c) Special deposition techniques, as illustrated in Fig. NF-4441-2, may be used as an alternative to inlay or overlay. Such techniques shall be demonstrated to meet the requirements of (a) above on material thickness equal to or greater than the production thickness but need not be more than 4 in. (102 mm), and on material of the same type and grade as the production material.

(d) The material shall meet the acceptance standards of SA-770, Through-Thickness Tension Testing of Steel Plates for Special Applications.

NF-4450 REPAIR OF WELD METAL DEFECTS

NF-4451 General Requirements

Defects in weld metal detected by the examinations required by NF-5000 shall be eliminated and repaired when necessary.

NF-4452 Elimination of Surface Defects

Weld metal surface defects may be removed by grinding or machining and need not be repaired by welding, provided that the requirements of (a) through (c) below are met.

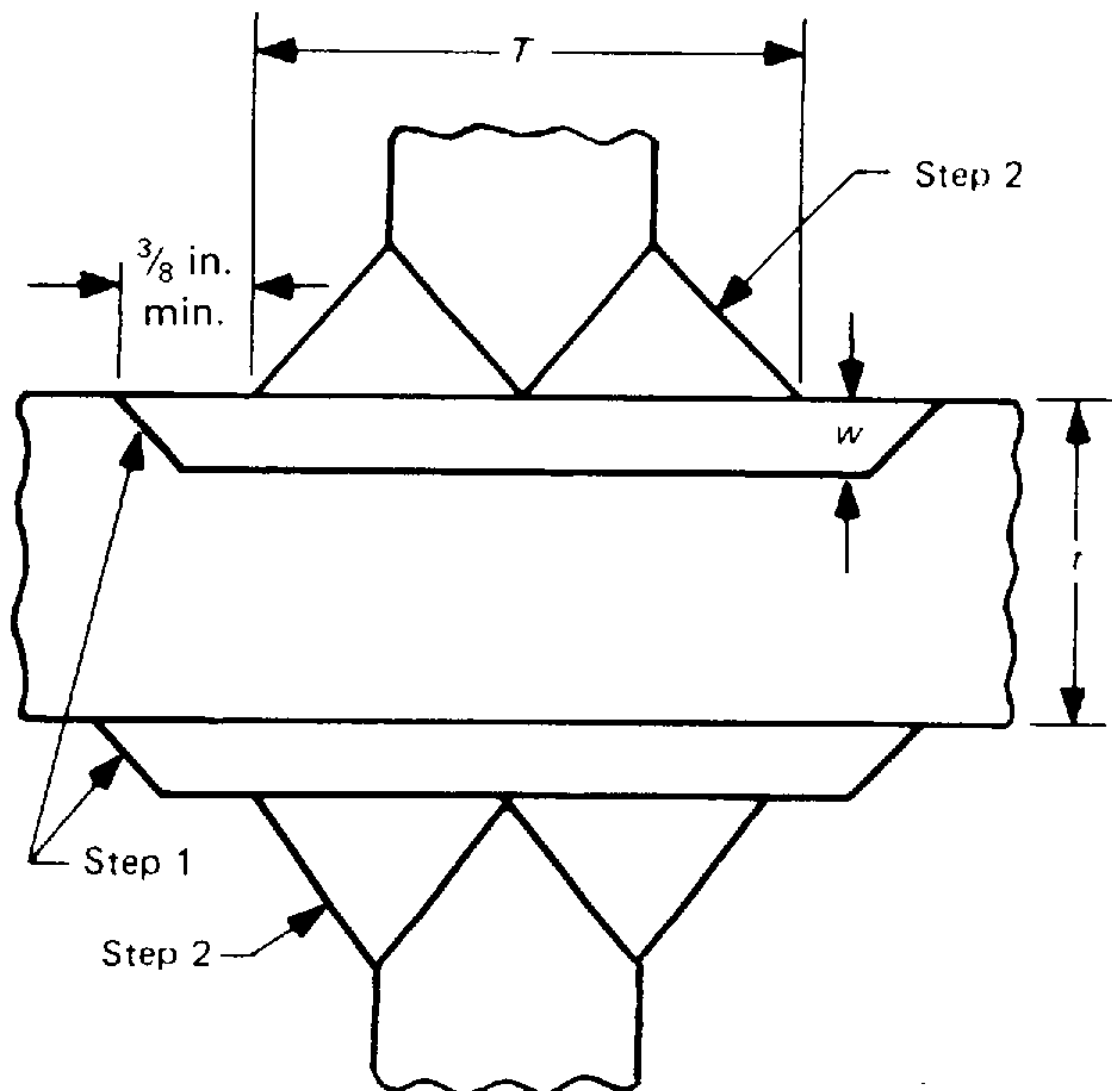
(a) The remaining thickness of the section is not reduced below that required by NF-3000.

(b) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(c) The area is examined after blending by a magnetic particle or liquid penetrant method in accordance with NF-5110 and meets the acceptance standards of NF-5300 to ensure that the defect has been removed or the indication reduced to an acceptable limit. Defects detected by the visual or volumetric method and located on an interior surface need only be reexamined by the method which initially detected the defect when the interior surface is inaccessible for surface examination.

NF-4453 Requirements for Making Repairs to Welds

Excavations in weld metal, when repaired by welding, shall meet the requirements of the following subparagraphs.



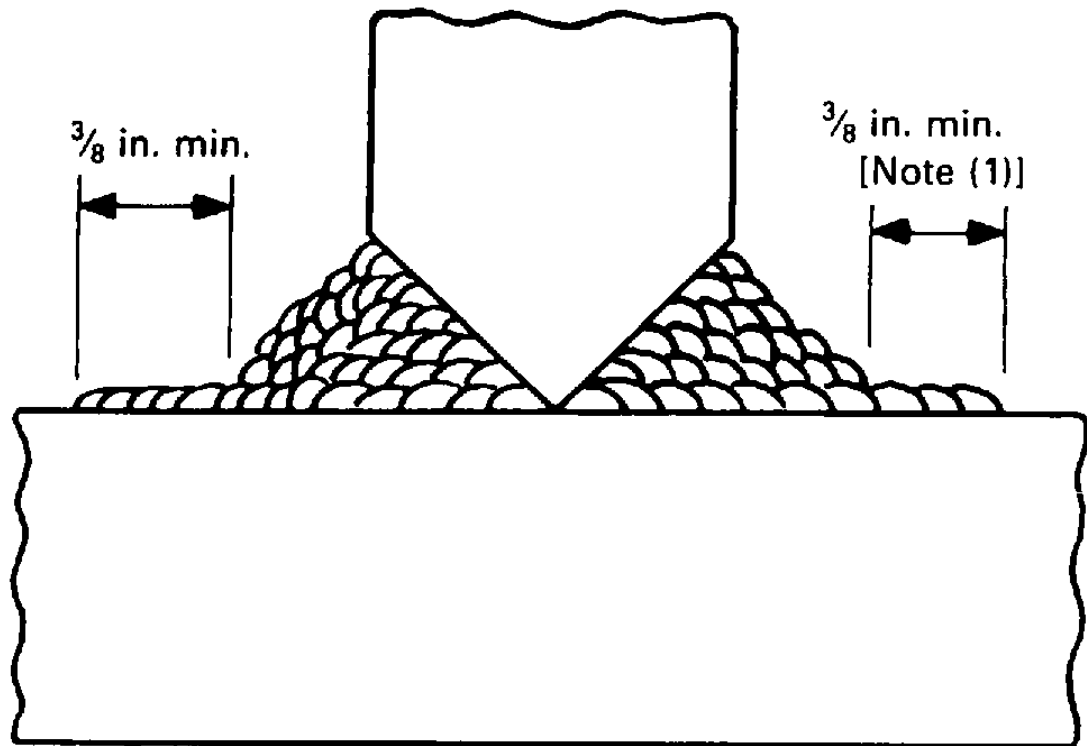
Step 1 Inlay or overlay weldment

Step 2 Completion of weldment

FIG. NF-4441-1 WELD JOINT PRODUCING THROUGH-THICKNESS LOADING

NF-4453.1 Defect Removal.

Defects may be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined by a liquid penetrant or magnetic particle method in accordance with NF-5110 and shall meet the acceptance



GENERAL NOTE: Members may be welded on one side only, or from both sides.

NOTE:

- (1) The initial layer(s) shall extend a minimum of $\frac{3}{8}$ in. beyond the toe of the fillet.

**FIG. NF-4441-2 SPECIAL DEPOSITION TECHNIQUE
FOR WELD JOINT PRODUCING THROUGH-
THICKNESS LOADING (TYPICAL)**

FIG. NF-4441-2 SPECIAL DEPOSITION TECHNIQUE FOR WELD JOINT PRODUCING THROUGH-THICKNESS LOADING (TYPICAL)

THROUGH-THICKNESS LOADING (TYPICAL)

NF-4453.2 Requirements for Welding Materials, Procedures, and Welders.

The weld repair shall be made using welding material, welders, and welding procedures qualified in accordance with NF-4125 and NF-4300.

NF-4453.3 Blending of Repaired Areas.

After repair, the surface shall be blended uniformly into the surrounding surface.

NF-4453.4 Examination of Repair Welds.

The examination of a weld repair shall be repeated as required for the original weld, except that it need only be reexamined by the liquid penetrant or magnetic particle method when the unacceptable indication was originally detected by the liquid penetrant or magnetic particle method and when the repair cavity does not exceed the following:

- (a) $\frac{1}{3}t_w$ for $t_w \leq \frac{3}{4}$ in. (19 mm)
- (b) $\frac{1}{4}$ in. (6 mm) for $\frac{3}{4}$ in. (19 mm) $< t_w \leq 2\frac{1}{2}$ in. (64 mm)
- (c) the lesser of $\frac{3}{8}$ in. or 10% t_w for $t_w > 2\frac{1}{2}$ in. (64 mm)

where t_w equals the nominal thickness of the original weld.

NF-4453.5 Heat Treatment of Repaired Areas.

The repaired area shall be heat treated when required by NF-4620.

NF-4500 BRAZING

NF-4510 RULES FOR BRAZING

NF-4511 Where Brazing May Be Used

Furnace brazing is permitted for the construction of supports in accordance with the rules of this Subsection provided the following additional requirements are met.

- (a) Brazing procedures and brazing operators shall be qualified in accordance with Section IX.
- (b) Clearance or interference between mating parts shall be in accordance with the Brazing Procedure Specification.
- (c) Base material shall be limited to material permitted by NF-2120 and Section IX, P-Nos. 101 and 102 ferritic material.
- (d) Brazing alloys shall be limited to Section IX, F-No. 105.
- (e) The allowable shear stress shall be 15.0 ksi or $0.4 \times$ yield strength of base material [NF-3322.1(b)], whichever is less, and the joint shall be loaded principally in shear only.
- (f) Postbrazing heat treatment to develop or restore base material mechanical properties shall be qualified by test specimens which meet the thickness requirements of Section IX, QB-451. The base material test specimens shall be exposed to the same thermal treatment as a brazed part but need not contain a brazed joint. Postbrazing heat treatment of actual parts or test specimens may be performed in the same heat cycle as the brazing operation or in a separate heat cycle. Postbrazing heat treatment shall not exceed 1850°F (1010°C).
- (g) Brazing alloy shall be preplaced on one side of the joint only. Each production joint shall be visually examined after brazing. Brazing metal must be continuous on the preplaced brazing metal side and 85% continuous on the other side.

NF-4512 Brazing Material

Where brazing is permitted, the brazing filler material and fluxes shall conform to the rules covering identification in NF-2150

(a) The filler material used in brazing shall be a nonferrous metal or alloy with a solidus temperature above 800°F (427°C) and at least 500°F (278°C) above the highest temperature of the joint in service.

Page 121

(b) The filler material shall melt and flow freely by capillary action within the desired temperature range, and in conjunction with a suitable flux or controlled atmosphere the filler material shall wet and adhere to the surfaces to be joined.

(c) Fluxes that are fluid and chemically active at the brazing temperature shall be used, when necessary, to prevent oxidation of the filler metal and the surfaces to be joined and to promote free flowing of the filler material.

NF-4600 HEAT TREATMENT

NF-4610 WELDING PREHEAT AND INTERPASS REQUIREMENTS

NF-4611 When Preheat Is Necessary

The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, elevated temperature, physical properties, and material thicknesses. Some practices used for preheating are given in Appendix D (Section III, Division 1, Appendices) as a general guide for the materials listed by P-Numbers of Section IX. It is cautioned that preheating suggested in Appendix D (Section III, Division 1, Appendices) does not necessarily ensure satisfactory completion of the welded joint and that the preheat requirements for individual materials within the P-Number listing may be more or less restrictive. The Welding Procedure Specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.

NF-4612 Preheating Methods

Preheat for welding or thermal cutting, when employed, may be applied by any method which does not harm the base material or any weld metal already applied or which does not introduce deleterious material into the welding area which is harmful to the weld.

NF-4613 Interpass Temperatures

Consideration should be given to limitations of interpass temperatures for quenched and tempered material to avoid detrimental effects on the mechanical properties.

NF-4620 POSTWELD HEAT TREATMENT

NF-4621 Heating and Cooling Methods

Postweld heat treatment (PWHT) may be accomplished by any suitable methods of heating and cooling, provided the required heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control are maintained.

NF-4622 PWHT Time and Temperature Requirements

NF-4622.1 General Requirements.¹

Except as otherwise permitted in NF-4622.7, all welds, including repair welds, shall be postweld heat treated. During postweld heat treatment, the metal temperature shall be maintained within the temperature ranges and for the minimum holding times specified in Table NF-4622.1-1, except as otherwise permitted in NF-4622.4(c). P-Number groups in Table NF-4622.1-1 are in accordance with Section IX, QW-420. Except as provided in NF-4624.3, PWHT shall be performed in temperature-surveyed and -calibrated furnaces, or PWHT shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. In addition, the requirements of the following subparagraphs shall apply.

NF-4622.2 Time-Temperature Recordings.

Time-temperature recordings of all postweld heat treatments shall be made available for review by the Authorized Inspector. Identification on the time-temperature recording shall be to the weld, part, or support. A summary of the time-temperature recording may be provided for permanent records in accordance with NCA-4134.17.

NF-4622.3 Definition of Nominal Thickness Governing PWHT.

The nominal thickness in Table NF-4622.7(b)-1 is the thickness of the weld, the base material, or the thinner of the base materials being joined, whichever is least. It is not intended that nominal thickness include material provided for forming allowance, thinning, or mill overrun when the excess material does not exceed $\frac{1}{8}$ in. (3.2 mm). For fillet welds, the nominal thickness is the throat thickness and, for partial penetration and material repair welds, the nominal thickness is the depth of the weld groove or preparation.

1 Any postweld heat treatment time which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

Page 122

Page 123

TABLE NF-4622.1-1
MANDATORY REQUIREMENTS FOR POSTWELD HEAT TREATMENT (PWHT) OF WELDS¹

P-Number (Sect. IX, QW-420)	Holding Temperature Range, °F [Note (2)]	Minimum Holding Time at Temperature for Weld Thickness (Nominal)			
		½ in. or Less	Over ½ in. to 2 in.	Over 2 in. to 5 in.	Over 5 in.
1, 3	1100–1250	30 min	1 hr/in.	2 hr plus 15 min each additional inch over 2 in.	2 hr plus 15 min each additional inch over 2 in.
4	1100–1250	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
5A, 5B, 5C, 6 except P-No. 6 Gr. 4	1250–1400	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
6 Gr. 4	1100–1150				
7	1300–1400	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
9A Gr.1	1100–1250	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
9B Gr. 1	1100–1175				
10A Gr. 1, 10C Gr. 1, 10F Gr. 1	1100–1250	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
10I Gr. 1	1300–1400				
11A Gr. 1	1025–1085	30 min	1 hr/in.	1 hr/in.	1 hr/in.
11A Gr. 4	1000–1050				
11A Gr. 5	1100–1150				
P-Nos. 8, 10H Gr. 1, 34, 42, 43, 45 and hard sur- facing on P-No. 1 base metal whose reported carbon content is not more than 0.30%	PWHT neither required nor prohibited				

NOTES:

- (1) Exemptions to the mandatory requirements of this Table are defined in NF-4622.7.
(2) All temperatures are metal temperatures.

TABLE NF-4622.1-1 MANDATORY REQUIREMENT FOR POSTWELD HEAT TREATMENT (PWHT) OF WELDS¹

NF-4622.4 Holding Times at Temperature

(a) The holding time at temperature as specified in Table NF-4622.1-1 shall be based on the nominal thickness of the weld. The holding time need not be continuous. It may be an accumulation of the times of multiple postweld heat treatment cycles.

(b) Holding time at temperature in excess of the minimum requirements of Table NF-4622.1-1 may be used, provided that specimens so heat treated are tested in accordance with NF-2200, NF-2400, and NF-4300.

(c) Alternatively, when it is impractical to postweld heat treat at the temperature range specified in Table NF-4622.1-1, it is permissible to perform the postweld heat treatment of certain materials at lower temperatures for longer periods of time in accordance with Table NF-4622.4(c)-1 and (1), (2), and (3) below.

(1) Except for P-No. 1 materials, when welds in the materials listed in Table NF-4622.4(c)-1 are to be postweld heat treated at these lower minimum temperatures, the impact test specimens for the welding procedure qualification required by NF-4300 shall be made using the same minimum temperatures and increased minimum holding time. Welding procedures, qualified at the temperature range and minimum holding time specified in Table NF-4622.1-1 and at the lower minimum temperature and increased minimum holding time permitted by Table NF-4622.4(c)-1, are also qualified for any temperature in between. When such an in-between temperature is used, the minimum holding time shall be interpolated from Table NF-4622.1-1 and the alternative requirements of Table NF-4622.4(c)-1.

(2) Except for P-No. 1 materials, when welds in the materials listed in Table NF-4622.4(c)-1 are to be postweld heat treated at these lower minimum temperatures, the welding material certification required by NF-2400 shall be made using the same minimum temperatures and increased minimum holding time. Welding material certified at the temperature range and minimum holding time specified in Table NF-4622.1-1, and at the lower minimum temperatures and increased minimum holding time permitted by Table NF-4622.4(c)-1 is also certified for any temperature in between.

(3) Base material certified in accordance with NF-2210 may be postweld heat treated at these lower minimum temperatures and increased minimum holding times without recertification. Postweld heat treatment at these lower minimum temperatures and increased minimum holding times may also be the tempering operation, provided a higher tempering temperature is not required by the material specification.

**TABLE NF-4622.4(c)-1
ALTERNATIVE HOLDING TEMPERATURES
AND TIMES¹**

Material P-Numbers	Alternative Minimum Holding Temperatures, °F	Alternative Minimum Holding Times
1, 3, 9A Gr. 1, 9B Gr. 1	1050	2 hr/in. thick
1, 3, 9A Gr. 1, 10A Gr. 1, 9B Gr. 1	1000	4 hr/in. thick

NOTE:

(1) All other requirements of NF-4622 shall apply.

TABLE NF-4622.4(c)-1 ALTERNATIVE HOLDING TEMPERATURES AND TIMES¹

NF-4622.5 PWHT Requirements When Different P-Number Materials Are Joined.

When materials of two different P-Number groups are joined by welding, the applicable postweld heat treatment shall be that specified in Table NF-4622.1-1 for the material requiring the higher PWHT temperature range.

NF-4622.6 PWHT Requirements for Nonpressure-Retaining Parts.

When nonpressure-retaining material is welded to pressure retaining material, the postweld heat treatment temperature range of the pressure retaining material shall control.

NF-4622.7 Exemptions to Mandatory Requirements.

Postweld heat treatment in accordance with this Subarticle is not required for:

(a) nonferrous materials;

(b) welds exempted in Table NF-4622.7(b)-1;

(c) welds subjected to temperatures above the PWHT temperature range specified in Table NF-4622.1-1, provided the Welding Procedure Specification is qualified in accordance with Section IX and the base material and the deposited weld material has been heat treated at the higher temperature;

(d) postweld heat treatment is not required for supports constructed of Type 405 material or of Type 410 material with carbon content not to exceed 0.08%, welded with electrodes that produce an austenitic chromium-nickel weld deposit or a non-air-hardening nickel-chromium-iron weld deposit, provided the plate nominal thickness at the welded joint does

not exceed $\frac{3}{8}$ in. (10 mm), and for thicknesses over $\frac{3}{8}$ in. to $1\frac{1}{2}$ in. (10 mm to 38 mm), provided a preheat of 450°F (232°C) is maintained during welding and the joints are completely radiographed.

**TABLE NF-4622.7(b)-1
EXEMPTIONS TO MANDATORY PWHT¹**

P-Number (Sect. IX, QW-420)	Type of Weld [Note (2)]	Nominal Thickness (NF-4622.3)	Max. Reported Carbon, % [Note (3)]	Min. Preheat Req'd, °F
1	All welds where the materials being joined are $1\frac{1}{2}$ in. and less	$1\frac{1}{4}$ in. and less Over $1\frac{1}{4}$ in. to $1\frac{1}{2}$ in. $\frac{3}{4}$ in. or less Over $\frac{3}{4}$ in. to $1\frac{1}{2}$ in.	0.30 or less 0.30 or less Over 0.30 Over 0.30	... 200 ... 200
	Fillet, partial penetration, and repair welds in material over $1\frac{1}{2}$ in.	$\frac{3}{4}$ in. or less	...	200
3 except Gr. 3	All welds	$\frac{1}{2}$ in. or less	0.25 or less	200
4	All welds in pipes or tubes with nominal O.D. 4 in. or less and attachment welds	$\frac{1}{2}$ in. or less	0.15 or less	250
5A, 5B, 5C	All welds in pipes or tubes with maximum specified chromium 3.00% or less and nominal O.D. 4 in. or less	$\frac{1}{2}$ in. or less	0.15 or less	300
6 or 7 Gr. 1 (For Type 405)	Type 405 and 410S welded with A-No. 8, A-No. 9, or F-No. 43 filler metal	$\frac{3}{8}$ in. or less	0.08 or less	...
9A Gr. 1	All welds, provided the procedure qualification is made using equal or greater thickness base material than the production weld	$\frac{5}{8}$ in. or less	...	200
	Attachment welds joining nonpressure-retaining material to pressure retaining material over $\frac{5}{8}$ in.	$\frac{1}{2}$ in. or less	...	200
	All welds in pipes or tubes with nominal O.D. 4 in. and less	$\frac{1}{2}$ in. or less	0.15 or less	250
9B Gr. 1	All welds, provided the procedure qualification is made using equal or greater thickness base material than the production weld	$\frac{5}{8}$ in. or less	...	200
	Attachment welds joining nonpressure-retaining material to pressure retaining material over $\frac{5}{8}$ in.	$\frac{1}{2}$ in. or less	...	200
10A Gr. 1	All welds, provided the procedure qualification is made using equal or greater thickness base material than the production weld	$\frac{5}{8}$ in. or less	...	200
	Attachment welds joining nonpressure-retaining material to pressure retaining material over $\frac{5}{8}$ in.	$\frac{1}{2}$ in. or less	0.25 or less	200

[Table NF-4622.7(b)-1 continues on next page]

TABLE NF-4622.7(b)-1 (CONT'D)
EXEMPTIONS TO MANDATORY PWHT¹

P-Number (Sect. IX, QW-420)	Type of Weld [Note (2)]	Nominal Thickness (NF-4622.3)	Max. Reported Carbon, % [Note (3)]	Min. Preheat Req'd, °F
10A Gr. 1 (cont'd)	All welds in pipes or tubes to pressure retaining material over $\frac{5}{8}$ in.	$\frac{1}{2}$ in. or less	0.25 or less	200
10C Gr. 1	All welds in materials over $1\frac{1}{2}$ in. and less	$1\frac{1}{4}$ in. and less	...	...
	Attachment welds joining nonpressure-retaining material to pressure retaining material over $1\frac{1}{4}$ in.	Over $1\frac{1}{4}$ in. To $1\frac{1}{2}$ in. $\frac{1}{2}$ in. or less		... 200 200
	Groove or fillet welds attaching nozzle connections not over 2 in. finished I.D. in material over $1\frac{1}{4}$ in., provided ligaments do not require an increased shell or head thickness	$\frac{1}{2}$ in. or less	...	200
10I Gr. 1	All welds in material $\frac{1}{2}$ in. and less	$\frac{1}{2}$ in. or less	...	...
11A Gr. 1	All welds in material $\frac{1}{2}$ in. and less	$\frac{1}{2}$ in. and less	...	...
11A Gr. 4	All welds in material $\frac{1}{2}$ in. and less	$\frac{1}{2}$ in. and less	...	250

NOTES:

(1) The exemptions noted in this Table do not apply to the following:

(a) electron beam welds in ferritic materials over $\frac{1}{8}$ in. in thickness;

(b) inertia and friction welds in material of any thickness of P-No. 3, P-No. 4, P-No. 5, P-No. 7 (except for Types 405 and 410S), P-No. 10, and P-No. 11 materials.

(2) Where the thickness of material is identified in the Type of Weld column, it is the thickness of the base material at the welded joint.

(3) Carbon level of the materials being joined.

TABLE NF-4622.7(b)-1 (CONT'D) EXEMPTION TO MANDATORY PWHT¹**NF-4623 PWHT Heating and Cooling Rate Requirements**

Above 800°F (427°C), the rate of heating and cooling in any hourly interval shall not exceed 400°F (222°C) divided by the maximum thickness in inches of the material being heat treated, but shall not exceed 400°F (222°C) and need not be less than 100°F (56°C) in any hourly interval. During the heating and cooling period there shall not be a greater variation in temperature than 250°F (139°C) within any 15 ft (4.6 m) interval of weld length. The exceptions of (a) and (b) below are permitted.

(a) P-No. 6 material may be cooled in air from the postweld heat treatment holding temperature specified in Table NF-4622.1-1.

(b) For P-No. 7 materials, the cooling rate at temperatures above 1200°F (649°C) shall not exceed 100°F/hr (56°C/hr) after which the rate of cooling shall be sufficiently rapid to prevent embrittlement.

NF-4624 Methods of Postweld Heat Treatment

The postweld heat treatment shall be performed in accordance with the requirements of one of the following subparagraphs.

NF-4624.1 Furnace Heating - One Heat.

Heating the support or item in a closed furnace in one heat is the preferred procedure and should be used whenever practical. The furnace atmosphere shall be controlled so as to avoid excessive oxidation, and direct impingement of flame on the support or item is prohibited.

NF-4624.2 Furnace Heating - More Than One Heat.

The support or item may be heated in more than one heat in a furnace, provided the furnace atmosphere control requirements of NF-4624.1 apply and overlap of the heated sections of the support or item is at least 5 ft (1.5 m). When this procedure is used, the portion of the support or item outside the furnace shall be shielded so that the temperature gradient is

Page 126

not harmful. The cross section where the support or item projects from the furnace shall not intersect a structural discontinuity.

NF-4624.3 Local Heating.

Welds may be locally postweld heat treated when it is not practical to heat treat the entire support or item. Local postweld heat treatment shall consist of heating a circumferential band around the support or item at temperatures within the ranges specified in this Subarticle. The minimum width of the controlled band at each side of the weld, on the face of the greatest weld width, shall be the thickness of the weld or 2 in. (51 mm), whichever is less. The temperature of the support or item from the edge of the controlled band outward shall be gradually diminished so as to avoid harmful thermal gradients. This procedure may also be used for postweld heat treatment after repairs.

NF-4624.4 Internal Heating.

The support or item may be heated internally by any appropriate means and with adequate indicating and recording temperature devices to aid in the control and maintenance of a uniform distribution of temperature in the support or item. Previous to this operation, the support or item should be fully enclosed with insulating material.

NF-4660 HEAT TREATMENT OF ELECTROSLAG WELDS

Electroslag welds in ferritic material over $1\frac{1}{2}$ in. (38 mm) in nominal thickness at the joints shall be given a grain refining heat treatment.

NF-4700 REQUIREMENTS FOR BOLTED CONSTRUCTION

NF-4710 BOLTING AND THREADING

NF-4711 Thread Engagement

The threads of all bolts or studs shall be engaged for the full length of thread in the load carrying nut unless otherwise specified in the Design Documents.

NF-4712 Thread Lubricants

Any lubricant or compound used in threaded joints shall be suitable for the service conditions and shall not react unfavorably with any support element material. Contact surfaces within friction-type joints shall be free of lubricants.

**TABLE NF-4721(a)-1
BOLT HOLE SIZES**

Bolt Size	Hole Size
≤ 1 in.	Bolt diameter plus $\frac{1}{16}$ in.
$1\frac{1}{8}$ in. to 2 in.	Bolt diameter plus $\frac{1}{8}$ in.
> 2 in.	Bolt diameter plus $\frac{3}{16}$ in.

TABLE NF-4721(a)-1 BOLT HOLE SIZES

NF-4713 Removal of Thread Lubricants

All threading lubricants or compounds shall be removed from surfaces which are to be welded.

NF-4720 BOLTING

NF-4721 Bolt Holes

For the purpose of this Article, high strength bolts shall be considered those with specified minimum yield strength greater than 80.0 ksi. Bolt holes shall meet the requirements of (a) through (e) below.

(a) Holes for nonfitted bolts shall meet the requirements of Table NF-4721(a)-1. For anchor bolts set in concrete or concrete expansion anchor, the hole sizes indicated in this Subsection may be increased by $\frac{1}{16}$ in. (1.6 mm). When the bolt hole size is $\frac{1}{8}$ in. (3.2 mm) larger than the bolt, and the bolt is $\frac{1}{2}$ in. (13 mm) or smaller, standard washers shall be used.

(b) Oversized or slotted bolt holes may be used with high strength bolts $\frac{1}{2}$ in. in diameter and larger, except as restricted in (1), (2), and (3) below.

(1) Oversized holes shall not exceed the requirements of Table NF-4721(b)-1. They may be used in any or all plies of friction-type connections. Hardened washers shall be installed over exposed oversized holes.

(2) Short-slotted holes shall not be wider than permitted by (a) above and shall not have a length exceeding the oversize diameter allowed in (1) above by more than $\frac{1}{16}$ in. (1.6 mm). They may be used in any or all plies of friction-type or bearing-type connections. The slots may be used without regard to direction of loading in friction-type connections, but shall be normal to the direction of the load in bearing-type connections. Hardened washers shall be installed over exposed short-slotted holes.

which exceeds $2\frac{1}{2}$ times the bolt diameter. In friction-type connections, the long-slotted holes may be used without regard to direction of loading, provided the stress on the bolts does not exceed 75% of the allowable working stress given in NF-3000. In bearing-type connections, the long diameter of the slot shall be normal to the direction of loading. Long-slotted holes may be used in only one of the connected parts of either a friction-type or bearing-type connection at an individual faying surface. Structural plate washers or a continuous bar not less than $\frac{5}{16}$ in. (8 mm) in thickness shall be used to cover long slots that are in the outer plies of joints. These washers or bars shall have a size sufficient to cover the slot completely after installation and shall meet the requirements of NF-3000.

**TABLE NF-4721(b)-1
TOLERANCES ON OVERSIZED HOLES**

Bolt Size	Hole Size
$\leq \frac{7}{8}$ in.	Bolt diameter plus $\frac{3}{16}$ in.
1 in.	Bolt diameter plus $\frac{1}{4}$ in.
> 1 in.	Bolt diameter plus $\frac{5}{16}$ in.

TABLE NF-4721(b)-1 TOLERANCES ON OVERSIZED HOLES

(c) Except as specified in (d) below, holes may be punched, provided the thickness of the material is not greater than the nominal diameter of the bolt plus $\frac{1}{8}$ in. (3.2 mm). When the thickness of the material is greater than the nominal diameter of the bolt plus $\frac{1}{8}$ in. (3.2 mm), holes shall be drilled, subpunched, and reamed, or thermally cut. Thermal cutting shall not be used unless the load bearing surfaces are machined or ground smooth. For subpunched holes, the die shall be at least $\frac{1}{16}$ in. (1.6 mm) smaller than the nominal diameter of the bolt.

(d) Bolt holes in material over $\frac{1}{2}$ in. (13 mm) thick having a specified minimum yield strength greater than 80.0 ksi (552 MPa) shall be drilled.

(e) For bolts not subjected to shear, the limits for oversized and slotted holes in (d) above may be increased if structural plate washers or continuous bars which meet the requirements of NF-3000 are provided.

NF-4722 Bolted Connections

(a) Surfaces of bolted parts in contact with the bolt head and nut shall not have a slope of more than 1:20 with respect to

a plane normal to the bolt axis. Where the surface of high strength bolted part has a slope of more than 1:20, a beveled washer shall be used to compensate for the lack of parallelism.

(b) Bolts loaded in pure shear shall not have threads located in the load bearing part of the shank unless permitted by the Design Specifications.

NF-4723 Precautions Before Bolting

All parts assembled for bolting shall have contact surfaces free from scale, chips, or other deleterious material. Surfaces and edges to be joined shall be smooth, uniform, and free from fins, tears, cracks, and other defects which would degrade the strength of the joint.

NF-4724 Bolt Tension

All high strength structural bolts shall be preloaded to a value not less than that given in the Design Specifications. Preloading shall be monitored by the turn of nut method, by properly calibrated wrenches, by load indicating washers, or by direct extension indicators. Bolts preloaded by means of a calibrated wrench shall be installed with a hardened washer under the nut or bolt head, whichever is the element turned in preloading. Hardened washers are required under the bolt head and the nut when the direct extension or load indicating washer method is used. Hardened washers are not required when bolts are preloaded by the turn of nut method, except that hardened washers are required under the nut and bolt head when the bolts are used to connect material having a specified yield strength less than 40.0 ksi (276 MPa).

NF-4725 Locking Devices

NF-4725.1 Types of Locking Devices.

Threaded fasteners shall be provided with locking devices to prevent loosening during service. Elastic stop nuts and thread locking compounds (when compatible with service conditions), lock nuts, including full or jam, slotted, drilled and wired, free spinning and prevailing torque are all acceptable locking devices. Upset threads by cold working or tack welding may serve as locking devices. Internally and externally toothed washers, and disk and helical spring lock washers shall not be used as locking devices.

NF-4725.2 Preloading of High Strength Fasteners.

Preloading threaded fasteners made of material with a yield strength of 80 ksi (552 MPa) or greater, loaded

Page 128

in tension, to a value at least 20% above the maximum load on the fastener for the specified loading conditions, limited to 70% of the specified minimum tensile strength of the fastener material satisfies the requirement for locking.

NF-4725.3 Preloading of Non-High Strength Fasteners.

When locking devices cannot be installed because of assembly geometry, preloading of the threaded fasteners in an assembly with fastener material of a yield strength below 80 ksi (552 MPa) is an acceptable method for locking provided the resulting preload is at least 20% above the maximum load on the fastener for the specified loading conditions, but is limited to 70% of the specified minimum tensile strength of the fastener. The threaded assembly shall be tested for the dynamic loading conditions specified in the Design Specification, and the established preload shall be verified on the assembly by properly calibrated wrenches, direct extension indicators, or the turn of the nut method. The results of the test, required preload, and specified thread lubrication shall be provided in the Design Report.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NF-5000

ARTICLE NF-5000 EXAMINATION

Page 129

NF-5100 GENERAL REQUIREMENTS FOR EXAMINATION

NF-5110 PROCEDURES, QUALIFICATIONS, AND EVALUATIONS

NF-5111 General Requirements

Nondestructive examinations shall be conducted in accordance with the examination methods of Section V, except as they may be modified by the requirements of this Article. Radiographic examination shall be in accordance with Section V, Article 2, except that the geometric unsharpness shall not exceed the limits of T-285. Ultrasonic examination shall be in accordance with Section V, Article 5; magnetic particle examination shall be in accordance with Section V, Article 7; liquid penetrant examination shall be in accordance with Section V, Article 6; and visual examination shall be in accordance with Section V, Article 9. The examinations required by this Article or by reference to this Article shall be performed by personnel who have been qualified as required by this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards of this Article.

NF-5112 Nondestructive Examination Procedures

All nondestructive examinations required by this Article shall be performed in accordance with detailed written procedures which have been proven by actual demonstration to the satisfaction of the Inspector. The procedures shall comply with the appropriate Article of Section V for the particular examination method. The digitization of radiographic film and radioscopy images shall meet the requirements of Section V, Article 2, Mandatory Appendix III, "Digital Image Acquisition, Display and Storage for Radiography and Radioscopy." Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Inspector on request. At least one copy of the procedure shall be readily available to all applicable nondestructive examination personnel for reference and use.

NF-5113 Post-Examination Cleaning

Following any nondestructive examination in which examination material is applied to the piece, the piece shall be thoroughly cleaned in accordance with applicable material or procedure specifications.

NF-5114 Rounding-Off of Weld Measurements

In order to properly evaluate specified dimensional sizes, measurements shall be rounded off to the nearest $\frac{1}{32}$ in. (0.8 mm) for undercut and $\frac{1}{16}$ in. (1.6 mm) for weld size. Other dimensions of welds shall be rounded off to the nearest $\frac{1}{8}$ in. (3.2 mm) or as otherwise specified in the design documents.

NF-5120 TIME OF EXAMINATION OF WELDS

Examinations of welds required by NF-5200 shall be performed at the times stipulated in (a) and (b) below during fabrication and installation.

(a) Radiography of welds may be performed prior to any postweld heat treatment.

(b) Magnetic particle or liquid penetrant examination shall be performed after any postweld heat treatment, except that welds in P-No. 1 material may be examined before or after postweld heat treatment.

Page 132

NF-5200 REQUIRED EXAMINATION OF WELDS

NF-5210 EXAMINATION OF CLASS 1 SUPPORT WELDS

NF-5211 Scope

The requirements of this subsubarticle shall apply to all Class 1 supports except that supports for Class 1 piping, NPS2 and less, may be examined by the rules of NF-5220.

NF-5212 Primary Member Welded Joints

- (a) All full penetration butt welded joints in primary members shall be examined by the radiographic method.
- (b) All other welded joints in primary members shall be examined by the liquid penetrant or magnetic particle method, except that the exposed ends of welds need only be visually examined.

NF-5213 Secondary Member Welded Joints

All welded joints in secondary members shall be examined by the visual method.

NF-5214 Special Requirements

For weldments that impose loads in the through thickness direction of primary members 1 in. and greater in thickness, the base material beneath the weld shall be ultrasonically examined, when required by NF-4440, over 100% of the referenced area using the procedure of SA-577 or SA-578, as detailed in Section V to the acceptance standards of NF-5332, except that a calibration block representative of the primary member shall be used. The block for straight beam examination shall have $\frac{1}{4}$ in. (6 mm) diameter flat-bottomed holes at one-fourth, one-half, and three-fourths of the thickness of the member being welded, from which a distance amplitude curve shall be established.

NF-5220 EXAMINATION OF CLASS 2 AND MC SUPPORT WELDS

NF-5221 Primary Member Welded Joints

- (a) All butt welded joints in primary members shall be examined by the liquid penetrant or magnetic particle method.
- (b) All partial penetration or fillet welds in primary members that have a groove depth or throat dimensions greater than 1 in. and T-welded joints welded with throat dimensions of $\frac{1}{2}$ in. or greater shall be examined by the liquid penetrant or magnetic particle method, except that the exposed ends of welds need only be visually examined.
- (c) All primary welds exclusive of those described in (a) and (b) above shall be examined by the visual method.

NF-5222 Secondary Member Welded Joints

All welded joints in secondary members shall be examined by the visual method.

NF-5224 Special Requirements

For weldments that impose loads in the through thickness direction of primary members 1 in. and greater in thickness, the base material beneath the weld shall be ultrasonically examined, when required by NF-4440, over 100% of the referenced area using the procedure of SA-577 or SA-578, as detailed in Section V to the acceptance standards of NF-5332, except that a calibration block representative of the primary member shall be used. The block for straight beam examination shall have $\frac{1}{4}$ in. diameter flat-bottomed holes at one-fourth, one-half, and three-fourths of the thickness of the member being welded, from which a distance amplitude curve shall be established.

NF-5230 EXAMINATION OF CLASS 3 SUPPORT WELDS

NF-5231 Primary Member Welded Joints

- (a) Primary member welded joints that have a groove depth or throat dimension greater than 1 in. shall be examined by the liquid penetrant or magnetic particle method, except that the exposed ends of welds need only be visually examined.
- (b) Primary welded joints exclusive of those described in (a) above shall be examined by the visual method.

NF-5232 Secondary Member Welded Joints

All welded joints in secondary members shall be examined by the visual method.

NF-5234 Special Requirements

For weldments that impose loads in the through thickness direction of primary members 1 in. and greater in thickness, the base material beneath the weld shall

Page 133

be ultrasonically examined, when required by NF-4440, over 100% of the referenced area using the procedure of SA-577 or SA-578, as detailed in Section V to the acceptance standards of NF-5332, except that a calibration block representative of the primary member shall be used. The block for straight beam examination shall have $\frac{1}{4}$ in. (6 mm) diameter flat-bottomed holes at one-fourth, one-half, and three-fourths of the thickness of the member being welded, from which a distance amplitude curve shall be established.

NF-5240 INERTIA AND CONTINUOUS DRIVE FRICTION WELDS

- (a) When radiographic examination is required by this Article, inertia and continuous drive friction welds shall also be examined by the ultrasonic method to verify bonding over the entire area.
- (b) The materials used shall be those assigned a P-Number by Section IX, but shall not include rimmed or semikilled steel.
- (c) One of the two parts to be joined must be held in a fixed position and the other part rotated. The two faces to be joined must be symmetrical with respect to the axis of rotation.
- (d) The weld between the two members shall be a full penetration weld.

NF-5300 ACCEPTANCE STANDARDS

NF-5320 RADIOGRAPHIC ACCEPTANCE STANDARDS

NF-5321 Evaluation of Indications

Indications shown on the radiographs of welds and characterized as imperfections are unacceptable under the following conditions:

- (a) any indication characterized as a crack or zone of incomplete fusion or penetration;
- (b) any other elongated indication which has a length greater than:
 - (1) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive
 - (2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (57 mm), inclusive
 - (3) $\frac{3}{4}$ in. for t over $2\frac{1}{4}$ in. (57 mm) where t is the thickness of the thinner portion of the weld;
- (c) internal root weld conditions are acceptable when the density change as indicated in the radiograph is not abrupt; elongated indications on the radiograph at either edge of such conditions shall be unacceptable, as provided in (b) above;
- (d) any group of aligned indications having an aggregate length greater than t in a length of $12t$ unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication;
- (e) rounded indications are not a factor in the acceptability of welds that are radiographed.

NF-5330 ULTRASONIC ACCEPTANCE STANDARDS

All imperfections which produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and evaluate them in terms of the acceptance standards as given in (a) and (b) below.

- (a) Imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths exceeding:
 - (1) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive
 - (2)

3 4 4

(3) $\frac{3}{4}$ in. for t over $2\frac{1}{4}$ in. (57 mm)

where t is the thickness of the weld being examined; if a weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses.

(b) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

NF-5332 Acceptance Standards for Laminar Indications

Any indication detected in the base material beneath the weld which is of a laminar type is unacceptable if the indication cannot be contained within a circle having a diameter equal to one-half of the thickness of the thinner of the members joined.

NF-5340 MAGNETIC PARTICLE ACCEPTANCE STANDARDS

NF-5341 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic

Page 134

permeability variations may produce similar indications which are not relevant.

(b) Any indication which is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. After an indication has been verified to be nonrelevant, it is not necessary to reinvestigate repetitive nonrelevant indications of the same type. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NF-5342 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks or linear indications;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);

(3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm), with the area taken in the most unfavorable location relative to the indications being evaluated.

NF-5350 LIQUID PENETRANT ACCEPTANCE STANDARDS

NF-5351 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities such as may occur from machining marks or surface conditions may produce similar indications which are not relevant.

(b) Any indication which is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NF-5352 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

- (1) any cracks or linear indications;
- (2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);
- (3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;
- (4) ten or more rounded indications in any 6 sq in. (3871 mm²) of surface with the major dimensions of this area not to exceed 6 in. (152 mm), with the area taken in the most unfavorable location relative to the indications being evaluated.

NF-5360 VISUAL ACCEPTANCE STANDARDS

When visual examination is performed in accordance with NF-5200, the acceptance standards shall be in accordance with the following.

(a) Cracks are unacceptable.

(b) A fillet weld is permitted to be less than the size specified by $\frac{1}{16}$ in. (1.6 mm) for one-fourth the length of the weld. Oversized fillet welds are acceptable if the oversized weld does not interfere with mating parts.

(c) In fillet welds, incomplete fusion of $\frac{3}{8}$ in. (10 mm) in any 4 in. (102 mm) segment, and $\frac{1}{4}$ in. (6 mm) in welds less than 4 in. (102 mm) long, is acceptable. For groove welds, incomplete fusion is not acceptable. For fillet and groove welds, rounded end conditions that occur in welding (starts and stops) shall not be considered indications of incomplete fusion and are irrelevant.

(d) Overlap is acceptable provided the criteria for weld size and fusion can be satisfied. When fusion in the overlap length cannot be verified, an overlap length of $\frac{3}{8}$ in. (10 mm) in any 4 in. (102 mm) segment, and $\frac{1}{4}$ in. (6 mm) in welds less than 4 in. (102 mm) long, is acceptable.

Page 135

(e) Craters are acceptable when the criteria for weld size are met. Craters that occur outside the specified weld length are irrelevant provided there are no cracks.

(f) Requirements for acceptability of undercuts are as follows:

(1) For material $\frac{3}{8}$ in. (10 mm) and less nominal thickness, undercut depth of $\frac{1}{32}$ in. (0.8 mm) on one side of the member for the full length of the weld, or $\frac{1}{32}$ in. (0.8 mm) on one side for one-half the length of the weld, and $\frac{1}{16}$ in. (1.6 mm) for one-fourth the length of the weld on the same side of the member is acceptable. For members welded on both sides where undercut exists in the same plane of a member, the cumulative lengths of undercut are limited to the lengths of undercut allowed on one side. Melt-through that results in a hole in the base metal is unacceptable.

(2) For material greater than $\frac{3}{8}$ in. (10 mm) nominal thickness, undercut depth of $\frac{1}{32}$ in. (0.8 mm) for the full length of the weld and $\frac{1}{16}$ in. (1.6 mm) for one-fourth the length of the weld on both sides of the member is acceptable. When either welds or undercut exist only on one side of the member or are not in the same plane, the allowable undercut depth of $\frac{1}{32}$ in. (0.8 mm) may be increased to $\frac{1}{16}$ in. (1.6 mm) for the full length of the weld.

(g) Only surface porosity whose major surface dimension exceeds $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant. Fillet and groove welds that contain surface porosity are unacceptable if:

(1) the sum of diameters of random porosity exceeds $\frac{3}{8}$ in. (10 mm) in any linear inch of weld or $\frac{3}{4}$ in. (19 mm) in any 12 in. (305 mm) of weld; or

(2) four or more pores are aligned and the pores are separated by $\frac{1}{16}$ in. (1.6 mm) or less, edge to edge.

(h) The length and location of welds shall be as specified on the detail drawing, except that weld lengths may be longer than specified. For weld lengths less than 3 in. (76 mm), the permissible underlength is $\frac{1}{8}$ in. (3.2 mm), and for welds 3 in. (76 mm) and longer, the permissible underlength is $\frac{1}{4}$ in. (6 mm). Intermittent welds shall be spaced within 1 in. (25 mm) of the specified location.

(i) Arc strikes and associated blemishes on the weld or in the base material are acceptable provided no cracking is visually detected.

(j) Slag whose major surface dimension is $\frac{1}{8}$ in. (3.2 mm) or less is irrelevant. Isolated surface slag that remains after weld cleaning and does not exceed $\frac{1}{4}$ in. (6 mm) in its major surface dimension is acceptable. [Slag is considered to be isolated when it does not occur more frequently than once per weld or more than once in a 3 in. (76 mm) weld segment.] Spatter remaining after the cleaning operation is acceptable.

NF-5400 ADDITIONAL EXAMINATION REQUIREMENTS FOR STANDARD SUPPORTS

NF-5410 REQUIRED EXAMINATION AND ACCEPTANCE STANDARDS FOR CLASS 1 SPRINGS

Springs for Class 1 variable, constant, and sway standard supports shall be examined after coiling by either the magnetic particle or liquid penetrant method. Linear indications shall be removed by grinding and blending. If the depth of the ground area exceeds 3% of the bar diameter or thickness, the spring shall be rejected.

NF-5420 REQUIRED EXAMINATION AND ACCEPTANCE STANDARDS FOR COILED WIRE ROPE USED AS A SPRING

Coiled wire rope used as a spring shall be visually examined after coiling and shall be free from kinks, loose strands, loose wires, or broken protruding wires.

NF-5500 QUALIFICATIONS AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

NF-5510 GENERAL REQUIREMENTS

Organizations performing Code required nondestructive examinations shall use personnel competent and knowledgeable to the degree specified by NF-5520. When these services are subcontracted by the Certificate Holder or Quality System Certificate Holder, he shall verify the qualification of personnel to the requirements of NF-5520. All nondestructive examinations required by this Subsection shall be performed by and the results evaluated by qualified nondestructive examination personnel.

NF-5520 PERSONNEL QUALIFICATION, CERTIFICATION, AND VERIFICATION

NF-5521 Qualification Procedure

(a) Personnel performing nondestructive examinations shall be qualified in accordance with the recommended

Page 136

guidelines of SNT-TC-1A.¹² The Employer's³ written practice required by paragraph 5 of SNT-TC-1A shall identify Employer requirements relative to the recommended guidelines. The recommended guidelines of SNT-TC-1A shall be considered minimum requirements except as modified in (1) through (5) below.

(1) Qualification of level III nondestructive examination personnel shall be by examination.

(a) The basic and method examinations, paragraphs 8.8(1) and 8.8(2) of SNT-TC-1A, may be prepared and administered by the Employer, ASNT, or an outside agency.

(b) The specific examinations, paragraph 8.8(3) of SNT-TC-1A, shall be prepared and administered by the Employer

or an outside Agency. The employer or outside agency administering the specific examination shall identify the minimum grade requirement in a written program when the basic and method examinations have been administered by ASNT which issues grades on a pass/fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(2) The written practice identified in paragraph 5 of SNT-TC-1A and the procedures used for examination of personnel shall be referenced in the Employer's Quality Program.

(3) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform a nondestructive examination of limited scope, may be less than that recommended in Table 6.3.1 of SNT-TC-1A. The training and experience times shall be described in the written practice and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate.

(a) The minimum classroom training time identified in Table SNT-TC-1A may be reduced from 8 and 16 hr to 4 and 8 hr, respectively, for visual examination personnel.

1 SNT-TC-1A is a Recommended Practice for Nondestructive Testing Personnel Qualification and Certification published by the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, Ohio 43228-0518. SNT-TC-1A-1992 is the applicable edition.

2 Personnel qualified by examination and certified to previous editions of SNT-TC-1A are considered to be qualified to the 1992 edition when the recertification is based on continuing satisfactory performance. All reexaminations and new examinations shall be in accordance with the 1992 edition.

3 Employer as used in this Article shall include: N Certificate Holders; Material Organizations' Certificate Holders; Material Organizations who are qualified in accordance with NCA-3862(a)(1); and organizations who provide subcontracted nondestructive examination services to organizations described above.

(4) For visual examination, the Jaeger Number 1 letters shall be used in lieu of the Jaeger Number 2 letters specified in paragraph 8.2(1) of SNT-TC-1A. The use of equivalent type and size letters is permitted.

(5) A Level I individual shall be qualified to perform specific setups, calibrations, and tests, and to record and evaluate data by comparison with specific acceptance criteria defined in written instructions. The Level I individual shall implement these written NDE instructions under the guidance of a Level II or III individual. A Level I individual may independently accept the results of nondestructive examinations when the specific acceptance criteria are defined in the written instructions.

(b) For nondestructive examination methods not covered by SNT-TC-1A documents, personnel shall be qualified to comparable levels of competency by subsection to comparable examinations on the particular method involved.

(c) The emphasis shall be on the individual's ability to perform the nondestructive examination in accordance with the applicable procedure for the intended application.

(d) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use personnel qualified to perform one or more operations. As an example, one person may be used who is qualified to conduct radiographic examination and another may be used who is qualified to interpret and evaluate the radiographic film.

NF-5522 Certification of Personnel

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of Level I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations [NF-5521(a)(1)(a)], the Employer may use a letter from ASNT as evidence on which to base the certification.

(c) When an outside agency is the examining agent for Level III qualification of the Employer's personnel, the examination results shall be included with the Employer's record.

NF-5523 Verification of Nondestructive Examination Personnel Certification

The Certificate Holder has the responsibility to verify the qualification and certification of nondestructive examination personnel employed by Material Organizations qualified by them in accordance with NCA 3820,

and subcontractors who provide nondestructive examination services to them.

NF-5530 RECORDS

Personnel qualification records identified in paragraph 9.4 of SNT-TC-1A shall be retained by the Employer.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NF-8000

ARTICLE NF-8000 CERTIFICATES OF AUTHORIZATION,
NAMEPLATES, STAMPING, AND DATA REPORTS

NF-8100 GENERAL REQUIREMENTS

The requirements for certificates of authorization, nameplates, stamping, and data reports shall be as specified in NCA-8000 and shall apply only to those items fabricated under an NCA-4000 Quality Assurance Program. Stamping is not required for supports supplied as material items, except for tubular products welded with filler metal.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NF SI UNITS

SI UNITS

The 1998 Edition of the Boiler and Pressure Vessel Code is based on U.S. Customary (ft-lb) units of measurement which are to be regarded as the standard. This supplement is provided as a convenience to the Code user and contains SI conversion factors for units contained in the Code.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

Quantity	Unit	Symbol	Other Units or Limitations
Space and Time			
plane angle	radian	rad	degree (decimalized)
length	meter	m	
area	square meter	m ²	
volume	cubic meter	m ³	liter (L) for liquid only (use without prefix other than in milliliter, mL)
time	second	s	minute (min), hour (h), day (d), week, and year
Periodic and Related Phenomena			
frequency	hertz	Hz	revolutions per second (r/s)
rotational frequency	revolutions per second	s ⁻¹	revolutions per minute (r/m)
Mechanics			
mass	kilogram	kg	
density	kilogram per cubic meter	kg/m ³	
moment of inertia	kilogram · meter ²	kg · m ²	
force	newton	N	
moment of force (torque)	newton-meter	N · m	
pressure and stress	pascal	Pa	(pascal = newton per square meter)
energy, work	joule	J	kilowatt-hour (kW · h)
power	watt	W	
impact strength	joule	J	
section modulus	meter ³	m ³	
moment of section (second moment of area)	meter ⁴	m ⁴	
fracture toughness	Pa · $\sqrt{m}$		
Heat			
temperature — thermodynamic [Note (2)]	kelvin	K	degree Celsius (°C)
temperature — other than thermodynamic	degree Celsius	°C	kelvin (K)
linear expansion coefficient	meter per meter-kelvin	K ⁻¹	°C ⁻¹
quantity of heat	joule	J	
heat flow rate	watt	W	
thermal conductivity	watt per meter-kelvin	W/(m · K)	W/(m · °C)
thermal diffusivity	square meter per second	m ² /s	
specific heat capacity	joule per kilogram-kelvin	J/(kg · K)	J/(kg · °C)
Electricity and Magnetism			
electric current	ampere	A	
electric potential	volt	V	
current density	ampere per meter ²	A/m ²	
magnetic field strength	ampere per meter	A/m	

NOTES:

- (1) Conversion factors between SI units and U.S. customary are given in SI-1, "ASME Orientation and Guide for Use of SI (Metric) Units," and ASTM E 380.
- (2) Preferred use for temperature and temperature interval is degrees Celsius (°C), except for thermodynamic and cryogenic work where kelvins may be more suitable. For temperature interval, 1 K = 1°C exactly.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

COMMONLY USED CONVERSION FACTORS
(For Others See ASTM E 380) [See Note (1)]

Quantity	To Convert From	To	Multiply by [Note (2)]	
plane angle	degree	rad	1.745 329	E-02
length	in	m	2.54*	E-02
	ft	m	3.048*	E-01
	yd	m	9.144*	E-01
area	in ²	m ²	6.451 6*	E-04
	ft ²	m ²	9.290 304*	E-02
	yd ²	m ²	8.361 274	E-01
volume	in ³	m ³	1.638 706	E-05
	ft ³	m ³	2.831 685	E-02
	US gallon	m ³	3.785 412	E-03
	Imperial gallon	m ³	4.546 09	E-03
	liter	m ³	1.0*	E-03
mass	lbm	kg	4.535 924	E-01
	ton (metric) (mass)	kg	1.000 00*	E+03
	ton (short 2000 lbm)	kg	9.071 847	E+02
force	kgf	N	9.806 65*	E+00
	lbf	N	4.448 222	E+00
bending, torque	kgf · m	N · m	9.806 65*	E+00
	lbf · in	N · m	1.129 848	E-01
	lbf · ft	N · m	1.355 818	E+00
pressure, stress	kgf/m ²	Pa	9.806 65*	E+00
	lbf/ft ²	Pa	4.788 026	E+01
	lbf/in ² (psi)	Pa	6.894 757	E+03
	kips/in ²	Pa	6.894 757	E+06
	bar	Pa	1.0*	E+05
energy, work	Btu (IT) [Note (3)]	J	1.055 056	E+03
	ft · lbf	J	1.355 818	E+00
power	hp (550 ft · lbf/s)	W	7.456 999	E+02
fracture toughness	ksi $\sqrt{\text{in}}$	Pa · $\sqrt{\text{m}}$	1.098 843	E+06
temperature	°C	K	$t_K = t_C + 273.15$	
	°F	K	$t_K = (t_F + 459.67)/1.8$	
	°F	°C	$t_C = (t_F - 32)/1.8$	
temperature interval	°C	K	1.0*	E+00
	°F	K or °C	5.555 555	E-01

NOTES:

- (1) Care should be taken when converting formulas or equations that contain constant terms or factors. The value of these terms must be understood and may also require conversion.
- (2)(a) Relationships that are exact in terms of the base units are followed by a single asterisk.
 (b) The factors are written as a number greater than 1 and less than 10 with 6 or less decimal places. The number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example: 3.523 907 E-02 is $3.523\ 907 \times 10^{-2}$ or 0.035 239 07.
- (3) International Table

COMMONLY USED CONVERSION FACTORS

July 1, 1998
American Society Of Mechanical Engineers
SEC III D1 MA APP NF-I
APPENDIX NF-I

Page 143

(In the Course of Preparation)

July 1, 1998
American Society Of Mechanical Engineers
SEC III D1 MA APP NF-II
APPENDIX NF-II DESIGN OF SINGLE ANGLE MEMBERS

Page 147

Page 149

ARTICLE NF-II-1000 INTRODUCTION

NF-II-1100 SCOPE

This Mandatory Appendix provides design rules for single angle members that are used in Section III, Division 1 Class 1, 2, 3, and MC linear component support construction.

NF-II-1200 GENERAL REQUIREMENTS

The requirements of Article NF-3000 shall be met except as modified by this Appendix.

Page 150

ARTICLE NF-II-2000 NOMENCLATURE

Nomenclature is given in NF-3313 except as noted in NF-II-3200 to NF-II-3600.

Page 151

ARTICLE NF-II-3000 DESIGN REQUIREMENTS

NF-II-3100 GENERAL

Single angle members are designed in accordance with NF-II-3200 to NF-II-3600.

NF-II-3200 TENSION

The allowable tension stress F_t shall not exceed $0.6S_y$ on the gross area A_g , nor $0.50S_u$ on the effective net area A_e .

(a) For members connected by bolting, the net area and effective net area shall be determined from NF-3322.8

(b) When the load is transmitted by longitudinal or combination of longitudinal and transverse welds through just one leg of the angle, the effective net area shall be:

$$(1) A_e = 0.85 A_g$$

(c) When the load is transmitted by transverse weld through just one leg of the angle, A_e is the area of the connected leg.

NF-II-3300 SHEAR

The allowable shear stress due to flexure and torsion shall be:

$$(2) F_v = 0.4S_y$$

NF-II-3400 COMPRESSION

The allowable compressive stress on the gross area of axially compressed members shall be:

when $Kl/r < C_c$

$$F_a = \frac{Q \left[1 - \frac{(Kl/r)^2}{2C_c'^2} \right] S_y}{5/3 + 3/8 \left(\frac{Kl/r}{C_c'} \right) - \frac{(Kl/r)^3}{8C_c'^3}} \quad (3)$$

(3)

when $Kl/R > C_c$

$$F_a = \frac{12 \pi^2 E}{23 (Kl/r)^2} \quad (4)$$

(4)

where

Kl/r

= largest effective slenderness ratio of any unbraced length as defined in NF-3322.2

$$C'_c = \sqrt{\frac{2 \pi^2 E}{Q S_y}}$$

The reduction factor Q shall be:

when $b/t \leq 76/\sqrt{S_y}$

$$(5) Q = 1$$

when $76/\sqrt{S_y} < b/t < 155/\sqrt{S_y}$

$$(6) Q = 1.340 - 0.00447 (b/t) \sqrt{S_y}$$

when $b/t \geq 155/\sqrt{S_y}$

$$(7) Q = 15,500/[S_y(b/t)^2]$$

where

b = full width of the longest angle leg

t = thickness of angle

For short, thin, or unequal leg angles, flexural-torsional buckling may produce a significant reduction in strength.

Page 152

In such cases, the allowable stress shall be determined by the previous equations substituting an equivalent slenderness ratio $(Kl/r)_{\text{equiv}}$ for Kl/r

$$(Kl/r)_{\text{equiv}} = \pi \sqrt{E/F_e}$$

where F_e is the elastic buckling strength for the flexural-torsional mode.

(a) For equal leg angles with w as the axis of symmetry:

$$F_e = \frac{F_{ew} + F_{ej}}{2H} \left[1 - \sqrt{1 - \frac{4 F_{ew} F_{ej} H}{(F_{ew} + F_{ej})^2}} \right]$$

(b) For unequal leg angles, F_e is the lowest root of the cubic equation:

$$(F_e - F_{ez})(F_e - F_{ew})(F_e - F_{ej}) - F_e^2(F_e - F_{ew})(z_o/\bar{r}_o)^2 - F_e^2(F_e - F_{ez})(w_o/\bar{r}_o)^2 = 0$$

where

E	= modulus of elasticity, ksi
G	= shear modulus, ksi
J	= torsional constant = $2bt^3/3 = t^3A/3$, in. ⁴
I_z, I_w	= moment of inertia about <i>principal</i> axes, in. ⁴
z_o, w_o	= coordinates of the shear center with respect to the centroid, in.

$$\bar{r}_o^2 = z_o^2 + w_o^2 + (I_z + I_w)/A, \text{ in.}^2; \quad I_z + I_w = I_x + I_y$$

$$H = 1 - (z_o^2 + w_o^2)/\bar{r}_o^2 = (I_z + I_w)/A\bar{r}_o^2$$

A	= cross-sectional area, in. ²
l	= unbraced length, in.
K_z, K_w	= effective length factors
r_z, r_w	= radii of gyration about principal axes

For members whose design is based on compressive force, the largest effective slenderness ratio preferably should not exceed 200.

NF-II-3500 FLEXURE

The allowable bending stress limits of NF-II-3510 shall be used as indicated in NF-II-3520 and NF-II-3530.

NF-II-3510 ALLOWABLE BENDING STRESS

The allowable bending stress, F_b , is a function of the unbraced length to width ratio (l/b) and the width to thickness ratio (b/t) of the single angle member.

For equal leg angles fabricated from materials with a minimum specified yield strength of 36 ksi and 50 ksi, Fig. NF-II-3510 may be used to determine the limiting combination of l/b and b/t for which F_b is equal to $0.66S_y$. For equal leg angles not meeting the limits of Fig. NF-II-3510 and for unequal leg angles, the bending stress is limited to the minimum allowable value F_b determined from NF-II-3511, NF-II-3512, and NF-II-3513 as applicable.

NF-II-3511

To prevent local buckling when the tip of an angle leg is in compression.

when $b/t \leq 65/\sqrt{S_y}$:

$$(8) F_b = 0.66S_y$$

when $65/\sqrt{S_y} < b/t \leq 76/\sqrt{S_y}$:

$$(9) F_b = 0.60S_y$$

when $b/t > 76/\sqrt{S_y}$:

$$(10) F_b = 0.60Q S_y$$

where

b = full width of angle leg in compression

Q = stress reduction factor per Eqs. (5), (6), and (7) with b as defined above

An angle leg shall be considered to be in compression if the tip of the angle leg is in compression, in which case the calculated stress f_b at the tip of this leg is used.

NF-II-3512

For the tip of an angle leg in tension

$$(11) F_b = 0.66S_y$$

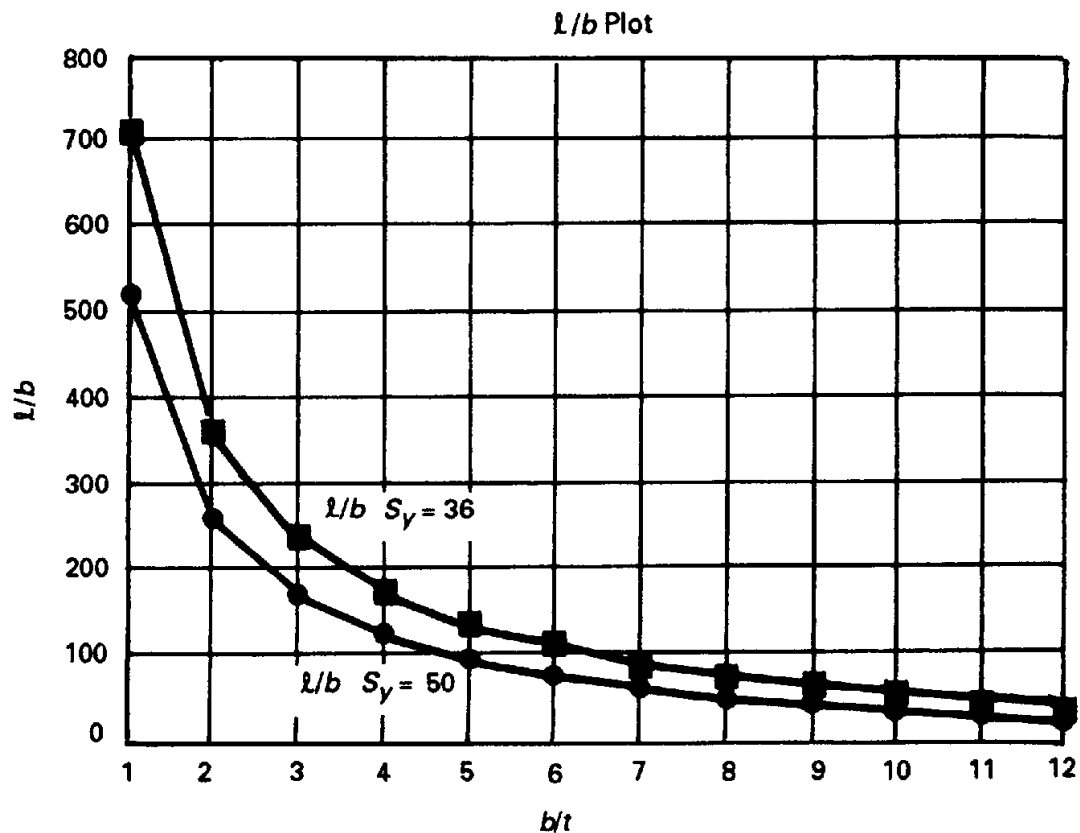


FIG. NF-II-3510 EQUAL LEG SINGLE ANGLE LIMITS FOR $F_b = 0.66S_y$
(Reprinted with Permission of AISC)

FIG. NF-II-3510 EQUAL LEG SINGLE ANGLE LIMITS FOR $F_b = 0.66S_y$

NF-II-3513

To prevent lateral-torsional buckling, the maximum compression stress shall not exceed:

when $F_{ob} \leq S_y$

$$(12) F_b = [0.55 - 0.10 F_{ob}/S_y] F_{ob}$$

when $F_{ob} > S_y$

$$(13) F_b = [0.95 - 0.50 \sqrt{S_y/F_{ob}}] S_y \leq 0.66S_y$$

where

F_b

= allowable bending stress at leg tip, ksi

F_{ob}

= elastic lateral-torsional buckling stress, from NF-II-3520 or NF-II-3530 as applicable, ksi

S_y

= yield stress, ksi

NF-II-3520 BENDING ABOUT GEOMETRIC AXES

NF-II-3521

(a) Angle bending members with lateral-torsion restraint along the length may be designed on the basis of geometric axis bending with stress limited by the provisions of NF-II-3511 and NF-II-3512.

(b) For equal leg angles if the lateral-torsional restraint is only at the point of maximum moment, the stress f_b is calculated on the basis of geometric axis bending limited by F_b in NF-II-3522.

NF-II-3522

Equal leg angle members without lateral-torsional restraint subjected to flexure applied about one of the geometric axes may be designed considering only geometric axis bending provided:

(a) The calculated compressive stress f_b using the geometric axis section modulus, is increased by 25%.

(b) For the angle leg tips in compression, the allowable bending stress F_b is determined according to NF-II-3513, where

$$F_{ob} = \frac{85,900}{(l/b)^2} C_b \left[\sqrt{1 + 0.78 (lt/b^2)^2} - 1 \right] \quad (14)$$

(14)

Page 154

and by b/t provisions in NF-II-3511. When the leg tips are in tension, F_b is determined only by NF-II-3512.

l = unbraced length, in.

C_b = $1.75 + 1.05(M_1/M_2) + 0.3(M_1/M_2)^2 \leq 1.5$, where M_1 is the smaller and M_2 the larger end moment in the unbraced segment of the beam; (M_1/M_2) is positive when the moments cause reverse curvature and negative when bent in single curvature. C_b shall be taken as unity when the bending moment at any point within an unbraced length is larger than at both ends of its length.

NF-II-3523

Unequal leg angle members without lateral-torsional restraint subjected to bending about one of the geometric axes shall be designed using NF-II-3530.

NF-II-3530 BENDING ABOUT PRINCIPAL AXES

Angles without lateral-torsional restraint shall be designed considering principal axis bending except for cases covered by NF-II-3522. Bending about both of the principal axes shall be evaluated using the interaction equations in NF-3322.1

(e)(1).

NF-II-3531 Equal Leg Angles

(a) *Major Axis Bending.* The principal bending compression stress f_{bw} shall be limited by F_b in NF-II-3513, where

$$F_{ob} = C_b \frac{28,250}{(l/t)} \quad (15)$$

(15) and by b/t provisions in NF-II-3511.

(b) *Minor Axis Bending.* The principal bending stress f_{bz} shall be limited by F_b in NF-II-3511 when the leg tips are in compression, and by NF-II-3512 when the leg tips are in tension.

[98]

NF-II-3532 Unequal Leg Angles

(a) *Major Axis Bending.* The principal bending compression stress f_{bw} shall be limited by F_b in NF-II-3513, where

$$F_{ob} = \frac{143,100 I_z}{S_w l^2} C_b \left[\sqrt{B_w^2 + 0.052 (lt/r_z)^2} + B_w \right] \quad (16)$$

(16) and by b/t provisions in NF-II-3511 for the compression leg.

S_w	= section modulus to tip of leg in compression, in. ³
I_z	= minor principal axis moment of inertia, in. ⁴
r_z	= radius of gyration for minor principal axis, in.

$$B_w = \left[\frac{1}{I_w} \int_A z (w^2 + z^2) dA \right] - 2z_o$$

= special section property for unequal leg angles, positive for short leg in compression and negative for long leg in compression, in. Table NF-II-3532-1 lists some values for standard angles. If the long leg is in compression anywhere along the unbraced length of the member, use the negative value of B_w .

z_o

= coordinate along z axis of the shear center with respect to centroid, in.

I_w

= major principal axis moment of inertia, in.⁴

TABLE NF-II-3532-1
 B_w VALUES FOR ANGLES

Angle Size, in.	B_w , in.
9 × 4	6.54
8 × 6	3.31
8 × 4	5.48
7 × 4	4.37
6 × 4	3.14
6 × 3.5	3.69
5 × 3.5	2.40
5 × 3	2.99
4 × 3.5	0.87
4 × 3	1.65
3.5 × 3	0.87
3.5 × 2.5	1.62
3 × 2.5	0.86
3 × 2	1.56
2.5 × 2	0.85
Equal legs	0.00

TABLE NF-II-3532-1 B_w VALUES FOR ANGLES

(b) *Minor Axis Bending.* The principal bending stress f_{bz} shall be limited by F_b in NF-II-3511 when leg tips are in compression and by NF-II-3512 when the leg tips are in tension.

[98]

NF-II-3600 COMBINED STRESSES

NF-II-3610 AXIAL COMPRESSION AND FLEXURE

Members subjected to both axial compression and bending shall satisfy the requirements of NF-3322.1(e)(1).

Page 155

NF-II-3611

In evaluating Eqs. (20) or (22) of NF-3322.1(e)(1) the maximum compression bending stresses due to each moment acting alone must be used even though they may occur at different cross sections of the member.

NF-II-3612

Equation (21) of NF-3322.1(e)(1) is to be evaluated at the critical member support cross section and need not be based on the maximum moments along the member length.

NF-II-3613

For members constrained to bend about a geometric axis with compressive stress and allowable stress determined per NF-II-3521(a), the radius of gyration r_b for F_e' shall be taken as the geometric axis value.

NF-II-3614

For equal leg angles without lateral-torsional restraint along the length and with bending applied about one of the geometric axes, the provisions of NF-II-3522 shall apply for the calculated and allowable bending stresses. If NF-II-3521 (b) or NF-II-3522 is used for F_b , the radius of gyration about the axis of bending r_b for F_e' shall be taken as the geometric axis value of r divided by 1.35 in the absence of a more detailed analysis.

NF-II-3615

For members that do not meet the conditions of NF-II-3613 or NF-II-3614, the evaluation shall be based on principal axis bending according to NF-II-3530, and the subscripts x and y in NF-3322.1(e)(1) shall be interpreted as the principal axes, w and z , in this Appendix when evaluating the length without lateral-torsional restraint.

NF-II-3620 AXIAL TENSION AND BENDING

Members subjected to both axial tension and bending stresses due to transverse loading shall satisfy the requirements of Eq. (22) of NF-3322.1(e)(1). Bending stress evaluation shall be as directed by NF-II-3613, NF-II-3614, and NF-II-3615 for compressive stresses.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 MA APP NF-III

APPENDIX NF-III ENERGY ABSORBING SUPPORT MATERIAL

Page 157

[98]

ARTICLE NF-III-1000 GENERAL REQUIREMENTS

Energy absorbing material of linear-type pipe supports designed to Subsection NF which is designed to dissipate energy associated with dynamic piping movements by yielding, shall be constructed for services in accordance with Section III, Division 1, Subsection NF, as modified by this Appendix.

[98]

Page 160

[98]

ARTICLE NF-III-2000 MATERIAL REQUIREMENTS

(a) When plate material is used, it shall not exceed 1 in. nominal thickness.

(b) Weld repairs of energy absorbing materials shall not be permitted.

(c) In lieu of NF-2311(a)(3), impact testing shall be in accordance with NF-2300. For SA-516 material, impact testing shall be required when the nominal section thickness exceed $\frac{5}{8}$ in. and the lowest service temperature is less than the values listed below:

Class	Normalized	As Rolled
Class 1, 2, and MC	30°F	70°F
Class 3	0°F	50°F

(d) All other requirements of NF-2000 shall apply.

[98]

Page 161

[98]

ARTICLE NF-III-3000 DESIGN

For the design of energy absorbing support material that perform by sustaining strains beyond elastic limits, the following rules shall apply in lieu of those in NF-3140 and NF-3300.

(a) *Fatigue Design*

(1) Energy absorbing support material may be designed by load rating. The load rating of these parts shall provide for a relationship between imposed strains and the allowable number of cycles.

(2) Cumulative fatigue effects associated with all strain cycles expected for the life of the energy absorbing support parts resulting from all service loadings shall be evaluated as follows:

$$\sum \frac{n_{ti}}{N_{ti}} + \sum \frac{n_{dj}}{N_{dj}} \leq 1$$

where

n_{dj}	= expected number of cycles associated with dynamic load, j
n_{ti}	= expected number of cycles associated with the supported piping system in going from one service temperature to another, i
N_{dj}	= allowable number of cycles read from the design fatigue curve, as defined below, corresponding to the amplitude of the strain induced by the dynamic load, j
N_{ti}	= allowable number of cycles read from the design fatigue curve, as defined below, corresponding to the amplitude of the strain induced by the dynamic load, i

(b) *Design Fatigue Curves.* Design fatigue curves based on testing of prototypical samples of energy absorbers shall be developed and used in the fatigue design. Samples tested shall represent the material used for construction, shapes used, and methods of fabrication. The fatigue design curves shall show a relationship between the amplitude of strain (ϵ) and the allowable number of cycles (N). The ordinate shall show the value of strain, ϵ , and the abscissa shall show the allowable number of cycles, N , calculated as follows:

$$N_{\text{mean}}/1.5 \text{ or } (N_{\text{mean}} - \sigma \times 2)$$

whichever is smaller, where

N_{mean}	= mean number of cycles to failure of specimen tested at strain value, ϵ
σ	= maximum deviation

(c) *Dead Weight Consideration.* Loads induced by the dead weight effect of a supported piping system should not exceed one-fifth of the elastic yield load capacity of the energy absorbing supports. The elastic yield load shall be based on the yield strength given in Appendix I (Section III, Division 1, Appendices) for the material of the energy absorbing parts.

(d) *Steady State Vibration Consideration.* Operational steady state vibration effects on the energy absorbing support parts, if present, shall be maintained within the endurance limit from the applicable fatigue design curves of Appendix I (Section III, Division 1, Appendices).

(e) *Piping Design Consideration.* The inelastic characteristics of energy absorbing support parts shall be considered in satisfying all design and service loadings for which the supported piping is evaluated.

[98]

Page 162

[98]

ARTICLE NF-III-4000 FABRICATION

(a) Welding shall not be permitted for fabrication and installation of energy absorbing support material.

(b) All other requirements of NF-4000 shall apply.

[98]

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP NF-A

APPENDIX NF-A STRUCTURAL BOLT PRELOADING

NONMANDATORY

APPENDICES

Page 165

ARTICLE NF-A-1000 INTRODUCTION

NF-A-1100 SCOPE

This Appendix provides general guidance on structural bolt preloading of steel to steel joints. AISC specifications should be followed when using A490 or A325 bolts. For other bolting materials, detailed specifications are not generally available and the following discussion is to be used in understanding the importance of proper tightening, and to help select a reliable method to be employed where detailed specifications are not available.

NF-A-1200 DISCUSSION

The American Institute of Steel Construction (AISC) provides a rather detailed specification when using A490 or A325 bolts. The AISC specification provides guidance with regard to:

- (a) bolt and nut specification;
- (b) washers;
- (c) faying surface coatings;
- (d) surface conditions;
- (e) hole types and tolerances;
- (f) allowable strengths and working stresses;
- (g) bearing force;
- (h) prying action;
- (i) tensile fatigue;

- (j) definition of "slip critical" joints;
- (k) allowable slip load; and
- (l) reuse of bolts.

It provides guidance for installation and tightening including: discussion of what is required for a tension calibrator; joint assembly for bearing loading; joint assembly for joints requiring full pretensioning; turn-of-the-nut tightening; and calibrated torque wrench tightening.

It should be noted that AISC (Ninth Edition) does not recommend use of torque wrenches as the preferred method of bolt tightening. Rather, it recommends turn-of-the-nut over the torque wrench method. This is true because of the variations in tension that are expected due to the many variables that are present in tensioning by use of a torque wrench. For "turn-of-the-nut" it provides a table for required turns for various diameters and squareness conditions of the bolted parts.

AISC also requires that torque wrenches are calibrated every day that they are used.

The following clarifies why such large variations are expected from bolt tensioning by use of a torque wrench.

The major consideration in any fastening problem is to determine as accurately as possible the best kind of fastener which, when properly tightened, will ensure engineering reliability of the end product. Reliability of threaded fasteners that will be subjected to cyclic/vibratory loads is based largely on the torque-tension relationship in which tension (preload as it is commonly called), not torque, is the most critical measurement.

Preload induced in a fastener is best set within an optimum range which is determined from maximum and minimum values of the variable joint loading. Too little preload will allow stress fluctuations in the joint which lead to fatigue failure. Too much preload may cause fracture or plastic elongation with resulting loss of clamping force.

Several methods are available for measuring preload. These are listed below with cost and anticipated accuracy.

Preload Measuring Method	Accuracy (%)	Relative Cost
Feel (operator's judgement)	±35	1
Torque wrench	±25	1½
Turn-of-the-nut	±15	3
Load-indicating washers	±10	7
Fastener elongation	±3 to 5	15
Strain gauges	±1	20

(REF: Industrial Fastener Institute.)

Improved accuracy incurs higher cost in assembly, for example, the use of strain gages would be approximately

20 times more expensive than merely relying upon the judgment and feel of the operator.

Each method possesses certain advantages and disadvantages with ultimate choice based on a compromise of application requirements.

NF-A-1300 BOLT TIGHTENING (PRELOAD METHODS)

NF-A-1310 TORQUE WRENCHES

The use of torque wrenches is the most popular method of preload measurement because of simplicity. Because of the many interrelated variables that directly or indirectly affect friction, such as: surface texture, type of coating or finish, amount of lubrication, speed of tightening, etc., it is possible to experience as much as ±25% variation in preload between similar fasteners receiving identical torques. Closer control of torque wrench calibration can reduce deviation to ±15%.

In all cases, hardened washers should be used beneath the bolt head or nut (whichever is rotated during tightening) when tightening by torque wrench method.

NF-A-1311 Empirical Equations for Tension From Bolt Torque

The following empirical equation is often used to provide an "estimate" of the torque required to induce a given preload in a bolt:

$$(1) T = KDW$$

where

T	= torque, lb-in.
K	= torque coefficient (not to be confused with coefficient of friction)
D	= nominal bolt size, in.
W	= bolt tension, lb

The torque coefficient K is the critical parameter in the above formula and can be calculated by various methods, all of which represent approximations at best. It is primarily influenced by the frictional conditions along the thread flank and at the bearing surfaces. Relative resiliency of the fastener and joint material also provide influence. For these reasons, it is best to experimentally determine K for critical applications using actual joint material and assembly tools. Arbitrary values for K are often assigned in noncritical applications as follows:

K	= 0.20 for nonplated steel fasteners ¹
K	= 0.15 for plated fasteners ¹

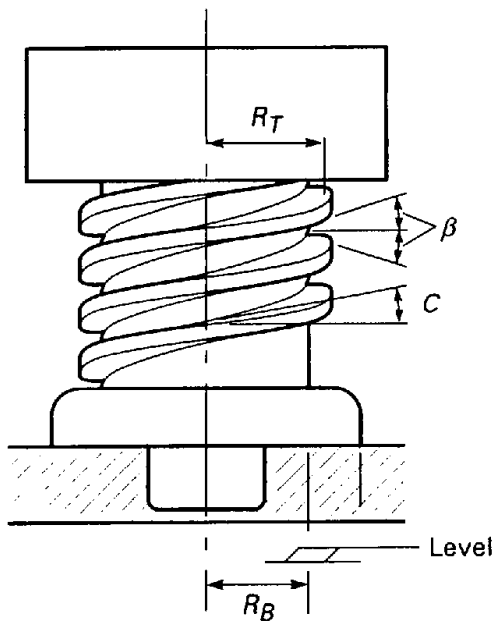


FIG. NF-A-1311

FIG. NF-A-1311

Generally, the above K values are conservative, and the actual preload induced by a given torque is slightly less than calculated.

A more exact value of K is expressed by the following equation, provided there is no thread interference such as by a locknut or wrench-tight thread fit:

$$K = U_B \frac{R_B}{D} + \frac{R_T}{D} \left(\frac{U_T \sec \beta + \tan C}{1 - U_T \sec \beta \tan C} \right) \quad (2)$$

(2)

where

U_B	= coefficient of friction at bearing face of nut or bolt
U_T	= coefficient of friction at thread contact surfaces
R_B	= effective radius of action of frictional forces on bearing face, in. (See Fig. NF-A-1311)
R_T	= effective radius of action of frictional forces on thread surfaces, in.
β	= thread half-angle (30 deg. for 60 deg. basic thread form; sec $\beta = 1.15$)
C	= helix angle of thread

1 In applications where additional lubricants such as greases, oils, and waxes are applied to the fasteners, K may be assumed to be as low as 0.12.

For threads used for fasteners, the denominator of the bracketed term is unity within $\pm 1/2\%$, so

$$\begin{aligned}
 K &= U_B \frac{R_B}{D} + U_T \frac{R_T}{D} \sec \beta + \frac{R_T}{D} \tan C \\
 &= K_1 + K_2 + K_3
 \end{aligned} \tag{3}$$

(3)

The approximate values of K_1 , K_2 , and K_3 can be calculated by inserting typical values such as $R_B/D = 0.625$; $U_B = U_T = 0.15$; $R_T/D = 0.45$; $\sec \beta = 1.15$; $\tan C = 0.04$.

$$K = 0.094 + 0.078 + 0.018 = 0.190$$

$$\frac{100K}{0.190} = 49.5\% + 41\% + 9.5\% = 100\%$$

So, it is observed that K_1 , K_2 , and K_3 contribute roughly 50%, 40%, and 10%, respectively, to the torque coefficient K .

Coefficient K_1 represents the torque resulting from friction on the bearing face of the nut or bolt. This is about 50% of the total torque. K_1 varies with the coefficient of bearing face friction (0.12-0.20) and also with the effective radius of the bearing face, R_B . The radius R_B is approximately the average radius of the bearing face if the contact pressure is uniform.

(NOTE: The exact theoretical values of R_B for uniform contact pressure is

$$R_B = \frac{2}{3} \left(\frac{R_o^3 - R_i^3}{R_o^2 - R_i^2} \right)$$

where R_o and R_i are the outer and inner bearing radii, respectively.)

If the bearing face is not true and flat and the pressure uniform, R_B may vary from the inner radius of the bearing face to the outer radius.

Coefficient K_2 represents the torque resulting from friction on the contact flanks of the threads. This represents about 40% of the total torque. K_2 varies with the coefficient of thread friction (0.12-0.20) and also with the radius of action of friction on thread faces, R_T . The radius R_T is approximately the pitch radius of the screw thread if thread contact pressure is uniform. If contact pressure is not uniform, R_T may vary from the inner to the outer radius of contact of threads. The radius R_T also will differ between coarse and fine threads, being larger for fine threads, resulting in higher torque. K_2 is also slightly variable with bolt tension because of increase in angle β due to thread bending under load. The increase in angle may be considerable at loads near thread failure by stripping.

Coefficient K_3 represents the useful torque producing bolt tension. This is about 10% of the total applied torque. K_3 varies with R_T (see K_2 above) and with the helix angle of the thread. The helix angle, C , varies with the bolt size, being somewhat larger for smaller bolt sizes. It also varies between coarse and fine threads, being slightly larger for coarse threads.

NF-A-1312 Summary of Tensioning by Torque

From the preceding discussion, the following summary can be made:

(a) Equation (1), using $K = 0.2$, gives a reasonable estimate of torque required to produce a given tension regardless of bolt size or thread pitch. This applies only to washer faced or double chamfered hex nuts (or bolts if bolt is torqued) having a width across flats of about 1.5 times the nominal diameter; to threads free of interference such as provided by a locknut or wrench-tight thread fit; to steel bolts and nuts as normally produced and without added plating or lubrication; and to applications where the torqued bearing face of the fastener is in contact with relatively smooth, unplated, nonlubricated steel surfaces.

(b) A more exact theoretical expression of K can be obtained from Equation (3).

(c) There is considerable variation in the value of K from bolt to bolt even when conditions are well controlled because of variation in coefficient of friction. Therefore, where closer control of tension is required, the value of K should be determined experimentally for the particular application. Even so, K will vary considerably because of variations in field conditions.

(d) There is little difference in K between coarse and fine threads - the value for coarse threads being only about $2\frac{1}{2}\%$ higher than that for fine threads, which is negligible. This may be surprising to some people who may think that the small helix angle of fine threads should produce tension with considerably less torque. Such is not the case, however, because 90% of the torque effort is consumed by friction regardless of the thread pitch. This high frictional effect also helps prevent loosening of the fastener.

(e) The value of K as estimated does not apply at or near the failure point of the bolt-nut combination, particularly if the imminent failure is by stripping of threads. In this situation, there may be galling of contact surfaces with greatly increased K . Also, the thread angle, β , becomes greatly distorted, further increasing K . These influences, added to the normal variations of K , result in an indeterminate value of K . From this, it is evident that the torque at failure cannot be taken as any reliable measure of the strength of the fastener.

NF-A-1320 TURN-OF-THE-NUT

Turn-of-the-nut tightening process encompasses a low initial "threshold" torque to achieve "snug tight" condition (achieved by a few impacts of an impact wrench or the force of a person using a spud wrench) followed by a prescribed amount of nut turning to develop the required preload. This technique has gained acceptance for installation of high strength structural bolts, and can be reliably extrapolated to smaller fasteners as long as assumptions upon which the technique is based are considered. For example, the ideal snug-tight condition will vary with each application.

Nut rotation through a prescribed amount eliminates the influence of all friction variables relative to final accuracies. Also, a one-half turn from snug-tight of a coarse thread nut on a bolt having a grip length (the clamping distance between the bolt head and nut) less than 8 in. will induce preload equal to or slightly over the bolt's rated proof load. For grip lengths greater than 8 in., two thirds of a turn beyond snug-tight is recommended.

NF-A-1330 LOAD-INDICATING WASHERS

Load-indicating washers provide high reliability for initial indication of fastener tension. The load-indicating washer employs small raised areas on a ductile washer face that will deform under compression at the time of tightening. A feeler gage is employed to measure the amount of deformation to supply the correct fastener tension. Although these devices are accurate within 10% of expected tension, they cannot be reused if the bolted joint is disassembled for any reason. In addition, if the preload relaxes over time, there is no way to check the bolt tension short of installing new load-indicating washers.

Presence or lack of lubrication during installation does not have an adverse effect on the ability of the load-indicating washer to measure the correct tension in the assembly. In general this simple method of measuring tension can be considered a reliable, fairly economical way to correctly tension bolted assemblies.

NF-A-1340 STRAIN GAGES

Strain gages provide high accuracy in measuring bolt tension, but are also, by far, the most expensive way of accomplishing this task.

The strain gage is a small electrical device with a foil or wire element that is mechanically bonded to the bolt shank. When the bolt is tightened the strain gage experiences the same elongation as the bolt shank. When the foil or wire element is subjected to this strain, its cross sectional area changes slightly causing its electrical resistance to change. Using sensitive equipment, a direct relationship between resistance change and strain can be determined.

Application of strain gage technology requires highly qualified personnel, careful care in application of the gages, and careful calibration of equipment. Other variables that can affect accurate strain gage readings are: the orientation (alignment) of the strain gage element; temperature effects. If out of squareness in the bolt heads or surfaces exists, bolt bending will occur, and this will give an incorrect indication of actual bolt tension. Strain gages installed 180 deg. to each other on the bolt shank can be wired to effectively cancel out the effects of fastener bending.

NF-A-1350 FASTENER ELONGATION/EXTENSION

Tightening by fastener elongation is a precise assembly technique which involves tightening to a predetermined value of

tensile strain. Greatest accuracy is achieved when the prestrain value is obtained from load-extension curves of the fastener being used. However, in most instances, calculation of the desired extension is made from Hooke's law. This gives an approximate solution subject to variation due to nonuniform cross sections.

Using this method one must accurately measure the axial elongation of the bolt shank or stud. If both ends of the fastener are accessible, a micrometer can be used to measure this fastener elongation.

Tightening by extension is slow and expensive; consequently, its use is normally confined to special applications, such as the assembly of very large-diameter bolts or studs where torque wrenches or turn-of-the-nut are impractical.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP NF-B

APPENDIX NF-B DESIGN ALLOWABLE STRESSES FOR PLATE-, SHELL-, AND LINEAR-TYPE SUPPORTS

Page 173

[98]

ARTICLE NF-B-1000 INTRODUCTION

[98]

NF-B-1100 OBJECTIVE

The objective of this Appendix is to provide background on the allowable stresses and design stress intensities used for the design of supports given in NF-3000.

[98]

[98]

NF-B-1200 SCOPE

Included in this Appendix is the background on the allowable stresses and design stress intensities, which are a function of material test data, for linear-, plate-, and shell-type supports. Most of the information herein pertains to linear supports while information on allowable stresses and design stress intensities for plate and shell supports is referenced in Appendix III, Article III-2000 (Section III, Division 1, Appendices) for Class 1 of this Section. Guidance is also given for special situations which arise in support design.

[98]

Page 176

[98]

ARTICLE NF-B-2000 LINEAR SUPPORTS - METHOD FOR ESTABLISHING ALLOWABLE STRESSES

Allowable stresses are based on mechanical properties of material, including yield and ultimate strength values, as well as the particular loads applied to the linear member, i.e., tension, bending, compression, shear, or combinations of these loads. The pertinent mechanical properties of materials, the material yield and ultimate strength, allowed for linear supports have been established and these are presented in Section II, Part D of this division. The various stress factors given in NF-3300 for linear elastic analysis are applied in most cases to the yield or ultimate strength values at temperature. Stress multipliers referred to as stress limit factors applicable to the various Service Limits are given in Tables NF-3523(b)-1 and NF-3623(b)-1 for linear supports. In general, these factors maintain elastic response for lower limits, A and B, and they allow higher stress and some possible permanent deformation for higher limits, C and D.

[98]

[98]

NF-B-2100 RESPONSIBILITY FOR ASSIGNING YIELD AND ULTIMATE STRENGTH VALUES

(a) The Boiler and Pressure Vessel Code Committee evaluates the available data and assigns strength values for materials.

(b) Where suitable test data on a specific material are not available, the Committee may base strength values on the available data for similar materials or on an evaluation of known experience with the material.

[98]

[98]

NF-B-2200 TENSION MEMBER ALLOWABLE STRESS

A tension member can fail either by excessive yielding of its gross area or by fracture of the net area at a load smaller than that required to yield the gross area. To prevent failure of a tension member (other than a pin-connected or threaded member), NF-3322.1(a) imposes a factor of safety of 1.67 against yield of the entire member and 2.0 against fracture of its weakest effective net area, which is computed in NF-3322.8 and accounts for shear lag at the connection. For pin-connected and threaded members, the factors of safety are greater.

[98]

[98]

NF-B-2300 BEAM BENDING ALLOWABLE STRESS

Classical beam flexure theory is used to establish bending stresses in linear support members. Allowable bending stresses are established on the basis of this classical theory, utilizing the following assumptions:

(a) stresses are elastic;

(b) deflections are small;

(c) plane sections, normal to the member axis, remain plane after loading.

For a straight member in flexure, the bending stress is tensile on one side of the neutral axis and compressive on the other side. The allowable values given in NF-3322.1(d) consider whether the stress is tensile or compressive, since a compressive stress (limited to two-thirds of the critical buckling value) subjects a beam element to possible buckling. Hence, the formulas for allowable stresses consider lateral-torsional buckling, by accounting for the unsupported length of the compression flange, and they also consider local buckling, by providing maximum values of width-thickness ratios of unstiffened elements of compression flanges.

[98]

Page 177

[98]

NF-B-2400 COMPRESSION MEMBER ALLOWABLE STRESS

Allowable stresses for linear support members which are loaded in axial compression are based on classical theory of centrally loaded columns. While most columns have some applied primary or secondary bending moment, and hence are beam-columns as described in NF-B-2500, a column with a load eccentricity up to $\frac{1}{1000}$ of its length is considered to be centrally loaded.

Compression members have two failure modes: elastic buckling for long members; and inelastic buckling for short and intermediate members. These two modes are reflected in the allowable stress formulas in NF-3322.1(c) which were originally developed for rolled carbon-steel structural shapes. End conditions of the column, i.e., whether it is free, pinned, or fixed, play an important role in the member allowable stress. These end conditions determine the value of K , the effective length factor, which is a parameter used in the allowable stress formulas. The effective length factor, K , is shown for different end conditions in Fig. NF-B-2400-1. The nomograph in Fig. NF-B-2400-2 gives effective length factors for semi-rigid end conditions in

which beams or girders which frame into the ends of columns provide partial moment restraint. The nominal safety factors for Design and Service Level A limits range from 1.67 for short columns, which exhibit post-buckling strength, to 1.92 for long columns, which buckle elastically and often without warning. A further limitation on compression member stress is given by the requirement that these stresses be limited to two-thirds of the member capacity regardless of the service limit.

Flexural support members also developed compressive stresses in flanges. The two failure modes associated with these stresses are: local buckling; and lateral torsional buckling. Local buckling is prevented by limiting the flange width/thickness ratios [NF-3322.2(d)] and lateral-torsional buckling is prevented by the allowable bending stresses [NF-3322.1(d)].

[98]

[98]

NF-B-2500 BEAM-COLUMN ALLOWABLE STRESS

Beam-columns are those linear support members which are subjected to combined flexure and axial compression. The interaction formulas of NF-3322.1(e)(1) account for these combined stresses and the resulting amplification of the bending stress induced by the applied axial load. The primary or secondary bending moment is one of the important parameters which is used in the interaction formulas. When the moment results in secondary stress, the limit of the plastic hinge criterion is increased by fifty percent. However, to ensure conservatism, the stability limits are not increased when the moment is shown to result in secondary stress. Limit analysis design methods in NF-3340 provide similar requirements for linear members loaded in combined axial compression and bending.

[98]

[98]

NF-B-2600 BOLTING ALLOWABLE STRESS

Bolted connections are subjected to tensile and shear loads. Shear connections are designed to be one of the two types:

(a) bearing connections; and

(b) friction connections.

Since bearing connections can be subjected to simultaneous shear and tension, an interaction formula is given in NF-3324.6 to account for the combined stresses in the bolts. Friction connections can also be subjected to simultaneous shear and tension. However, the bolts will not be subjected to shear if the design had provided an adequate clamping force, T_i .

The Code does not require specific values of bolt preload force for either bearing-type or friction-type connections. The design must consider such factors as applied tensile load, susceptibility of the bolt material to stress corrosion cracking (when preload is excessive) and possible opening of joints under high dynamic loads (when preload is not great enough). These factors as well as the applied shear in a friction connection will affect the selection of bolt preload and the method of applying that load, i.e., by torque or tensioner.

[98]

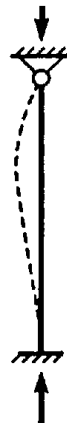
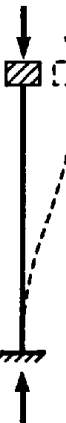
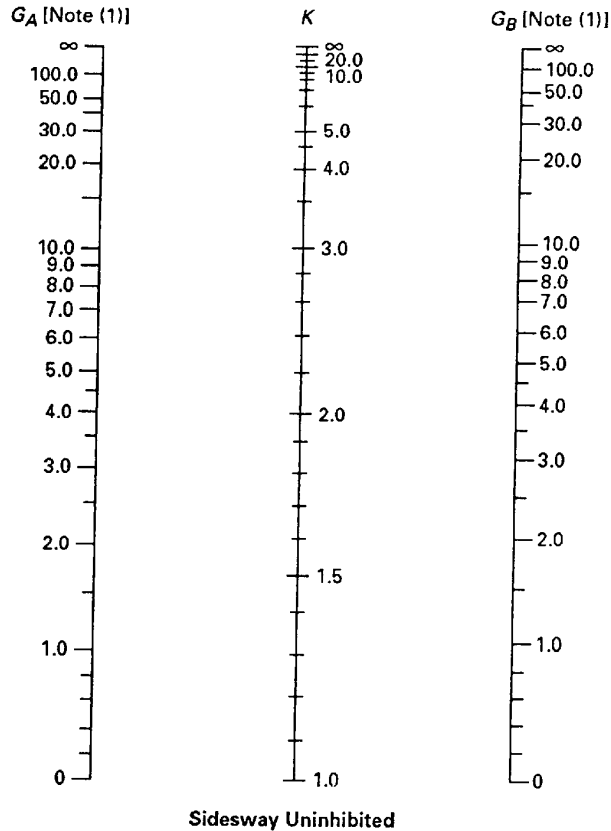
Buckled shape of column is shown by dashed line	(a)	(b)	(c)	(d)	(e)	(f)
						
	Theoretical K value	0.5	0.7	1.0	1.0	2.0
	Recommended design value when ideal conditions are approximated	0.65	0.80	1.2	1.0	2.10
End condition code	   	Rotation fixed and translation fixed Rotation free and translation fixed Rotation fixed and translation free Rotation free and translation free				

FIG. NF-B-2400-1 EFFECTIVE LENGTH FACTOR FOR VARIOUS END CONDITIONS

[98]

FIG. NF-B-2400-1 EFFECTIVE LENGTH FACTOR FOR VARIOUS END CONDITIONS



NOTE:

(1) The subscripts *A* and *B* refer to the joints at the two ends of the column section being considered.

G is defined as

$$G = \frac{\sum \frac{I_c}{L_c}}{\sum \frac{I_q}{L_q}}$$

in which Σ indicates a summation of all members rigidly connected to that joint and lying in the plane in which buckling of the column is being considered. I_c is the moment of inertia, and L_c the unsupported length of a column section, and I_q is the moment of inertia and L_q the unsupported length of a girder or other restraining member. I_c and I_q are taken about axes perpendicular to the plane of buckling being considered.

For column ends supported by but not rigidly connected to a footing or foundation, *G* is theoretically infinity, but, unless actually designed as a true friction free pin, may be taken as "10" for practical designs. If the column end is rigidly attached to a properly designed footing, *G* may be taken as 1.0. Smaller values may be used if justified by analysis.

FIG. NF-B-2400-2 ALIGNMENT CHART FOR EFFECTIVE LENGTH OF COLUMNS IN CONTINUOUS FRAMES

[98]

FIG. NF-B-2400-2 ALIGNMENT CHART FOR EFFECTIVE LENGTH OF COLUMNS IN CONTINUOUS FRAMES

[98]

ARTICLE NF-B-3000 PLATE AND SHELL SUPPORTS - ALLOWABLE STRESSES

Allowable stresses for Class 1, 2, and 3 plate and shell type supports are established in accordance with NF-3220, NF-3250, and NF-3260, respectively. For Class 1 construction allowable stresses are a function of the material design stress intensity (S_m) and for Class 2 and 3 construction the allowable stresses are a function of the material allowable (S). The procedure for establishing design stress intensities (S_m) and allowable stress (S) are given in Appendix III, Article III-2000 (Section III, Division 1, Appendices). Stress multipliers, i.e., stress limit factors which are applicable to various levels of service limits are given in Tables NF-3522(b)-1, NF-3552(b)-1, and NF-3652(b)-1. In general, these factors maintain elastic response for lower limits, A and B, and they allow higher stresses and some possible permanent deformation for higher limits, C and D.

[98]

Page 181

[98]

ARTICLE NF-B-4000 MATERIALS WITH LOW RATIOS OF TENSILE TO YIELD STRENGTH

Allowable stresses for linear support members were originally developed for materials which exhibit a considerable amount of strain hardening. The ratio of tensile to yield strength for these materials (S_u/S_y) is as high as 1.61 for SABE. However, materials with much lower values of S_u/S_y ratio are now included in the Code and these are covered by the NF design rules and allowable stresses in NF-3000. The lower bound of S_u/S_y is 1.07. For certain allowable stresses the factor of safety against failure is lower for materials with low S_u/S_y ratios than it is for high strain hardening materials. The allowable tensile stress (see NF-B-2200) takes into account materials with low strain hardening by imposing a nominal factor of safety of 2.0 on tensile strength on effective net area. Table NF-B-4000 shows that minimum factor of safety is 1.34 for a material with the lower bound S_u/S_y ratio of 1.07. The minimum factor of safety for a high strain hardening material is about 1.43.

Designers should use caution when materials with low S_u/S_y ratios are utilized in support design. The material ductility and other material qualities, including S_u/S_y ratios, should be considered so that the minimum factors of safety will not be less than those shown in Table NF-B-4000.

[98]

Page 182

TABLE NF-B-4000
FACTORS OF SAFETY FOR A MATERIAL WITH A LOW
VALUE OF S_u/S_y RATIO

Service Level	Tension	Bending	Compression
A	2.00	1.78	1.67
B	1.50	1.34	1.50
C	1.43	1.43	1.50
D	1.43	1.43	1.50

GENERAL NOTES:

- (a) The ratio of tensile to yield strength (S_u/S_y) is 1.07 for the factors of safety shown. This is a lower bound for linear support materials allowed by the Code.
- (b) Materials with higher S_u/S_y ratios will have higher factors of safety.

[98]

TABLE NF-B-4000 FACTORS OF SAFETY FOR A MATERIAL WITH A LOW VALUE OF S_u/S_y RATIO

[98]

ARTICLE NF-B-5000 SPECIAL CONSIDERATION

[98]

NF-B-5100 COPPER-BASED ALLOYS

Copper-based alloys are not intended for use as main structural members. However, the Code does provide for their use in the load patch of a support. Use of copper-based alloys is restricted by NF-2122(b) to bearing-type applications. This restriction was incorporated because experience with these materials as main members in supports is lacking and behavior of elements fabricated of these materials has not been confirmed with test data.

[98]

[98]

NF-B-5200 STAINLESS STEEL

Allowable stresses for stainless steel are based on the same consideration given to other Code materials. These are discussed

in NF-B-1000 and NF-B-2000. However, stainless steel in compression requires special consideration because the compression stress-strain curve is nonlinear rather than bilinear as it is for carbon steels. For linear support members this difference in stress-strain relationships results in overestimating the column capacity of members fabricated from austenitic stainless steel.

To account for the different characteristics with austenitic stainless steel exhibits when it is subjected to compressive stress, NF-3322.1 provides special rules for stainless steel columns. These alternate rules provide a minimum factor-of-safety of 2.15 for Design and Level A Service Limits. The allowable compressive stress is a bilinear function of slenderness ratio, Kl/r , rather than a parabolic function which is used for other materials.

[98]

[98]

NF-B-5300 NONDUCTILE BEHAVIOR AND STRESS CORROSION CRACKING

High strength materials are susceptible to brittleness and stress corrosion cracking. Conditions which exacerbate these problems include:

- (a) installation in a corrosive environment such as damp air;
- (b) long-term high stress including bolt preload and dead bolts;
- (c) residual stress caused by fabrication;
- (d) certain material manufacturing processes which enhance hardness.

The design specification can reduce the susceptibility of the support material to brittle fracture by requiring impact testing per NF-2300. Also, designers should exercise caution when using high strength materials when supports are subjected to impact loads.

[98]

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NG A98

1998 ADDENDA SUMMARY OF CHANGES

Page XXV

Changes given below are identified on the pages by a margin note, **98**, placed next to the affected area.

<i>Page</i>	<i>Location</i>	<i>Change</i>
11	NG-2110	Subparagraph (b)(3) definition revised
53	NG-3222.4	Footnote 6 corrected by Errata
58	NG-3227.1	Subparagraph (b)(2) revised, subparagraph (c) redesignated as (d) and new (c) added by Errata
67	NG-3352	Second to last sentence added

NOTE:

Volume 42 of the Interpretations to Section III, Divisions 1 and 2, of the ASME Boiler and Pressure Vessel Code follows the last page of the Edition to Subsection NCA.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NG INTRO INTRODUCTION

**1998 ASME
BOILER &
PRESSURE VESSEL CODE
AN INTERNATIONAL CODE**

III

Division 1 -
Subsection NG

Core Support
Structures

**RULES FOR
CONSTRUCTION
OF NUCLEAR
POWER PLANT
COMPONENTS**

[ASME logo] The American Society of
Mechanical Engineers

IMPORTANT INFORMATION ON THE 1998 BOILER AND PRESSURE VESSEL CODE ADDENDA DISTRIBUTION SCHEDULE

There is a change in the way the Addenda to the 1998 Edition of the ASME Boiler and Pressure Vessel Code are distributed. The 1998 Edition, published July 1, 1998, incorporates the 1998 Addenda revisions, additions, or deletions. There will be no separate 1998 Addenda issued in a replacement page format. Two additional Addenda to the 1998 Edition, in the form of replacement pages, will be issued on July 1, 1999 and July 1, 2000.

The Summary of Changes published with the 1998 Edition lists and describes the revisions that are part of the 1998 Addenda. These changes are identified with a margin note, **98**, denoting the affected area.

The Addenda for 1999 and 2000 will also have a Summary of Changes and identifiers printed on the replacement pages. The revisions, additions, or deletions will be incorporated directly into the affected pages. It is advisable to retain the title sheets and all replaced pages for reference.

The effective dates for Code Editions and Addenda are described in the Foreword.

**ASME BOILER AND PRESSURE VESSEL CODE
AN INTERNATIONAL CODE**

**RULES FOR
CONSTRUCTION OF
NUCLEAR POWER
PLANT COMPONENTS**

III

Division 1 -
Subsection NG

Core Support

Structures

1998 Edition

July 1, 1998

ASME BOILER AND
PRESSURE VESSEL
COMMITTEE
SUBCOMMITTEE ON
NUCLEAR POWER

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
NEW YORK, NEW YORK

Date of Issue - July 1, 1998

(Includes all Addenda dated December 1997 and earlier)

This code or standard was developed under procedures accredited as meeting the criteria for American National Standards. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment which provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not "approve," "rate," or "endorse" any item, construction, proprietary device, or activity.

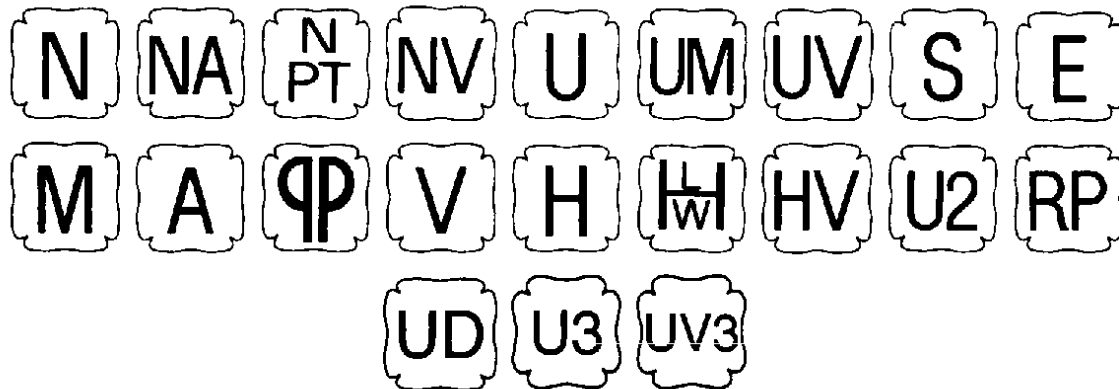
ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of any applicable Letters Patent, nor assume any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations issued in accordance with governing ASME procedures and policies which preclude the issuance of interpretations by individual volunteers.

The footnotes in this document are part of this American National Standard.

[ASME logo] ASME collective membership mark



LOGOS

The above ASME symbols are registered in the U.S. Patent Office.

"ASME" is the trademark of the American Society of Mechanical Engineers.

No part of this document may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Library of Congress Catalog Card Number: 56-3934

Printed in the United States of America

Adopted by the Council of the American Society of Mechanical Engineers, 1914.

Revised 1940, 1941, 1943, 1946, 1949, 1952, 1953, 1956, 1959, 1962, 1965, 1968, 1971, 1974, 1977, 1980, 1983, 1986, 1989, 1992, 1995, 1998

The American Society of Mechanical Engineers
Three Park Avenue, New York, NY 10016-5990

Copyright © 1998 by
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
All Rights Reserved

1998 ASME BOILER AND PRESSURE VESSEL CODE

SECTIONS

I Rules for Construction of Power Boilers

II Materials

Part A - Ferrous Material Specifications

Part B - Nonferrous Material Specifications

Part C - Specifications for Welding Rods, Electrodes, and Filler Metals

Part D - Properties

III Subsection NCA - General Requirements for Division 1 and Division 2

III Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

III Division 2 - Code for Concrete Reactor Vessels and Containments

III Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

IV Rules for Construction of Heating Boilers

V Nondestructive Examination

VI Recommended Rules for the Care and Operation of Heating Boilers

VII Recommended Guidelines for the Care of Power Boilers

VIII Rules for Construction of Pressure Vessels

Division 1

Division 2 - Alternative Rules

Division 3 - Alternative Rules for Construction of High Pressure Vessels

IX Welding and Brazing Qualifications

X Fiber-Reinforced Plastic Pressure Vessels

XI Rules for Inservice Inspection of Nuclear Power Plant Components

ADDENDA

Colored-sheet Addenda, which include additions and revisions to individual Sections of the Code, are published annually and will be sent automatically to purchasers of the applicable Sections up to the publication of the 2001 Code. The 1998 Code is available only in the loose-leaf format; accordingly, the Addenda will be issued in the loose-leaf, replacement-page format.

INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code. The Interpretations for each individual Section will be published separately and will be included as part of the update service to that Section. They will be issued semiannually (July and December) up to the publication of the 2001 Code. Interpretations of Section III, Divisions 1 and 2, will be included with the update service to Subsection NCA.

CODE CASES

The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 1998

FOREWORD

The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety governing the design, fabrication, and inspection during construction of boilers and pressure vessels, and to interpret these rules when questions arise regarding their intent. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property and to provide a margin for deterioration in service so as to give a reasonably long, safe period of usefulness. Advancements in design and material and the evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction,¹ and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

¹ Construction, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are responsible for the application of these programs to their design.

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practice as determined by the engineer.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Boiler and Pressure Vessel Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Mandatory Appendix covering preparation of technical inquiries). Proposed revisions to the Code resulting from inquiries will be presented to the Main Committee for appropriate action. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by ASME.

Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute and published in *Mechanical Engineering*

to invite comments from all interested persons. After the allotted time for public review and final approval by ASME,

to invite comments from all interested persons. After the allotted time for public review and final approval by ASME, revisions are published annually in Addenda to the Code.

Code Cases may be used in the construction of components to be stamped with the ASME Code symbol beginning with the date of their approval by ASME.

Code Editions may be used on or after the date of issue shown in the Edition. After Code revisions are approved by ASME, they may be used beginning with the date of issue shown on the Addenda. Revisions to material specifications are originated by the American Society for Testing and Materials (ASTM) and other recognized national or international organizations, and are usually adopted by ASME. However, those revisions may or may not have any effect on the suitability of material, produced to earlier editions of specifications, for use in ASME construction. ASME material specifications approved for use in each construction Code are listed in the Appendices of Section II, Parts A and B. These Appendices list, for each specification, the latest edition adopted by ASME, and earlier and later editions considered by ASME to be identical for ASME construction.

Owners of nuclear power plants are cautioned that Code Editions, Addenda, and Cases to be used in construction shall be acceptable to the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

Each state and municipality in the United States and each province in Canada that adopts or accepts one or more Sections of the Boiler and Pressure Vessel Code is invited to appoint a representative to act on the Conference Committee to the Boiler and Pressure Vessel Committee. Since the members of the Conference Committee are in active contact with the administration and enforcement of the rules, the requirements for inspection in this Code correspond with those in effect in their respective jurisdictions. The required qualifications for an Authorized Inspector under these rules may be obtained from the administrative authority of any state, municipality, or province which has adopted these rules.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, method of fabrication, inspection, and safety devices. Permission may be granted to regulatory bodies and organizations publishing safety standards to use a complete Section of the Code by reference. If usage of a Section, such as Section IX, involves exceptions, omissions, or changes in provisions, the intent of the Code might not be attained.

Where a state or other regulatory body, in the printing of any Section of the Boiler and Pressure Vessel Code, makes additions or omissions, it is recommended that such changes be clearly indicated.

The National Board of Boiler and Pressure Vessel Inspectors is composed of chief inspectors of states and municipalities in the United States and of provinces in Canada that have adopted the Boiler and Pressure Vessel Code. This Board, since its organization in 1919, has functioned to uniformly administer and enforce the rules of the Boiler and Pressure Vessel Code. The cooperation of that organization with the Boiler and Pressure Vessel Committee has been extremely helpful.

The Code Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The Scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Code for vessels or components not considered to be within its Scope or may establish additions or deletions in that Scope. Accordingly, inquiries regarding such laws or regulations are to be directed to the issuing enforcement or regulatory body.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the ASME Boiler and Pressure Vessel Committee. ASME is to be notified should questions arise concerning improper use of an ASME Code symbol.

The specifications for materials given in Section II are identical with or similar to those of specifications published by ASTM, AWS, and other recognized national or international organizations. When reference is made in an ASME material specification to a non-ASME specification for which a companion ASME specification exists, the reference shall be interpreted as applying to the ASME material specification. Not all materials included in the material specifications in Section II have been adopted for use in this Section. Usage is limited to those materials and grades listed in at least one of the tables of Section II, Part D, Subpart 1, identified as applicable to this Section. All materials allowed by this Section and used for construction within the scope of these rules shall be furnished in accordance with material specifications

contained in Section II or referenced in Appendices A of Section II, Parts A and B except where otherwise provided in Code Cases or in this Section of the Code. Materials covered by these specifications are acceptable for use in items covered by the Code Sections only to the degree indicated in the applicable Section. Materials for Code use should preferably be ordered, produced, and documented on this basis. Material produced to an acceptable specification with requirements different from the requirements of the corresponding specification listed in Appendix A of Part A or Part B may also be used in accordance with the above, provided the material manufacturer or vessel manufacturer certifies with evidence acceptable to the Authorized Inspector that the corresponding ASME specification requirements of specifications listed in Appendix A of Part A or Part B have been met. Material produced to an acceptable material specification is not limited as to country of origin.

When required by context in this Section, the singular shall be interpreted as the plural, and vice-versa; and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

Publication of the SI (Metric) Edition of the ASME Boiler and Pressure Vessel Code was discontinued with the 1986 Edition. Effective October 1, 1986, the SI Edition was withdrawn as an ASME Boiler and Pressure Vessel Code document.

STATEMENT OF POLICY ON THE USE OF CODE SYMBOLS AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use Code Symbols for marking items or constructions which have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the symbols, Certificates of Authorization, and reference to Code construction. The American Society of mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications which might so indicate. An organization holding a Code Symbol and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code."

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified items will carry the symbol. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

The ASME logo, which is the cloverleaf with the letters ASME within, shall not be used by any organization other than ASME.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Code Symbol Stamp described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the various Code Symbols shall not be used on any item which is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME which tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

PERSONNEL ASME Boiler and Pressure Vessel Committee Subcommittees, Subgroups, and Working Groups

As of December 31, 1997

MAIN COMMITTEE

D. A. Canonico, *Chair*
G. G. Karcher, *Vice Chair*
J. S. Brzuszkiewicz, *Secretary*
R. W. Barnes
F. P. Barton
D. L. Berger
M. D. Bernstein
M. N. Bressler
W. J. Carter
T. M. Cullen
J. R. Farr
R. E. Feigel
J. G. Feldstein
M. Gold
O. F. Hedden
A. J. Justin
D. F. Landers
W. M. Lundy
J. R. MacKay
T. J. Mawson
T. G. McCarty
G. C. Millman
R. A. Moen
C. C. Neely
C. J. Pieper
R. F. Reedy
B. W. Roberts
F. J. Schaaf, Jr.
A. Selz
K. K. Tam
D. E. Tanner

EXECUTIVE COMMITTEE (MAIN COMMITTEE)

G. G. Karcher, *Chair*
D. A. Canonico, *Vice Chair*
J. S. Brzuszkiewicz, *Secretary*
F. P. Barton

J. R. Farr
J. G. Feldstein
M. Gold
O. F. Hedden
A. J. Justin
J. R. MacKay
T. G. McCarty
T. P. Pastor
T. E. Quaka
R. F. Reedy
A. J. Spencer

HONORARY MEMBERS (MAIN COMMITTEE)

R. D. Bonner
R. J. Bosnak
H. M. Canavan
L. J. Chockie
J. S. Clarke
W. E. Cooper
W. D. Doty
R. C. Griffin
E. J. Hemzy
E. C. Kistner, Jr.
J. E. Lattan
J. LeCoff
F. N. Moschini
C. E. Rawlins
W. E. Somers
L. P. Zick, Jr.

HONORS AND AWARDS COMMITTEE

J. R. MacKay, *Chair*
A. J. Spencer, *Vice Chair*
F. R. Lyons, *Secretary*
F. P. Barton
W. J. Carter
J. G. Feldstein
M. Gold
F. E. Gregor
E. C. Kistner, Jr.
T. P. Pastor
R. F. Reedy

MARINE CONFERENCE GROUP

J. Tiratto, *Chair*
C. F. Banks
L. W. Douthwaite
J. L. Jones
G. F. Wright

CONFERENCE COMMITTEE

D. E. Tanner - Tennessee (*Chair*)
R. D. Reetz - North Dakota (*Vice Chair*)
A. J. Justin - National Board of Boiler and Pressure Vessel Inspectors (*Secretary*)
R. J. Aben, Jr. - Michigan
J. S. Aclaro - Los Angeles, California
E. A. Anderson - Chicago, Illinois
J. Anderson - South Dakota
R. Barkdoll - Washington
F. P. Barton - Virginia
C. Castle - Nova Scotia, Canada
R. R. Cate - Louisiana
L. Chase - Northwest Territories, Canada
R. A. Coomes - Kentucky
J. Corcoran - Connecticut
M. H. Diehl, Jr. - Maryland
D. A. Douin - Illinois
D. Eastman - Newfoundland and Labrador, Canada
G. L. Ebeyer - New Orleans, Louisiana
F. Ellis - New Hampshire
E. Everett - Georgia
P. C. Hackford - Utah
D. Hanrath - North Carolina
J. B. Harlan - Delaware
K. Hynes - Prince Edward Island, Canada
D. T. Jagger - Ohio
D. J. Jenkins - Kansas
M. Kotb - Quebec, Canada
J. P. Larson - Minnesota
K. T. Lau - Alberta, Canada
J. Lemire - California
G. A. Lundberg - Florida
W. C. Lundine - Oregon
M. A. Malek - Maine
I. W. Mault - Manitoba, Canada
H. T. McEwen - Mississippi
A. W. Meiring - Indiana
R. Mile - Ontario, Canada
T. J. Monroe - Oklahoma
Y. Nagpaul - Hawaii
J. D. Payton - Pennsylvania
D. K. Peetz - Missouri
D. C. Price - Yukon Territory, Canada
R. S. Pucek - Wisconsin
T. E. Rennie - Arizona
L. Roussinos - British Columbia, Canada

M. Shuff - West Virginia
R. Snyder - New Jersey
N. Surtees - Saskatchewan, Canada
M. J. Verhagen - Wisconsin
R. B. West - Iowa
M. J. Wheel - Vermont
K. A. White - Nevada
R. K. White - New York
T. F. Wickham - Rhode Island
C. S. Withers - Colorado

SUBCOMMITTEE ON POWER BOILERS (SC I)

J. R. MacKay, *Chair*
M. D. Bernstein, *Vice Chair*
P. D. Stumpf, *Secretary*
D. L. Berger
E. Everett
D. N. French
F. R. Gerety
J. Hainsworth
T. E. Hansen
J. S. Hunter
W. L. Lowry
T. C. McGough
P. A. Molvie
D. K. Parrish
J. T. Pillow
R. G. Presnak
B. W. Roberts
R. D. Schueler, Jr.
R. V. Wielgoszinski
R. L. Williams

Page xiv

Subgroup on Design (SC I)

M. D. Bernstein, *Chair*
R. D. Schueler, Jr., *Vice Chair*
P. A. Molvie, *Secretary*
M. A. Farrugia
J. D. Fishburn
C. F. Jeerings
K. C. Morrison
A. Nassif
N. Surtees
R. V. Wielgoszinski

Subgroup on Fabrication and Examination (SC I)

D. L. Berger, *Chair*

R. E. McLaughlin, *Secretary*

R. W. Boyce

D. N. French

J. Hainsworth

T. E. Hansen

M. H. Iken

J. M. Lyons

J. T. Pillow

M. E. Reese

R. D. Schueler, Jr.

R. F. Slack, Sr.

R. V. Wielgoszinski

Subgroup on General Requirements (SC I)

T. C. McGough, *Chair*

M. D. Bernstein, *Vice Chair*

W. L. Lowry, *Secretary*

D. L. Berger

E. Everett

F. R. Gerety

J. Hainsworth

C. F. Jeerings

J. M. Lyons

R. E. McLaughlin

D. K. Parrish

J. T. Pillow

W. E. Somers

R. L. Williams

Subgroup on Materials (SC I)

B. W. Roberts, *Chair*

C. E. Spaeder, Jr., *Chair*

J. S. Hunter, *Secretary*

T. M. Cullen

D. N. French

J. F. Henry

J. P. Libbrecht

F. Masuyama

J. M. Tanzosh

Subgroup on Piping (SC I)

T. E. Hansen, *Chair*

D. L. Berger

M. D. Bernstein

P. D. Edwards

W. L. Lowry

T. C. McGough

R. G. Presnak

E. Whittle
P. L. Ziegler

SUBCOMMITTEE ON MATERIALS (SC II)

M. Gold, *Chair*
T. M. Cullen, *Vice Chair*
F. R. Lyons, *Secretary*
A. P. Ahrendt
M. N. Bressler
A. Cohen
R. Dirscherl
W. D. Doty
W. D. Edsall
D. Gandy
M. H. Gilkey
J. J. Heger
J. F. Henry
G. C. Hsu
F. Masuyama
E. Michalopoulos
R. A. Moen
R. K. Nanstad
E. G. Nisbett
J. T. Parsons
D. W. Raho
B. W. Roberts
E. Shapiro
C. E. Spaeder, Jr.
R. W. Swindeman
J. M. Tanzosh
B. E. Thurgood
A. W. Zeuthen

Subgroup on External Pressure (SC II)

R. W. Mikitka, *Chair*
D. J. Green
D. S. Griffin
E. Michalopoulos
B. R. Morelock
D. Nadel
C. E. Spaeder, Jr.
C. H. Sturgeon

Subgroup on Ferrous Specifications (SC II)

E. G. Nisbett, *Chair*
B. M. Dingman
W. D. Edsall
T. Graham

W. N. Holliday
E. A. Jonas
D. C. Krouse
J. F. Longenecker
W. C. Mack
A. S. Melilli
J. T. Parsons
E. J. Rozic, Jr.
E. Upitis
A. W. Zeuthen
R. H. Zong

Subgroup on International Material Specifications (SC II)

J. T. Parsons, *Chair*
D. C. Agarwal
J. Cameron
R. Dirscherl
W. D. Doty
D. M. Fryer
M. Gold
M. H. Iken
W. M. Lundy
H. Masahisa
T. F. Miskell
F. Osweiller
A. P. Povilonis
R. D. Schueler, Jr.
R. R. Seeley
E. A. Steen
E. Upitis
E. O. Woolridge

Subgroup on Nonferrous Alloys (SC II)

D. W. Rahoi, *Chair*
D. C. Agarwal, *Secretary*
W. R. Apblett
L. G. Coffee
A. Cohen
R. Dirscherl
M. H. Gilkey
G. C. Hsu
M. Katcher
E. Shapiro
L. E. Shoemaker
R. C. Sutherlin

Subgroup on Strength, Ferrous Alloys (SC II)

B. W. Roberts, *Chair*

J. M. Tanzosh, *Secretary*

A. P. Ahrendt

W. R. Apblett

T. M. Cullen

M. Gold

J. J. Heger

C. L. Hoffmann

A. Iseda

F. Masuyama

R. A. Moen

D. W. Raho

C. E. Spaeder, Jr.

R. W. Swindeman

B. E. Thurgood

Subgroup on Strength of Weldments (SC II & SC IX)

C. E. Spaeder, Jr., *Chair*

W. D. Doty

D. W. Raho

B. W. Roberts

C. Robino

W. J. Sperko

J. M. Tanzosh

B. E. Thurgood

Subgroup on Toughness (SC II)

J. M. Barsom

D. A. Hansen

A. Selz

R. S. Vecchio

S. Yukawa

R. Zawierucha

Page xv

SUBCOMMITTEE ON NUCLEAR POWER (SC III)

C. J. Pieper, *Chair*

R. M. Jessee, *Vice Chair*

C. A. Sanna, *Secretary*

J. P. Allen III

Y. Asada

R. W. Barnes

J. N. Baysden

W. H. Borter

E. B. Branch

M. N. Bressler

F. C. Cherny

G. D. Cooper

R. P. Deubler

W. D. Doty

F. R. Drahos
K. Ennis
B. A. Erler
D. Hanrath
C. L. Hoffmann
K.-H. Hsu
D. F. Landers
W. C. LaRochelle
T. J. Mawson
W. N. McLean
R. A. Moen
D. B. Nickerson
R. F. Perrin
R. F. Reedy
M. W. Smith
J. D. Stevenson
R. E. Tome
K. R. Wichman

Subgroup on Containment Systems for Spent Fuel and High-Level Waste Transport Packagings (SC III)

J. D. Stevenson, *Chair*
H. H. Chung
R. R. Doggart
E. L. Farrow
K. Goldmann
R. H. Jones
W. H. Lake
R. W. Lambert
H. W. Lee
P. McConnell
R. E. Nickell
D. J. Nolan
D. T. Raske
T. Saegusa
R. H. Smith
K. B. Sorenson
P. Turula
N. Urabe
C. R. Witt
S. Yukawa

Subgroup on Design (SC III)

R. W. Barnes, *Chair*
E. B. Branch, *Vice Chair*
R. S. Hill III, *Secretary*
Y. Asada
M. N. Bressler

C. W. Bruny
J. R. Cole
G. D. Cooper
R. P. Deubler
N. W. Edwards
R. E. Gimple
D. Hanrath
R. W. Haupt
T. Iida
B. Jarman
D. F. Landers
W. N. McLean
D. B. Nickerson
E. C. Rodabaugh
J. R. Santangelo
G. C. Slagis
J. D. Stevenson
J. H. Wawrzeniak
K. R. Wichman
R. Wray

Working Group on Administration (SG-D) (SC III)

E. B. Branch, *Chair*
R. W. Barnes, *Vice Chair*
R. S. Hill III, *Secretary*
C. W. Bruny
G. D. Cooper
R. P. Deubler
J. T. Land
D. F. Landers
W. N. McLean
D. B. Nickerson
J. R. Santangelo
R. Wray

Working Group on Core Support Structures (SG-D) (SC III)

J. T. Land, *Chair*
R. H. Hansen
K. B. Larsen
J. F. Mullooly
B. L. Silverblatt

Working Group on Dynamic and Extreme Load Conditions (SG-D) (SC III)

R. Wray, *Chair*
A. E. Meligi, *Secretary*
P. L. Anderson
M. K. Au-Yang
R. D. Blevins

G. J. Bohm
D. L. Caldwell
P.-Y. Chen
A. Hadjian
M. Hartzman
W. S. LaPay
H. Lockert
P. R. Olson
R. F. Perry
J. Wallach

Working Group on Piping (SG-D) (SC III)

D. F. Landers, *Chair*
R. S. Hill III, *Vice Chair*
P. Hirschberg, *Secretary*
T. M. Adams
G. A. Antaki
J. R. Cole
A. B. Glickstein
R. W. Haupt
J. C. Hennart
R. D. Hookway
R. B. Jenkins
K. A. Manoly
J. C. Minichiello
S. E. Moore
A. N. Nguyen
D. B. Nickerson
O. O. Oyamada
R. D. Patel
E. C. Rodabaugh
J. R. Santangelo
M. S. Sills
G. C. Slagis
E. A. Wais

Working Group on Pumps (SG-D) (SC III)

D. B. Nickerson, *Chair*
H. L. Brammer
P. Burchett
R. E. Cornman, Jr.
A. A. Fraser
M. Higuchi
G. R. Jones
J. W. Leavitt
J. E. Livingston
R. A. Schussler
H. Tafarrodi

G. K. Vaghasia

Working Group on Supports (SG-D) (SC III)

R. P. Deubler, *Chair*

R. M. Dulin, Jr., *Secretary*

U. S. Bandyopadhyay

F. J. Birch

M. N. Bressler

J. R. Cole

J. C. Finneran, Jr.

R. W. Haupt

J. C. Hennart

A. S. Laurenson

A. Lee

R. J. Masterson

A. E. Meligi

A. N. Nguyen

J. R. Stinson

Working Group on Valves (SG-D) (SC III)

W. N. McLean, *Chair*

E. A. Bake

R. R. Brodin

W. G. Knecht

R. Koester

J. J. McGavin

S. N. Shields

H. R. Sonderegger

J. C. Tsacoyeanes

R. G. Visalli

J. R. Zahorsky

Working Group on Vessels (SG-D) (SC III)

C. W. Bruny, *Chair*

T. K. Burr, Sr.

G. D. Cooper

G. A. Deaver

N. W. Edwards

D. Hanrath

W. J. Heilker

B. Jarman

T. M. Khan

O. Maekawa

K. A. Manoly

A. Merend

G. K. Miller

W. Z. Novak

E. Pelling

Special Working Group on Environmental Effects (SG-D) (SC III)

R. S. Hill III, *Chair*
Y. Asada
W. J. Heilker
C. L. Hoffmann
R. A. Moen
W. Z. Novak
S. Yukawa

Special Working Group on Seismic Piping Rules (SG-D) (SC III)

E. B. Branch, *Chair*
T. M. Adams
G. A. Antaki
R. D. Hookway
J. C. Minichiello
M. S. Sills
E. A. Wais

Subgroup on General Requirements (SC III & SC 3C)

W. C. LaRochelle, *Chair*
K. Ennis, *Secretary*
A. Appleton
J. R. Barbee
J. N. Baysden
L. M. Beason
B. H. Berg
R. E. Kelley
G. S. Korin
A. S. Laurenson
C. Lizotte
M. J. Meyer
M. R. Minick
L. C. Oakes
R. F. Perrin
U. Potapovs
B. B. Scott
D. E. Tanner
D. V. Walshe

Subgroup on Materials, Fabrication, and Examination (SC III)

C. L. Hoffmann, *Chair*
G. P. Milley, *Secretary*
C. W. Allison
D. Doyle
F. R. Drahos
G. M. Foster

G. B. Georgiev
J. E. Harris
R. W. Jackson
R. M. Jessee
C. C. Kim
R. A. Moen
C. J. Pieper
R. R. Seeley
N. M. Simpson
R. C. Soin
W. J. Sperko
K. B. Stuckey
S. Yukawa

Subgroup on Pressure Relief (SC III)

F. C. Cherny, *Chair*
S. F. Harrison, Jr.
E. M. Petrosky
M. W. Smith
A. L. Szeglin
B. S. York
J. R. Zahorsky

Special Working Group on Editing and Review (SC III)

R. F. Reedy, *Chair*
W. H. Borter
M. N. Bressler
R. P. Deubler
B. A. Erler
W. C. LaRochelle
M. W. Smith
J. D. Stevenson
E. O. Woolridge

JOINT ACI-ASME COMMITTEE ON CONCRETE COMPONENTS FOR NUCLEAR SERVICE (SC 3C)

B. A. Erler, *Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
R. M. Attar
A. C. Eberhardt
J. Gutierrez
D. J. Haavik
M. F. Hessheimer
T. E. Johnson
G. R. Murphy
S. F. Putman
B. B. Scott
R. E. Shewmaker

J. D. Stevenson
A. Y. Wong

Subgroup on Design (SC 3C)

D. G. Adams
A. C. Eberhardt
T. E. Johnson
S. F. Putman
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Materials, Construction, and Examination (SC 3C)

D. J. Haavik, *Chair*
J. F. Artuso
R. M. Attar
B. A. Erler
J. Gutierrez

SUBCOMMITTEE ON HEATING BOILERS (SC IV)

F. P. Barton, *Chair*
P. A. Molvie, *Vice Chair*
B. P. Feder, *Secretary*
R. B. Duggan
W. L. Haag, Jr.
W. M. Hiddleston
J. D. Hoh
K. M. McTague
R. I. Mullican
E. A. Nordstrom
J. L. Seigle
D. E. Tanner
S. V. Voorhees
R. H. Weigel
R. V. Wielgoszinski
J. I. Woodworth
T. L. Bedeaux, *Alternate*

Subgroup on Care and Operation of Heating Boilers (SC IV)

J. I. Woodworth, *Chair*
B. P. Feder, *Secretary*
K. J. Hoey
J. D. Hoh
F. M. Lucas
K. M. McTague
P. A. Molvie
R. I. Mullican
R. H. Weigel
T. F. Wickham

T. L. Bedeaux, Alternate

Subgroup on Cast Iron Boilers (SC IV)

K. M. McTague, *Chair*

R. B. Duggan

R. H. Weigel

T. F. Wickham

J. I. Woodworth

T. L. Bedeaux, Alternate

Subgroup on Water Heaters (SC IV)

W. L. Haag, Jr., *Chair*

T. D. Gantt

W. M. Hiddleston

F. M. Lucas

K. M. McTague

R. I. Mullican

D. Smith

D. E. Tanner

M. A. Taylor

Subgroup on Welded Boilers (SC IV)

P. A. Molvie, *Chair*

T. L. Bedeaux

D. H. Mapes

E. A. Nordstrom

J. L. Seigle

R. F. Slack, Sr.

R. P. Sullivan

D. E. Tanner

R. V. Wielgoszinski

SUBCOMMITTEE ON NONDESTRUCTIVE EXAMINATION (SC V)

T. G. McCarty, *Chair*

J. E. Batey, *Vice Chair*

F. S. Fitzgerald, *Secretary*

A. S. Birks

B. H. Clark, Jr.

W. T. Clayton

R. A. Coomes

N. Y. Faransso

H. C. Graber

O. F. Hedden

G. W. Hembree

F. B. Kovacs

J. F. Manning

W. C. McGaughey

R. D. McGuire

Subgroup on General Requirements/Personnel Qualifications and Inquiries (SC V)

R D. McGuire, *Chair*

J. E. Batey

W. T. Clayton

N. Y. Faransso

H. C. Graber

G. W. Hembree

J. R. MacKay

J. P. Swezy

Subgroup on Surface Examination Methods (SC V)

H. C. Graber, *Chair*

S. J. Akrin

T. Alexander

A. S. Birks

B. H. Clark

R. A. Coomes

G. W. Hembree

Subgroup on Volumetric Methods (SC V)

J. E. Batey, *Chair*

S. J. Akrin

W. T. Clayton

N. Y. Faransso

H. C. Graber

G. W. Hembree

B. Kellerhall

E. K. Kietzman

F. B. Kovacs

R. W. Kruzic

J. F. Manning

W. C. McGaughey

J. R. Mitchell

Working Group on Acoustic Emissions (SG-VM) (SC V)

B. H. Clark, Jr.

P. M. Horrigan

J. F. Manning

J. R. Mitchell

Working Group on Radiography (SG-VM) (SC V)

G. W. Hembree, *Chair*

S. J. Akrin

T. Alexander

J. E. Batey

N. Y. Faransso

H. C. Graber

F. B. Kovacs

Working Group on Ultrasonics (SG-VM) (SC V)

W. T. Clayton, *Chair*
O. F. Hedden
B. Kellerhall
E. K. Kietzman
J. F. Manning
W. C. McGaughey
R. Paillaman
F. J. Sattler
M. L. Shakinovsky

SUBCOMMITTEE ON PRESSURE VESSELS (SC VIII)

T. P. Pastor, *Chair*
K. Mokhtarian, *Vice Chair*
A. J. Roby, *Secretary*
A. P. Ahrendt
V. Bogosian
S. M. Caldwell
W. J. Carter
S. C. Cyr
R. Dirscherl
R. M. Elliott
J. R. Farr
R. E. Feigel
J. G. Feldstein
G. L. Hollinger
M. J. Houle
W. S. Jacobs
G. G. Karcher
G. B. Komora
K. T. Lau
R. W. Mikitka
U. R. Miller
C. C. Neely
K. J. Schneider
A. Selz
J. R. Sims, Jr.
A. J. Spencer
E. A. Steen
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Design (SC VIII)

U. R. Miller, *Chair*
R. E. Knoblock, *Secretary*
M. R. Bauman
M. R. Breach
S. M. Caldwell

N. W. Edwards
J. R. Farr
J. A. Hayward
G. L. Hollinger
W. S. Jacobs
G. G. Karcher
G. B. Komora
R. W. Mikitka
K. Mokhtarian
T. P. Pastor
M. D. Rana
A. Selz
S. C. Shah
J. W. Stokes
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Fabrication and Inspection (SC VIII)

E. A. Steen, *Chair*
K. Mokhtarian, *Vice Chair*
W. J. Bees
R. W. Boyce
S. C. Cyr
R. E. Feigel
H. E. Gordon
M. J. Houle
W. S. Jacobs
R. A. Johnson
A. S. Lester III
F. C. Ouyang
M. J. Rice
W. P. Webb

Subgroup on General Requirements (SC VIII)

R. M. Elliott, *Chair*
A. P. Ahrendt
V. Bogosian
W. J. Carter
W. P. Crow
J. P. Glaspie
C. R. Good
D. B. Kadakia
J. C. Keenan
W. E. Laveck, Jr.
A. S. Mann
C. C. Neely
A. S. Olivares

K. J. Schneider
A. J. Spencer

Subgroup on Materials (SC VIII)

R. Dirscherl, *Chair*
D. C. Agarwal
A. P. Ahrendt
J. Cameron
W. D. Doty
W. D. Edsall
M. Katcher
W. M. Lundy
E. E. Morgenegg
E. G. Nisbett
J. T. Parsons
D. W. Rahoi
K. K. Tam
B. K. Thakur

Special Working Group on Heat Transfer Equipment (SC VIII)

G. B. Komora, *Chair*
R. P. Zoldak, *Secretary*
C. F. Andreone
D. E. Bolt
S. M. Caldwell
T. K. Haldas
M. J. Holtz
W. G. Jandrasits
R. Mahadeen
U. R. Miller
F. Osweiller
J. E. Soehrens
A. I. Soler
W. A. Treff
S. Yokell

Page xviii

Special Working Group on High-Pressure Vessels (SC VIII)

J. R. Sims, Jr., *Chair*
P. A. Reddington, *Secretary*
L. P. Antalffy
J. E. Baxter
R. C. Biel
T. B. Boyd
D. J. Burns
P. N. Chaku
E. L. Danfelt
R. E. Feigel
D. M. Fryer

D. M. Fryer
J. L. Heck, Jr.
A. H. Honza
V. T. Hwang
M. M. James
P. Jansson
J. A. Kapp
D. P. Kendall
A. K. Khare
S. C. Mordre
G. J. Mraz
E. H. Perez
L. M. Picqueur
E. D. Roll
W. L. Stewart
J. F. Sullivan
F. W. Tatar

Special Working Group on Toughness (SC VIII)

W. S. Jacobs, *Chair*
J. Cameron
W. D. Doty
D. A. Hansen
G. G. Karcher
G. B. Komora
K. Mokhtarian
J. L. Mooney
C. C. Neely
M. D. Rana
J. W. Stokes

SUBCOMMITTEE ON WELDING (SC IX)

J. G. Feldstein, *Chair*
W. J. Sperko, *Vice Chair*
J. Labrador, *Secretary*
R. Barkdoll
D. A. Bowers
M. L. Carpenter
W. D. Doty
P. D. Flenner
M. J. Houle
R. A. Johnson
W. M. Lundy
R. D. McGuire
J. J. Meyer
A. H. Miller
B. R. Newmark
P. P. Norris

S. D. Reynolds, Jr.
W. K. Scattergood
G. W. Spohn III
M. J. Stanko
J. M. Tanzosh
R. R. Young

Subgroup on Brazing (SC IX)

M. J. Houle, *Chair*
A. S. Artayet
M. L. Carpenter
C. F. Jeerings
A. H. Miller
C. Robino

Subgroup on General Requirements (SC IX)

B. R. Newmark, *Chair*
R. Barkdoll
P. R. Evans
P. C. Filean
R. M. Jessee
D. W. Mann
A. S. Olivares
C. E. Wainwright
R. A. Weiss
K. R. Willens

Subgroup on Materials (SC IX)

M. L. Carpenter, *Chair*
L. P. Connor
P. D. Flenner
R. M. Jessee
A. H. Miller
H. A. Sadler
C. E. Sainz
C. E. Spaeder, Jr.
W. J. Sperko
M. J. Stanko
R. R. Young

Subgroup on Performance Qualification (SC IX)

J. J. Meyer, *Chair*
V. A. Bell
D. A. Bowers
L. P. Connor
R. A. Coomes
P. D. Flenner
G. Herrmann
M. J. Houle

W. M. Lundy
R. D. McGuire
S. R. Nordman
P. P. Norris
W. K. Scattergood
G. W. Spohn III

Subgroup on Procedure Qualification (SC IX)

J. J. Meyer, *Chair*
R. K. Brown, Jr.
R. A. Johnson
A. H. Miller
P. P. Norris
A. S. Olivares
F. C. Ouyang
S. D. Reynolds, Jr.
M. J. Rice
W. K. Scattergood
W. J. Sperko
T. C. Wiesner

SUBCOMMITTEE ON FIBER-REINFORCED PLASTIC PRESSURE VESSELS (SC X)

P. J. Conlisk, *Chair*
D. Eisberg, *Vice Chair*
A. J. Roby, *Secretary*
K. M. Agrawal
F. L. Brown
J. L. Bustillos
T. W. Cowley
T. J. Fowler
S. V. Hoa
L. E. Hunt
J. C. Murphy
A. L. Newberry
D. J. Painter
J. A. Rolston
B. F. Shelley
P. R. Wilt

SUBCOMMITTEE ON NUCLEAR INSERVICE INSPECTION (SC XI)

O. F. Hedden, *Chair*
T. J. Mawson, *Vice Chair*
G. L. Fechter, *Secretary*
C. W. Allison
W. H. Bamford, Jr.
R. L. Beverly
J. M. Bloom
R. W. Boyce

C. D. Cowfer
D. D. Davis
R. L. Dyle
T. N. Epps III
R. E. Gimple
F. E. Gregor
L. B. Gross
K. Iida
C. A. Ireland
R. D. Kerr
D. F. Landers
T. F. Lentz
J. T. Lindberg
G. C. Millman
C. R. Osman
P. C. Riccardella
L. Sage
F. J. Schaaf, Jr.
J. E. Staffiera
R. P. Sullivan
R. W. Swayne
R. J. Tamminga
J. C. Tobin
R. A. Yonekawa

Honorary Members (SC XI)

S. H. Bush
L. J. Chockie
J. P. Houstrup
L. R. Katz
R. R. MacCary

Page xix

Subgroup on Evaluation Standards (SC XI)

W. H. Bamford, Jr., *Chair*
M. Kupinski, *Secretary*
J. M. Bloom
R. C. Cipolla
R. M. Gamble
T. J. Griesbach
P. J. Hijeck
K. Iida
Y. Imamura
J. G. Merkle
S. Ranganath
P. C. Riccardella
D. A. Scarth
W. L. Server

C. A. Tomes
W. A. Van Der Sluys
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa

Working Group on Flaw Evaluation (SG-ES) (SC XI)

R. C. Cipolla, *Chair*
W. H. Bamford, Jr.
M. Basol
J. M. Bloom
E. Friedman
T. J. Griesbach
F. D. Hayes
D. N. Hopkins
K. Iida
Y. Imamura
M. Kupinski
H. S. Mehta
J. G. Merkle
J. S. Panesar
R. K. Qashu
S. Ranganath
D. A. Scarth
T. S. Schurman
W. L. Server
F. A. Simonen
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Working Group on Operating Plant Criteria (SG-ES) (SC XI)

T. J. Griesbach, *Chair*
W. H. Bamford, Jr.
H. Behnke
B. A. Bishop
W. F. Brady
E. Friedman
S. R. Gosselin
E. M. Hackett
P. J. Hijeck
S. D. Leshnoff
P. Manbeck

J. S. Panesar
W. E. Pennell
J. H. Phillips
S. Ranganath
S. T. Rosinski
W. L. Server
E. A. Siegel
F. A. Simonen
T. D. Spry
K. K. Yoon
S. Yukawa

Working Group on Pipe Flaw Evaluation (SG-ES) (SC XI)

D. A. Scarth, *Chair*
G. M. Wilkowski, *Secretary*
W. H. Bamford, Jr.
J. M. Bloom
R. C. Cipolla
N. G. Cofie
S. K. Daftuar
G. H. De Boo
E. Friedman
D. N. Hopkins
K. Iida
H. S. Mehta
J. G. Merkle
J. S. Panesar
D. Quinones
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Subgroup on Liquid-Metal-Cooled Systems (SC XI)

C. G. McCargar, *Chair*
W. L. Chase
S. Hattori
R. Hundal
W. Kwant
J. C. Tobin

Working Group on Liquid-Metal Reactor Covers (SG-LMCS) (SC XI)

W. L. Chase, *Chair*
S. Hattori
R. Hundal
W. Kwant

Subgroup on Nondestructive Examination (SC XI)

R. L. Beverly, *Chair*

N. R. Bentley, *Secretary*
D. C. Adamonis
F. L. Becker
F. T. Carr
C. B. Cheezem
W. T. Clayton
C. D. Cowfer
F. J. Dodd
T. N. Epps III
D. O. Henry
M. R. Hum
S. N. Liu
R. D. McGuire
M. C. Modes
C. R. Osman
F. J. Schaaf, Jr.
J. C. Spanner, Jr.
C. J. Wirtz

Working Group on Personnel Qualification and Surface Visual and Eddy Current Examination (SG-NDE) (SC XI)

C. J. Wirtz, *Secretary*
B. L. Curtis
N. Economos
H. B. Garland
D. O. Henry
H. E. Houserman
J. J. McArdle III
R. D. McGuire
S. A. Redner
M. F. Sherwin
A. L. Smith
D. Spake
J. C. Spanner, Sr.
J. C. Spanner, Jr.
T. V. Tran

Working Group on Pressure Testing (SG-NDE) (SC XI)

G. P. Alexander
T. M. Anselmi
T. B. Basso
J. Boughman
T. R. Bugelholll
R. J. Cimocho
C. E. Jensen
W. N. Keisler
D. Lamond
F. J. Schaaf, Jr.
D. Terao

Working Group on Procedure Qualification and Volumetric Examination (SG-NDE) (SC XI)

C. D. Cowfer, *Chair*
C. E. Larsen, *Secretary*
D. C. Adamonis
F. L. Becker
N. R. Bentley
B. Bevins
F. T. Carr
C. B. Cheezem
W. T. Clayton
S. R. Doctor
F. J. Dodd
T. N. Epps III
B. Kellerhall
G. A. Lofthus
J. K. McClanahan
M. C. Modes
M. Saporito
T. T. Taylor
S. M. Walker

Subgroup on Repairs, Replacements, and Modifications (SC XI)

R. E. Gimple, *Chair*
W. C. Holston, *Secretary*
R. W. Boyce
M. N. Bressler
S. B. Brown
C. E. Hartz
R. A. Hermann
C. A. Ireland
R. D. Kerr
D. F. Landers
R. S. Lewis
T. J. Mawson
M. S. McDonald
R. R. Stevenson
R. P. Sullivan
R. W. Swayne
R. E. Tome
D. E. Waskey
R. A. Yonekawa

Page xx

Working Group on Design Reconciliation (SG-RR&M) (SC XI)

W. C. Holston, *Chair*
J. T. Conner, *Secretary*
R. W. Boyce

S. B. Brown
J. E. Charnley
T. E. Hiss
E. V. Imbro
D. N. Irvine, Jr.
D. F. Landers
R. W. Swayne
F. Tehranchi
H. J. Thailer
R. E. Tome

Working Group on Responsibilities and Program Requirements (SG-RR&M) (SC XI)

R. A. Yonekawa, *Chair*
R. R. Stevenson, *Secretary*
S. K. Fisher
G. M. Foster
C. E. Hartz
R. S. Lewis
M. S. McDonald
U. Potapovs
S. M. Swilley
A. J. Walcutt
J. Ghergurovich, *Alternate*

Working Group on Welding and Special Repair Processes (SG-RR&M) (SC XI)

D. E. Waskey, *Chair*
R. E. Cantrell, *Secretary*
D. A. Delsignore
A. L. Finney
P. D. Fisher
A. J. Giannuzzi
R. A. Hermann
R. P. Indap
R. D. Kerr
B. R. Newton
P. P. Norris
J. E. O'Sullivan
J. H. Sodergren
K. R. Willens

Subgroup on Water-Cooled Systems (SC XI)

T. F. Lentz, *Chair*
K. Christian, *Secretary*
C. W. Allison
W. J. Briggs
T. R. Bugelholz
D. D. Davis
A. F. Deardorff

R. L. Dyle
L. B. Gross
T. C. Hinkle
S. D. Kulat
M. P. Lintz
J. E. Staffiera
C. W. Tahnk
R. J. Tamminga
D. Terao
S. M. Walker
R. A. West

Working Group on Concrete Containment (SG-WCS) (SC XI)

W. J. Briggs, *Chair*
B. Talmadge, *Secretary*
H. G. Ashar
K. K. N. Chao
M. J. Ferlisi
H. T. Hill
R. D. Hough
C. N. Krishnaswamy
D. Naus
S. C. Petitgout
C. G. Ranganath

Working Group on Implementation of Risk-Based Examination (SG-WCS) (SC XI)

T. J. Mawson, *Chair*
A. McNeill III, *Secretary*
J. Agold
S. A. Ali
B. A. Bishop
J. W. Connor
A. F. Deardorff
H. Q. Do
R. Fougrousse
S. R. Gosselin
J. T. Lindberg
I. Mach
R. K. Mattu
P. J. O'Regan
J. H. Phillips
F. A. Simonen
T. V. Vo
R. A. West

Working Group on Inspection of Systems and Components (SG-WCS) (SC XI)

R. L. Dyle, *Chair*
G. C. Park, *Secretary*

G. L. Belew
T. W. Brombach
R. Fougereousse
T. C. Hinkle
M. R. Hum
S. D. Kulat
J. T. Lindberg
M. P. Lintz
T. K. McLellan
C. Pendleton
C. M. Ross
C. W. Tahnk
K. B. Thomas
E. Throckmorton
R. A. West
J. Whitiman

Working Group on Metal Containment (SG-WCS) (SC XI)

J. E. Staffiera, *Chair*
W. E. Norris, *Secretary*
W. J. Briggs
K. K. N. Chao
M. J. Ferlisi
R. W. Hammelmann
M. P. Lintz
S. C. Petitgout
C. G. Ranganath
G. W. Robin
R. T. Zak

Special Working Group on Low-Temperature Heavy Water Reactors (SG-WCS) (SC XI)

C. D. Cowfer, *Chair*
J. M. Morrison, *Secretary*
B. Awadalla
K. F. Schmidt
P. R. Vormelker
S. H. Zaidi

Working Group on General Requirements (SC XI)

A. T. Roberts III, *Chair*
R. G. Edl, *Secretary*
D. A. Graham
L. B. Gross
C. A. Ireland
D. A. Jackson
R. K. Mattu
L. Sage
R. J. Scott
J. C. Shropshire

R. J. Tamminga

Special Working Group on Editing and Review (SC XI)

R. W. Swayne, *Chair*

R. L. Beverly

L. B. Gross

M. P. Lintz

J. E. Staffiera

C. J. Wirtz

Special Working Group on Plant Life Extension (SC XI)

F. E. Gregor, *Chair*

L. B. Gross, *Secretary*

D. D. Davis

D. A. Graham

D. L. Harrison

M. P. Lintz

P. Manbeck

H. W. Massie, Jr.

D. W. Peltola

D. A. Piccione

C. M. Regan

V. N. Shah

R. J. Tamminga

SUBCOMMITTEE ON TRANSPORT TANKS (SC XII)

A. Selz, *Chair*

P. D. Stumpf, *Secretary*

A. N. Antoniou

S. C. Cyr

K. Ennis

M. Hennemand

C. H. Hochman

G. G. Karcher

P. P. Laluc

G. McRae

M. R. Minick

T. P. Pastor

M. D. Rana

C. M. Serratella

G. R. Stoeckinger

N. Surtees

J. P. Swezy

A. P. Varghese

S. V. Voorhees

W. L. White

Subgroup on Design and Materials (SC XII)

M. D. Rana, *Chair*
D. A. Canonico
W. D. Doty
G. G. Karcher
P. P. Laluc
T. P. Pastor
T. A. Rogers
C. M. Serratella
A. P. Varghese
E. Whittle

Subgroup on Fabrication and Inspection (SC XII)

S. V. Voorhees, *Chair*
D. A. Canonico
M. L. Coats
M. Hennemand
D. J. Kreft
G. McRae
M. R. Minick
N. Surtees
J. P. Swezy

Subgroup on General Requirements (SC XII)

C. H. Hochman, *Chair*
T. Alexander
A. N. Antoniou
D. Carter
K. Ennis
M. A. Garrett
J. C. Keenan
F. A. Licari
G. R. Stoeckinger
W. L. White

SUBCOMMITTEE ON BOILER AND PRESSURE VESSEL ACCREDITATION (SC-BPVA)

A. J. Spencer, *Chair*
A. J. Justin, *Vice Chair*
K. I. Baron, *Secretary*
M. B. Doherty
D. A. Douin
P. D. Edwards
R. M. Elliott
C. E. Ford
J. J. Greene
R. C. Howard
B. B. MacDonald
M. L. Sisk
B. C. Turczynski

R. V. Wielgoszinski
R. L. Williams
V. A. Bell, Alternate
V. Bogosian, Alternate
M. A. De Vries, Alternate
J. R. Farr, Alternate
R. G. Friend, Alternate
W. C. LaRochelle, Alternate
A. S. Lester III, Alternate
K. M. McTague, Alternate
G. P. Milley, Alternate
R. E. Muise, Alternate
P. G. Scheckermann, Alternate
N. Surtees, Alternate

SUBCOMMITTEE ON NUCLEAR ACCREDITATION (SC-NA)

T. E. Quaka, *Chair*
R. R. Stevenson, *Vice Chair*
S. Griffin, *Secretary*
C. W. Allison
M. N. Bressler
G. Deily
F. R. Drahos
J. E. Harris
M. Kotb
W. C. LaRochelle
U. Potapovs
H. B. Prasse
A. J. Spencer
G. M. Tolson
L. M. Beason, Alternate
R. W. Boyce, Alternate
S. Dasgupta, Alternate
P. D. Edwards, Alternate
J. P. Ellenberger, Alternate
R. E. Feigel, Alternate
D. Hanrath, Alternate
K. A. Huber, Alternate
A. J. Justin, Alternate
N. C. Kist, Alternate
A. A. Lotfi, Alternate
R. P. McIntyre, Alternate
O. E. Trapp, Staff Representative

SUBCOMMITTEE ON DESIGN (SC-D)

W. J. Carter, *Chair*
F. S. Fitzgerald, *Secretary*

R. W. Barnes
C. Becht IV
O. F. Hedden
R. W. Mikitka
K. Mokhtarian
W. J. O'Donnell
R. D. Schueler, Jr.
M. P. Schwartz
A. Selz

Subgroup on Design Analysis (SC-D)

T. P. Pastor, *Secretary*
P. J. Conlisk
A. G. Eggers
J. L. Hechmer
G. L. Hollinger
D. P. Jones
A. Kalnins
W. J. Koves
T. H. Liu
O. Maekawa
A. Merend
T. V. Narayanan
E. L. Thomas, Jr.

Subgroup on Elevated Temperature Design (SC-D)

C. Becht IV, *Chair*
J. M. Corum, *Secretary*
C. R. Brinkman
R. D. Campbell
D. S. Griffin
R. I. Jetter
C. Lawton
W. J. O'Donnell
D. A. Osage
C. C. Schultz, Jr.
L. K. Severud
D. F. Shaw
A. L. Snow
B. E. Thurgood

Subgroup on Fatigue Strength (SC-D)

C. R. Brinkman
P. R. Donavin
J. A. Hayward
J. L. Hechmer
D. P. Jones
G. Kharshafdjian

C. Lawton
A. Merend
H. H. Ziada

Subgroup on Openings (SC-D)

M. P. Schwartz, *Chair*
R. W. Mikitka, *Secretary*
M. R. Breach
V. T. Hwang
S. C. Lou
R. B. Luney
J. P. Madden
K. C. Morrison
D. R. Palmer
M. D. Rana
E. C. Rodabaugh

Special Working Group on Bolted Flanged Joints (SC-D)

R. W. Mikitka, *Chair*
G. D. Bibel
G. Kharshafdjian
D. L. Kurle
E. Michalopoulos
S. N. Pagay
J. R. Payne
R. W. Schneider
R. D. Schueler, Jr.
A. Selz

SUBCOMMITTEE ON SAFETY VALVE REQUIREMENTS (SC-SVR)

E. C. Kistner, Jr., *Chair*
M. D. Bernstein, *Vice Chair*
U. D'Urso, *Secretary*
J. F. Ball
J. A. Cox
R. D. Danzy
R. J. Doelling
D. A. Douin
R. G. Friend
H. I. Gregg
S. F. Harrison, Jr.
C. F. Laitner
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson
D. J. Scallan
C. M. Schroepfer
A. J. Spencer

J. C. Standfast
E. A. Steen
L. L. Thompson
J. A. West
T. J. Ferrigan, Alternate

Page xxii

Subgroup on Design (SC-SVR)

R. G. Friend, *Chair*
J. Cahoon, Jr.
R. D. Danzy
D. B. DeMichael
R. J. Doelling
H. I. Gregg
S. R. Irvin
C. F. Laitner
P. R. Sievert
A. J. Spencer
E. A. Steen
T. R. Tarbay
J. A. West

Subgroup on General Requirements (SC-SVR)

M. D. Bernstein, *Chair*
J. F. Ball
V. M. Deluca
D. A. Douin
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson
J. C. Standfast
L. L. Thompson

Subgroup on Testing (SC-SVR)

S. F. Harrison, Jr., *Chair*
S. Cammeresi
J. A. Cox
W. F. Hart
D. M. Papa
D. J. Scallan
C. M. Schroepfer
D. E. Snyder

Page xxiii

ORGANIZATION OF SECTION III

1. GENERAL

Section III consists of Division 1, Division 2, and Division 3. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter "N" for Division 1, by the letter "C" for Division 2, and by the letter "W" for Division 3. The following eleven books make up the three Divisions.

Subsection NCA - General Requirements for Division 1 and Division 2

Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

Division 2 - Code for Concrete Reactor Vessels and Containments

Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

The Division 2 book includes Subsection CC - Concrete Containments and Division 2 Appendices.

The Division 3 book includes Subsections WA and WB for General Requirements and Class TP (Type B) Containment, respectively.

2. SUBSECTIONS

Subsections are divided into Articles, Subarticles, paragraphs, and, where necessary, subparagraphs and subsubparagraphs.

3. ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections followed by Arabic numbers, such as NB-1000. Where possible, Articles dealing with the same topics are given the same number in each Subsection in accordance with the following general scheme:

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination
6000	Testing
7000	Overpressure Protection
8000	Nameplates, Stamping, and Reports

The numbering of Articles and the material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the rules have been prepared with some gaps in the numbering.

4. SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

5. SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as NB-2130, and generally have no text. When a number such as NB-1110 is followed by text, it is considered a paragraph.

6. PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

7. SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as NB-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

8. SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

Page xxiv

9. REFERENCES

References used within Section III generally fall into one of the following four categories.

A. References to Other Portions of Section III

When a reference is made to another Article, Subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to NB-3000 includes all material in Article NB-3000; reference to NB-3200 includes all material in Subarticle NB-3200; reference to NB-3230 includes all paragraphs NB-3231 through NB-3236.

B. References to Other Sections

Other Sections referred to in Section III are:

Section II, Materials. When a requirement for a material, or for the examination or testing of a material, is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II. These references begin with the letter "S."

Section V, Nondestructive Examination. Section V references begin with the letter "T" and relate to the nondestructive examination of material or welds.

Section IX, Welding and Brazing Qualifications. Section IX references begin with the letter "Q" and relate to welding and brazing requirements.

Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components. When a reference is made to inservice inspection, the rules of Section XI shall apply.

C. Reference to Specifications and Standards Other Than Published in Code Sections

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials. At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E 71-64 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

2 The American National Standards Institute (ANSI) was formerly known as the American Standards Association. Standards approved by the Association were designated by the prefix "ASA" followed by the number of the standard and the year of publication. More recently, the American National Standards Institute was known as the United States of America Standards Institute. Standards were designated by the prefix "USAS" followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the numbers of the standards have remained unchanged.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by the American Society of Mechanical Engineers and approved by the American National Standards Institute.² When a product is to conform to such a standard, for example ANSI B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NB-3132-1, for example ANSI B16.5-1977. Standards published by the American Society of Mechanical Engineers are available from ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-6, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, 127 Park Street, N.E., Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NB-3132-1, for example MSS SP-6-1963.

(4) Specifications for welding and brazing materials are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33135. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix "SF," for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-620 and API-2000. When documents so designated are referred to in Section III, they are standards published by the American Petroleum Institute.

D. References to Appendices

Two types of Appendices are used in Section III and are designated Mandatory and Nonmandatory.

(1) Mandatory Appendices contain requirements which must be followed in construction; such references are designated by a Roman numeral followed by Arabic numerals. References to II-1100 or XI-3212, for example, relate to the Mandatory Appendices.

(2) Nonmandatory Appendices provide information or guidance for the use of Section III; such references are designated by a capital letter followed by Arabic numerals. A reference to D-1100, for example, relates to a Nonmandatory Appendix.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NG-1000

ARTICLE NG-1000 INTRODUCTION

Page 1

NG-1100 SCOPE

NG-1110 ASPECTS OF CONSTRUCTION COVERED BY THESE RULES

Subsection NG establishes rules for materials, design, fabrication, examination, and preparation of reports required in the manufacture and installation of core support structures.¹²

NG-1120 DEFINITION OF STRUCTURES AND APPLICATION OF THESE RULES TO THEM

NG-1121 Core Support Structures

Core support structures shall be constructed to the rules of this Subsection. Core support structures are those structures or parts of structures which are designed to provide direct support or restraint of the core (fuel and blanket assemblies) within the reactor pressure vessel. Structures which support or restrain the core only after the postulated failure of core support

structures are considered to be internal structures (NG-1122).

1 (a) The rules of Subsection NG are not directed to sealing against coolant leakage. Further, gross hydrostatic loading may not be typical of the loads experienced by core support structures. Thus, hydrostatic testing of the structures is not required.

(b) The most severe loads on which design must be predicated usually result from abnormal, rather than normal, load conditions. Core support structures need not remain leak tight to perform their function. However, if leak tightness is required for a structure, the rules for pressure boundary construction may be appropriate.

2 In Subsection NG it is recognized that the design functions are frequently handled separately from the fabrication functions of the Certificate Holder manufacturing core supports. The separation of these functions is necessary because the design of core support structures cannot be performed completely independent of the nuclear or hydraulic design of the coolant system. Furthermore, portions of a set of structures may be fabricated by a specialist and assembled at the site without any one fabricator having a controlling position for fabrication of the complete structure. Therefore, provisions are made herein for separate organizations to perform the design and fabricating functions of the Certificate Holder. This Section (NCA-3510), however, requires that one organization have overall responsibility for compliance with the requirements of this Subsection NG. The use of the term Certificate Holder therefore must be understood to mean the design or fabricating organization assuming the overall responsibility for compliance with this Section. The term Certificate Holder, as used in this Subsection, applies to the Certificate Holder manufacturing core supports who shall be responsible for certifying that all core support structures and internal structures, as defined in NG-1120, comply with the requirements of this Subsection.

3 Note that some fuel and blanket positions in the core matrix may be filled with structures related to reflector or shielding functions. These structures also fall into the fuel and blanket category described above.

NG-1122 Internal Structures

(a) Internal structures are *all* structures within the reactor pressure vessel other than core support structures, fuel³ and blanket assemblies, control assemblies, and instrumentation.

(b) The rules of this Subsection apply to internal structures as defined in (a) above, only when so stipulated by the Certificate Holder manufacturing core supports, hereafter referred to in this Subsection as Certificate Holder.

(c) The Certificate Holder shall certify² that the construction of all internal structures is such as not to affect adversely the integrity of the core support structure.

NG-1123 Temporary Attachments

A temporary attachment is an element in contact with or connected to the core support structure which is removed prior to operation. Temporary attachments include items such as alignment lug tie straps and braces.

Page 4

NG-1130 BOUNDARIES OF JURISDICTION APPLICABLE TO THIS SUBSECTION

NG-1131 Boundary Between Core Support Structure and Reactor Pressure Vessel

The jurisdictional boundary between a core support structure and the reactor pressure vessel shall be the surface of the core support structure. The first connecting weld of a core support structure to the reactor pressure vessel shall be considered part of the reactor pressure vessel unless the weld is more than $2t$ from the pressure retaining portion of the reactor pressure vessel, where t is the nominal thickness of the pressure retaining material. Beyond the first connecting weld to the reactor pressure vessel, or beyond $2t$ from the pressure retaining portion of the reactor pressure vessel, the first weld shall be considered part of the core support structure, unless otherwise specified in the Design Specification. Mechanical fasteners used to connect a core support structure to the reactor pressure vessel shall meet the requirements of this Subsection. Figure NG-1131-1 is provided as an aid in defining the boundary and construction requirements of this Subsection.

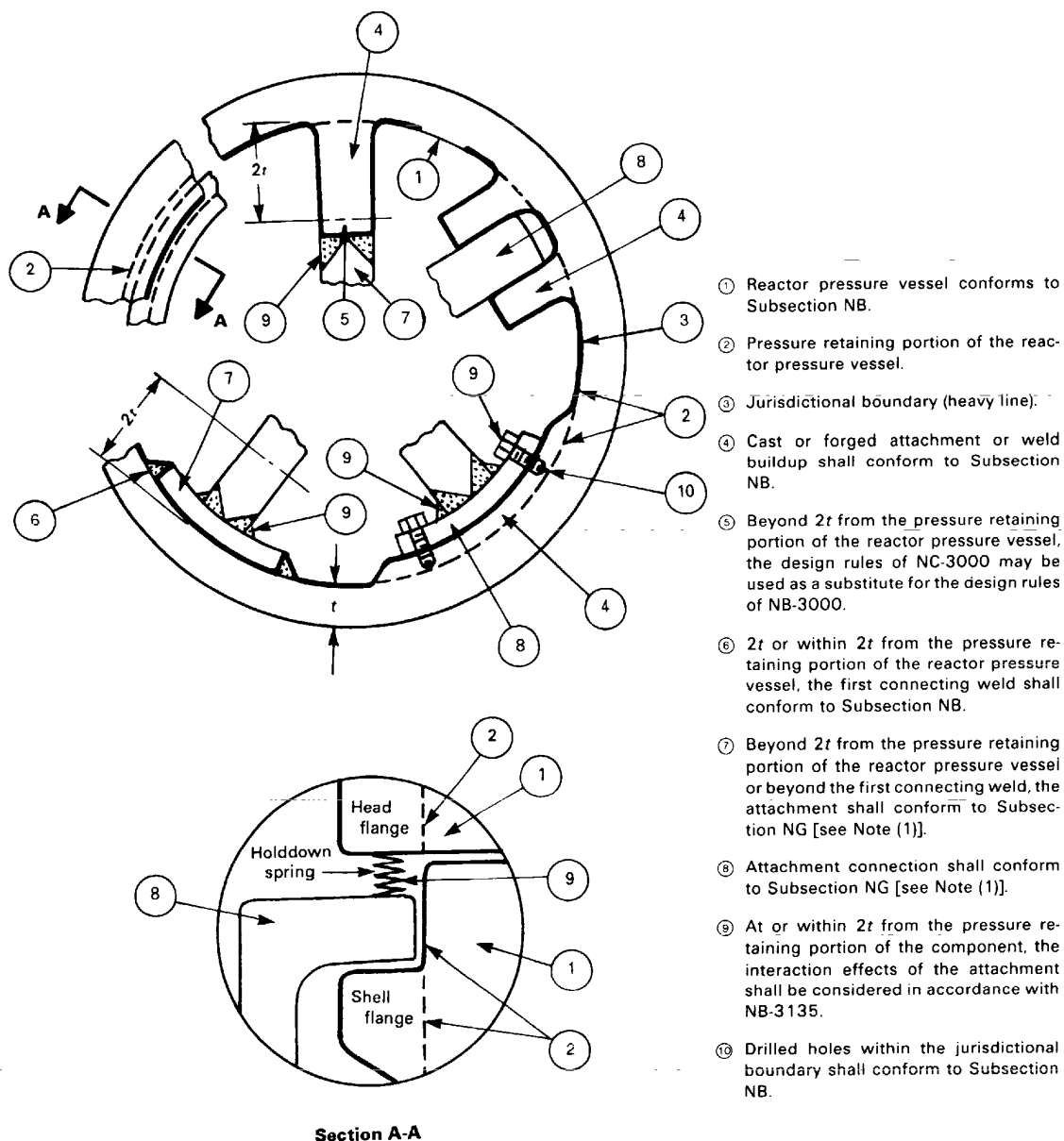
NG-1132 Boundary Between Core Support Structure and Internal Structure

(a) Internal structures may bear on or may be welded, cast, or fastened to core support structures.

(b) The jurisdictional boundary between a core support structure and an internal structure is the surface of the core support structure. The means by which the internal structure is connected to the core support structure shall fall within the jurisdiction of this Subsection.

NG-1133 Boundary Between Core Support Structure and Temporary Attachment

The jurisdictional boundary between a core support structure and a temporary attachment shall be the surface of the core support structure.



GENERAL NOTE:

These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

NOTE:

- (1) If the attachment is an internal structure [NG-1122], material, design, and connections, as appropriate, are outside Code jurisdiction except when the Certificate Holder stipulates they shall conform to Subsection NG.

FIG. NG-1131-1 JURISDICTIONAL BOUNDARY BETWEEN CORE SUPPORT STRUCTURE AND REACTOR PRESSURE VESSEL

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NG-2000

ARTICLE NG-2000 MATERIAL

Page 7

NG-2100 GENERAL REQUIREMENTS FOR MATERIAL

[98]

NG-2110 SCOPE OF PRINCIPAL TERMS EMPLOYED

(a) The term *material* as used in this Subsection is defined in NCA-1220. The term *Material Organization* is defined in NCA-9000.

(b) The requirements of this Article make reference to the term *thickness*. For the purpose intended, the following definitions of nominal thickness apply:

(1) *plate* - the thickness is the dimension of the short transverse direction

(2) *forgings* - the thickness is the dimension defined as follows:

(a) *hollow forgings* - the nominal thickness is measured between the inside and outside surfaces (radial thickness)

(b) *disk forgings* (axial length less than the outside diameter) - the nominal thickness is the axial length

(c) *flat ring forgings* (axial length less than the radial thickness) - for axial length ≤ 2 in. (51 mm), the axial length is the nominal thickness; for axial length > 2 in. (51 mm), the radial thickness is the nominal thickness

(d) *rectangular solid forgings* - the least rectangular dimension is the nominal thickness

(3) *castings* - thickness, t , is defined as the largest nominal thickness of the load carrying portion of the casting.

[98]

NG-2120 MATERIAL FOR CORE SUPPORT STRUCTURES

NG-2121 Permitted Material Specifications

(a) Core support structural material, and material welded thereto, and threaded structural fasteners, with the exception of welding material (NG-2430), hard surfacing material (Section IX, QW-251.4), cladding which is 10% or less of the thickness of the base material (NG-3122), or the material excluded by NG-4231.2, shall conform to the requirements of the specifications for material given in Tables 2A, 2B, and 4, Section II, Part D, Subpart 1 and to all of the special requirements of this Article which apply to the product form in which the material is used.

(b) The requirements of this Article apply to the internal structures (NG-1122) only as specifically stipulated by the Certificate Holder; however, the Certificate Holder shall certify that the material used for the internal structures shall not adversely affect the integrity of the core support structure.

(c) Welding material used in manufacture of items shall comply with an SFA Specification in Section II, Part C, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article. The requirements of this Article do not apply to materials used as backing rings or backing strips in welded joints.

NG-2122 Special Requirements Conflicting With Permitted Material Specifications

Special requirements stipulated in this Article shall apply in lieu of the requirements of the material specification wherever the special requirements conflict with the material specification requirements (NCA-3856). Where the special requirements include an examination, test, or treatment which is also required by the material specification, the examination, test, or treatment need be performed only once. Required nondestructive examinations shall be performed as specified for each product form in NG-2500. Any examination, repair, test, or treatment required by the material specification or this Article may be performed by the Material Organization or the Certificate Holder as provided in NG-4121.1. Any hydrostatic or pneumatic pressure test required by a material specification need not be performed provided the material is not used in a pressure retaining function.

NG-2124 Size Ranges

Material outside the limits of size or thickness given in any specification in Section II may be used if the material is in compliance with the other requirements of the specification and no size limitation is given in the rules for construction. In those specifications in which chemical composition, mechanical properties, or both are indicated to vary with size or thickness, any material outside the specification range shall be required to conform to the composition and mechanical properties shown for the nearest specified range (NCA-3856).

NG-2130 CERTIFICATION OF MATERIAL

All material used in the construction or installation of core support structures shall be certified as required in NCA-3862 and NCA-3861. Certified Material Test Reports are required for core support material except as provided by NCA-3862. A Certificate of Compliance may be provided in lieu of Certified Material Test Reports for all other material. Copies of all Certified Material Test Reports and Certificates of Compliance applicable to material used in a core support structure shall be furnished with the material.

NG-2140 WELDING MATERIAL

For the requirements governing the material to be used for welding, see NG-2400.

NG-2150 MATERIAL IDENTIFICATION

The identification of material for core support structures shall meet the requirements of NCA-3856. Material for small items shall be controlled during manufacture of the core support structures so that they are identifiable as acceptable material at all times. Welding material shall be controlled during the repair of material and the manufacture and installation of core support structures so that they are identifiable as acceptable material until the material is actually consumed in the process (NG-4122).

NG-2160 DETERIORATION OF MATERIAL IN SERVICE

Consideration of deterioration of material caused by service is generally outside the scope of this Subsection. It is the responsibility of the Owner to select material suitable for the conditions stated in the Design Specifications (NCA-3250), with specific attention being given to the effects of service conditions upon the properties of the material.

NG-2170 HEAT TREATMENT TO ENHANCE IMPACT PROPERTIES

Carbon steels, low alloy steels, and high alloy chromium (Series 4XX) steels may be heat treated by quenching and tempering to enhance their impact properties. Postweld heat treatment of the component at a temperature of not less than 1100°F may be considered to be the tempering phase of the heat treatment.

NG-2180 PROCEDURES FOR HEAT TREATMENT OF MATERIAL

When heat treating temperature or time is required by the material specification and the rules of this Subsection, the heat treating shall be performed in temperature-surveyed and -calibrated furnaces or the heat treating shall be controlled by measurement of material temperature by thermocouples in contact with the material or attached to blocks in contact with the material or by calibrated pyrometric instruments. Heat treating shall be performed under furnace loading conditions such

that the heat treatment is in accordance with the material specification and the rules of this Subsection.

NG-2190 TEMPORARY ATTACHMENT MATERIAL

Material used for temporary attachments need not comply with NG-2000 and may be welded to the core support structure provided the requirements of NG-4430 are met.

Page 13

NG-2200 MATERIAL TEST COUPONS AND SPECIMENS FOR FERRITIC STEEL MATERIAL

NG-2210 HEAT TREATMENT REQUIREMENTS

NG-2211 Test Coupon Heat Treatment for Ferritic Material¹

Where ferritic steel material is subjected to heat treatment during construction, the material used for the tensile and impact test specimens shall be heat treated in the same manner as the core support structures, except that test coupons and specimens for P-No. 1 material with a nominal thickness of 2 in. or less are not required to be so heat treated. The Certificate Holder shall provide the Material Organization with the temperature and heating and cooling rate to be used. In the case of postweld heat treatment, the total time at temperature or temperatures for the test material shall be at least 80% of the total time at temperature or temperatures during actual postweld heat treatment of the material and the total time at temperature or temperatures for the test material, coupon, or specimen may be performed in a single cycle.

NG-2212 Test Coupon Heat Treatment for Quenched and Tempered Material

NG-2212.1 Cooling Rates.

Where ferritic steel material is subjected to quenching from the austenitizing temperature, the test coupons representing those materials shall be cooled at a rate similar to and no faster than the main body of the material except in the case of certain forgings and castings (NG-2223.3 and NG-2226.4). This rule shall apply for coupons taken directly from the material as well as for separate test coupons representing the material, and one of the general procedures described in NG-2212.2 or one of the specific procedures described in NG-2220 shall be used for each product form.

1 Any postweld heat treatment time which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specifications. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

2 Annex A1 of SA-654 may be used to satisfy the requirements of NG-2212.2(a) and (b) for forgings.

NG-2212.2 General Procedures.²

One of the general procedures stipulated in (a), (b), and (c) below may be applied to quenched and tempered material or test coupons representing the material, provided the specimens are taken relative to the surface of the product in accordance with NG-2220. Further specific details of the methods to be used shall be the obligation of the Material Organization and the Certificate Holder.

(a) Any procedure may be used which can be demonstrated to produce a cooling rate in the test material that matches the cooling rate of the main body of the product at the region midway between midthickness and the surface ($1/4t$) and no nearer any heat treated edge than a distance equal to the nominal thickness t being quenched within 25°F and 20 sec at all temperatures after cooling begins from the austenitizing temperature.

(b) If cooling rate data for the material and cooling rate control devices for the test specimens are available, the test specimens may be heat treated in the device to represent the material provided that the provisions of (a) above are met.

(c) When any of the specific procedures described in NG-2220 are used, faster cooling rates at the edges may be compensated for by:

(1) taking the test specimens at least t from a quenched edge where t equals the material thickness;

(2) attaching a steel pad at least t wide by a partial penetration weld (which completely seals the buffered surface) to the edge where specimens are to be removed;

(3) using thermal barriers or insulation at the edge where specimens are to be removed.

It shall be demonstrated (and this information shall be included in the Certified Material Test Report) that the cooling rates are equivalent to (a) or (b) above.

NG-2220 PROCEDURE FOR OBTAINING TEST COUPONS AND SPECIMENS FOR QUENCHED AND TEMPERED MATERIAL

NG-2221 General Requirements

The procedure for obtaining test coupons and specimens for quenched and tempered material is related to the product form. Coupon and specimen location and the number of tension test specimens shall be in accordance with the material specifications, except as required by this Subarticle. References to dimensions signify nominal values.

NG-2222 Plates

NG-2222.1 Number of Tension Test Coupons.

The number of tension test coupons required shall be in accordance with the material specification and SA-20,

Page 14

except that from carbon steel plates weighing 42,000 lb (20050 kg) and over and alloy steel plates weighing 40,000 lb (18140 kg) and over, two tension test coupons shall be taken, one representing the top end of the plate and one representing the bottom end of the plate.

NG-2222.2 Orientation and Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from a rolled surface and with the midlength of the specimen at least t from any heat treated edge, where t is the nominal thickness of the material.

NG-2222.3 Requirements for Separate Test Coupons.

Where a separate test coupon is used to represent the core support structure material, it shall be of sufficient size to ensure that the cooling rate of the region from which the test coupons are removed represents the cooling rate of the material at least $\frac{1}{4}t$ deep and t from any edge of the product. Unless cooling rates applicable to the bulk pieces or product are simulated in accordance with NG-2212.2(b), the dimensions of the coupon shall be not less than $3t \times 3t \times t$, where t is the nominal material thickness.

NG-2223 Forgings

NG-2223.1 Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from any surface and with the midlength of the specimens at least t from any second surface, where t is the maximum heat treated thickness. A thermal buffer as described in NG-2212.2(c) may be used to achieve these conditions, unless cooling rates applicable to the bulk forgings are simulated as otherwise provided in NG-2212.2.

NG-2223.2 Very Thick and Complex Forgings.

Test coupons for forgings which are both very thick and complex, such as contour nozzles, flanges, nozzles, and other complex forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment, may be removed from prolongations or other stock provided on the product. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service. The coupons shall be taken so that specimens shall have their longitudinal axes at a distance below the nearest heat treated surface, equivalent at least to the greatest distance that the indicated high tensile stress surface will be from the nearest surface during heat

treatment, and with the midlength of the specimens a minimum of twice this distance from a second heat treated surface. In any case, the longitudinal axes of the specimens shall not be nearer than $\frac{3}{4}$ in. (19 mm) to any heat treated surface and the midlength of the specimens shall be at least $1\frac{1}{2}$ in. (38 mm) from any second heat treated surface.

NG-2223.3 Coupons From Separately Produced Test Forgings.

Test coupons representing forgings from one heat and one heat treatment lot may be taken from a separately forged piece under the conditions given in (a) through (e) below.

(a) The separate test forging shall be of the same heat of material and shall be subjected to substantially the same reduction and working as the production forging it represents.

(b) The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forging.

(c) The separate test forging shall be of the same nominal thickness as the production forging.

(d) Test coupons for simple forgings shall be taken so that specimens shall have their longitudinal axes at the region midway between midthickness and the surface and with the midlength of the specimens no nearer any heat treated edge than a distance equal to the forging thickness except when the thickness-to-length ratio of the production forging does not permit, in which case a production forging shall be used as the test forging and the midlength of the specimens shall be at the midlength of the test forging.

(e) Test coupons for complex forgings shall be taken in accordance with NG-2223.2.

NG-2224 Location of Coupons

(a) *Bars.* Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside or rolled surface and with the midlength of the specimens at least t from a heat treated end, where t is either the bar diameter or thickness.

(b) *Bolting Material.* For bolting material, the coupons shall be taken in conformance with the applicable material specification and with the midlength of the specimen at least one diameter or thickness from a heat treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

Page 15

NG-2225 Tubular Products and Fittings

NG-2225.1 Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the inside or outside surface and with the midlength of the specimens at least t from a heat treated end, where t is the nominal wall thickness of the tubular product.

NG-2225.2 Separately Produced Coupons Representing Fittings.

Separately produced test coupons representing fittings may be used. When separately produced coupons are used, the requirements of NG-2223.3 shall be met.

NG-2226 Castings

NG-2226.1 Castings With 2 in. (51 mm) Maximum Thickness and Less.

For castings with a maximum thickness of 2 in. (51 mm) and less, the specimens shall be taken from either the standard separately cast coupons or the casting, in accordance with the material specification.

NG-2226.2 Castings With Thicknesses Exceeding 2 in. (51 mm) Maximum Thickness.

For castings exceeding a thickness of 2 in. (51 mm), the coupons shall be taken from the casting (or an extension of it) so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ of the maximum heat treated thickness from any surface and with the midlength of the specimens at least t from any second surface. A thermal buffer may be used [NG-2212.2 (c)].

NG-2226.3 Separately Cast Test Coupons for Castings With Thicknesses Exceeding 2 in (51 mm).

In lieu of the requirements of NG-2226.2, separately cast test coupons may be used under the conditions in (a), (b), and (c) below.

(a) The separate test coupon representing castings from one heat and one heat treatment lot shall be of the same heat of material and shall be subjected to substantially the same foundry practices as the production casting it represents.

(b) The separate test coupon shall be heat treated in the same furnace charge and under the same conditions as the production casting, unless cooling rates applicable to the bulk castings are simulated in accordance with NG-2212.2.

(c) The separate test coupon shall be not less than $3t \times 3t \times t$, where t equals the nominal thickness of the casting. Test specimens shall be taken with their longitudinal axes at the region midway between midthickness and the surface and with the midlength of the specimens no nearer any heat treated edge than a distance equal to the casting thickness.

NG-2226.4 Castings Machined or Cast to Finished Configuration Before Heat Treatment.

In lieu of the requirements of NG-2226.1, NG-2226.2, or NG-2226.3, test coupons may be removed from prolongations or other stock provided on the product. The coupons shall be taken so that specimens shall have their longitudinal axes at a distance below the nearest heat treated surface equivalent at least to the greatest distance that the indicated high tensile stress surface will be from the nearest outside surface during heat treatment and with the midlength of the specimens a minimum of twice this distance from a second heat treated surface. In any case, the longitudinal axes of the specimens shall be at least $\frac{3}{4}$ in. from any heat treated surface and the midlength of the specimens shall be at least $1\frac{1}{2}$ in. from any second heat treated surface. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service.

NG-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL

NG-2310 MATERIAL TO BE IMPACT TESTED

NG-2311 Components for Which Impact Testing of Material Is Required

(a) When the Design Specifications for core support structures require impact testing³ they shall be impact tested in accordance with the requirements of NG-2300, except that the following materials are not to be impact tested as a requirement of this Subsection:

- (1) material with a nominal section thickness of $\frac{5}{8}$ in. (16 mm) and less;
- (2) threaded structural fasteners, including studs, nuts, and bolts with a nominal size of 1 in. (25 mm) and less;
- (3) bars with a nominal cross-sectional area of 1 sq in. (645 mm²) and less;
- (4) all thicknesses of materials for pipe, tube, and fittings with a nominal pipe size 6 in. (DN 150) diameter and smaller;
- (5) austenitic stainless steels;
- (6) nonferrous material.

³ When impact testing is required, the methods of Appendix G may be used as an alternative procedure for assuring protection against nonductile fracture.

(b) Drop weight tests are not required for martensitic high alloy chromium (Series 4XX) steels and precipitation-hardening

steels listed in Tables 2A and 2B, Section II, Part D, Subpart 1. The other requirements of NG-2331 and NG-2332 apply for these steels. For nominal wall thickness greater than $2\frac{1}{2}$ in. (64 mm), the required C_v value shall be 40 mils (1.00 mm) lateral expansion.

NG-2320 IMPACT TEST PROCEDURES

NG-2321 Types of Tests

NG-2321.1 Drop Weight Tests.

The drop weight test, when required, shall be performed in accordance with ASTM E 208-91. Specimen types P-1, P-2, or P-3 may be used. The orientations and locations of all test specimens and the results of all tests performed to meet the requirements of NG-2330 shall be reported in the Certified Material Test Report.

NG-2321.2 Charpy V-Notch Tests.

The Charpy V-notch test (C_v), when required, shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Fig. 11, Type A. A test shall consist of a set of three full-size 10 mm × 10 mm specimens. The lateral expansion and absorbed energy, as applicable, and the test temperature, as well as the orientation and location of all tests performed to meet the requirements of NG-2330 shall be reported in the Certified Material Test Report.

NG-2322 Test Specimens

NG-2322.1 Location of Test Specimens.

Impact test specimens for quenched and tempered material shall be removed from the locations in each product form specified in NG-2220 for tensile test specimens. For material in other heat treated conditions, impact test specimens shall be removed from the locations specified for tensile specimens in the material specification. For all other material, the number of tests shall be in accordance with NG-2340. For threaded structural fasteners, the C_v impact test specimens shall be taken with the longitudinal axis of the specimen located at least one-half radius or 1 in. (25 mm) below the surface plus the machining allowance per side, whichever is less. The fracture plane of the specimens shall be at least one diameter or thickness from the heat treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

NG-2322.2 Orientation of Impact Test Specimens

(a) Specimens for Charpy V-notch tests shall be oriented as follows.

(1) Specimens for forgings, other than threaded structural fasteners and bars, shall be oriented in a direction normal to the principal direction in which the material was worked. Specimens are neither required nor prohibited from the thickness direction.

(2) Specimens from material for pipe, tube, and fittings, except for those made from plate, shall be oriented in the axial direction.

(3) Specimens from threaded structural fastener material and bars shall be oriented in the axial direction.

(4) Specimens for all plate material, including those used for pipe, tube, and fittings, shall be oriented in a direction normal to the principal rolling direction, other than thickness direction.

(5) Specimens for cast material shall have their axes oriented the same as the axes of the tensile specimens (NG-2226).

(6) In cases (1) through (5) above, the length of the notch of the C_v specimen shall be normal to the surface of the material.

(b) Specimens for drop weight tests may have their axes oriented in any direction. The orientation used shall be reported in the Certified Material Test Report.

NG-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS⁴

NG-2331 Material for Core Support Structures Not Exceeding 2 in. Maximum Thickness

Material for core support structures (other than threaded structural fasteners) with nominal thickness 2 in. and less shall be tested as required in (a) and (b) below.

(a) Test three C_v specimens at a temperature lower than or equal to the lowest service temperature.⁵ All

4 In addition to providing a basis for acceptance standards for material, the test data are designated to be used as a basis for establishing in-service operation and for use in fracture prevention evaluation (Appendix G).

5 Lowest service temperature is the minimum temperature of the fluid around the component or, alternatively, the calculated volumetric average metal temperature expected during normal operation whenever the pressure within the reactor vessel exceeds 20% of the preoperational system hydrostatic test pressure.

Page 17

three specimens shall meet the requirements of Table NG-2331(a)-1.

**TABLE NG-2331(a)-1
REQUIRED C_v VALUES FOR CORE
STRUCTURE MATERIAL WITH 2 in. MAXIMUM
THICKNESS (OTHER THAN THREADED
STRUCTURAL FASTENERS)**

Nominal Wall Thickness, in.	Lateral Expansion, mils
$\frac{5}{8}$ or less	No test required
Over $\frac{5}{8}$ to $\frac{3}{4}$, incl.	20
Over $\frac{3}{4}$ to $1\frac{1}{2}$, incl.	25
Over $1\frac{1}{2}$ to $2\frac{1}{2}$, incl.	40

TABLE NG-2331(a)-1 REQUIRED C_v VALUES FOR CORE STRUCTURE MATERIAL WITH 2 in. MAXIMUM THICKNESS (OTHER THAN THREADED STRUCTURAL FASTENERS)

(b) Apply the procedures of (a) above to:

(1) base material;

(2) the base material, the heat affected zone, and weld metal from the weld procedure qualification tests in accordance with NG-4330;

with NG-4330;

(3) the weld metal of NG-2431.

NG-2332 Material With Thickness Exceeding 2 in. (51 mm)

Material for core support structures (other than threaded structural fasteners) with nominal wall thickness over 2 in. shall meet the requirements of (a) through (d) below.

(a) Establish a reference temperature RT_{NDT} ; this shall be done as required in (1) through (5) below.

(1) Determine a temperature T_{NDT} which is at or above the nil-ductility transition temperature by drop weight tests.

(2) At a temperature not greater than $(T_{NDT} + 60^\circ\text{F})$, each specimen of the C_v test (NG-2321.2) shall exhibit at least 35 mils lateral expansion and not less than 50 ft-lb absorbed energy. Retesting in accordance with NG-2350 is permitted. When these requirements are met, T_{NDT} is the reference temperature RT_{NDT} .

(3) In the event that the requirements of Step (2) are not met, conduct additional C_v tests in groups of three specimens (NG-2321.2) to determine the temperature T_{C_v} at which they are met. In this case, the reference temperature $RT_{NDT} = T_{C_v} - 60^\circ\text{F}$. Thus, the reference temperature RT_{NDT} is the higher of T_{NDT} or $(T_{C_v} - 60^\circ\text{F})$.

TEXT

(4) When a C_v test has not been performed at $(T_{NDT} + 60^\circ\text{F})$ or when the C_v test at $(T_{NDT} + 60^\circ\text{F})$ does not exhibit a minimum of 50 ft-lb energy absorption and 35 mils lateral expansion, a temperature representing a minimum of 50 ft-lb energy absorption and 35 mils lateral expansion may be obtained from a full C_v impact curve developed from the minimum data points of all the C_v tests performed.

TABLE NG-2333-1 REQUIRED C_v VALUES FOR THREADED STRUCTURAL FASTENER MATERIAL

Nominal Diameter, in.	Lateral Expansion, mils	Absorbed Energy, ft-lb
1 or less	No test required	No test required
1 through 4	25	No requirements
Over 4	25	45

TABLE NG-2333-1 REQUIRED C_v VALUES FOR THREADED STRUCTURAL FASTENER MATERIAL

(5) The lowest service temperature shall be not lower than $RT_{NDT} + 100^\circ\text{F}$ unless a lower temperature is justified by using methods similar to those contained in G-2000.

(b) Apply the procedures of (a) above to:

(1) the base material;

(2) the base material, the heat affected zone, and weld metal from the weld procedure qualification tests in accordance with NG-4330;

(3) the weld metal of NG-2431.

(c) Product forms having dimensions which prohibit obtaining drop weight test specimens shall be tested in accordance with NG-2331.

(d) Consideration shall be given to the effects of irradiation on material toughness properties (such as core beltline region of reactor). The Design Specifications shall include additional requirements, as necessary, to assure adequate fracture toughness for the service lifetime of the core support structures. The toughness properties may be verified in service periodically by a material surveillance program using the methods of ASTM E 185-82 and the material conditions monitored by the in-service inspection requirements of Section XI.

NG-2333 Threaded Structural Fasteners

For threaded structural fastener material, including studs and nuts, test three C_v specimens at a temperature no higher than the preload temperature or the lowest service temperature, whichever is the lesser. All three specimens shall meet the requirements of Table NG-2333-1.

Page 18

NG-2340 NUMBER OF IMPACT TESTS REQUIRED

NG-2341 Plates

One test shall be made from each plate as heat treated. Where plates are furnished in the nonheat-treated condition and qualified by heat treated test specimens, one test shall be made for each plate as-rolled. The term *as-rolled* refers to the plate rolled from a slab or directly from an ingot, not to its heat treated condition.

NG-2342 Forgings and Castings

(a) Where the weight of an individual forging or casting is less than 1000 lb (454 kg), one test shall be made to represent each heat in each heat treatment lot.

(b) When heat treatment is performed in a continuous type furnace with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a heat treatment charge shall be considered as the lesser of a continuous run not exceeding 8 hr duration or a total weight, so treated, not exceeding 2000 lb (907 kg).

(c) One test shall be made for each forging or casting of 1000 lb to 10,000 lb (454 kg to 4540 kg) in weight.

(d) As an alternative to (c) above, a separate test forging or casting may be used to represent forgings or castings of different sizes in one heat and heat treat lot, provided the test piece is a representation of the greatest thickness in the heat treat lot. In addition, test forgings shall have been subjected to substantially the same reduction and working as the forgings represented.

(e) Forgings or castings larger than 10,000 lb (4540 kg) shall have two tests per part for Charpy V-notch and one test for drop weights. The location of drop weight or C_v impact test specimens shall be selected so that an equal number of specimens is obtained from positions in the forging or casting 180 deg. apart.

(f) As an alternative to (e) for static castings, a separately cast test coupon (NG-2226.3) may be used; one test shall be made for Charpy V-notch and one test for drop weight.

NG-2343 Bars

One test shall be made for each diameter or size having a nominal cross-sectional area greater than 1 sq in. in each lot, where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed 6000 lb (2720 kg).

NG-2344 Tubular Products and Fittings

On products which are seamless or welded without filler metal, one test shall be made from each lot. On products which are welded with filler metal, one additional test with the specimens taken from the weld area shall also be made on each lot. A lot shall be defined as stated in the applicable material specification but in no case shall a lot consist of products from more than one heat of material and of more than one diameter, with the nominal thickness of any product included not exceeding that to be impact tested by more than $1/4$ in.; such a lot shall be in a single heat treatment load or in the same continuous run in a continuous furnace controlled within a 50°F range and equipped with recording pyrometers.

NG-2345 Threaded Structural Fastener Material

One test shall be made for each lot of material where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed in weight the following:

$1\frac{3}{4}$ in. diameter and less	1,500 lb
Over $1\frac{3}{4}$ in. to $2\frac{1}{2}$ in. diameter	3,000 lb
Over $2\frac{1}{2}$ in. to 5 in. diameter	6,000 lb
Over 5 in. diameter	10,000 lb

NG-2346 Test Definition

Unless otherwise stated in NG-2341 through NG-2345, the term *one test* is defined to include the combination of the drop weight test and the C_v test when RT_{NDT} is required (NG-2332) and only the C_v test when determination of RT_{NDT} is not required (NG-2331).

NG-2350 RETESTS

- (a) For C_v tests required by NG-2330, one retest at the same temperature may be conducted, provided:
- (1) the average value of the test results meets the minimum requirements;
 - (2) not more than one specimen per test is below the minimum requirements;
 - (3) the specimen not meeting the minimum requirements is not lower than 10 ft-lb (13.6 J) or 5 mils (0.13 mm) below the specified requirements.
- (b) A retest consists of two additional specimens taken as near as practicable to the failed specimens.
-

Page 19

For acceptance of the retest, both specimens shall meet the minimum requirements.

NG-2360 CALIBRATION OF INSTRUMENTS AND EQUIPMENT

Calibration of temperature instruments and C_v impact test machines used in impact testing shall be performed at the frequency specified in (a) or (b) below.

- (a) Temperature instruments used to control test temperature of specimens shall be calibrated and the results recorded to meet the requirements of NCA-3868 at least once in each 3 month interval.
- (b) C_v test machines shall be calibrated and the results recorded to meet the requirements of NCA-3868. The calibrations shall be performed at least once per year using methods outlined in ASTM E 23-72 and employing standard specimens obtained from the National Institute of Standards and Technology.

NG-2400 WELDING MATERIAL

NG-2410 GENERAL REQUIREMENTS

- (a) All welding material used in the construction and repair of components or material, except welding material used for hard surfacing, shall conform to the requirements of the material specification or to the requirements for other welding material as permitted in Section IX. In addition, welding material shall conform to the requirements stated in this Subarticle and to the rules covering identification in NG-2150.
- (b) The Certificate Holder shall provide the organization performing the testing with the information listed below, as applicable:
- (1) welding process;
 - (2) SFA Specification and classification;
 - (3) other identification if no SFA Specification applies;
 - (4) minimum tensile strength [NG-2431.1(e)] in either the as-welded or heat treated condition, or both [NG-2431.1(c)];
 - (5) drop weight test for material as-welded or heat treated, or both (NG-2332);
 - (6) Charpy V-notch test for material as-welded or heat treated, or both (NG-2331); the test temperature, and the lateral expansion or the absorbed energy, shall be provided;
 - (7) the preheat and interpass temperatures to be used during welding of the test coupon [NG-2431.1(c)];
 - (8) postweld heat treatment time, temperature range, and maximum cooling rate, if the production weld will be heat treated [NG-2431.1(c)];
 - (9) elements for which chemical analysis is required per the SFA Specification or WPS, and NG-2432;
 - (10) minimum delta ferrite (NG-2433).

NG-2420 REQUIRED TESTS

The required tests shall be conducted for each lot of covered, flux cored, or fabricated electrodes; for each heat of bare electrodes, rod, or wire for use with the OFW, GMAW, GTAW, PAW, and EGW (electro-gas welding) processes (Section IX, QW-492); for each heat of consumable inserts; for each combination of heat of bare electrodes and lot of submerged arc flux; for each combination of lot of fabricated electrodes and lot of submerged arc flux; for each combination of heat of bare electrodes or lot of fabricated electrodes and dry blend of supplementary powdered filler metal and lot of submerged arc flux; or for each combination of heat of bare electrodes and lot of electrosag flux. Tests performed on welding material in the qualification of weld procedures will satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used, provided the tests required by NG-4000 and this Subarticle are made and the results conform to the requirements of this Article. The definitions in (a) through (h) below apply.

(a) A *dry batch of covering mixture* is defined as the quantity of dry covering ingredients mixed at one time in one mixing vessel; a dry batch may be used singly or may be subsequently subdivided into quantities to which the liquid binders may be added to produce a number of wet mixes [(c) below].

(b) A *dry blend* is defined as one or more dry batches mixed in a mixing vessel and combined proportionately to produce a uniformity of mixed ingredients equal to that obtained by mixing the same total amount of dry ingredients at one time in one mixing vessel.

(c) A *wet mix* is defined as the combination of a dry batch or dry blend [(a) and (b) above, respectively] and liquid binder ingredients at one time in one mixing vessel.

(d) A *lot of covered, flux cored, or fabricated electrodes* is defined as the quantity of electrodes produced from the same combination of heat of metal and dry batch, dry blend, or chemically controlled mixes of flux or core materials. Alternatively, a lot of covered, flux cored, or fabricated electrodes may be considered one type and size of electrode, produced in a continuous period, not to exceed 24 hr and not to exceed 100,000

Page 20

lb (45360 kg), from chemically controlled tube, wire, or strip and a dry batch, a dry blend, or chemically controlled mixes of flux, provided each container of welding materials is coded for identification and traceable to the production period, the shift, line, and the analysis range of both the mix and the rod, tube, or strip used to make the electrodes.

(1) *Chemically controlled tube, wire, or strip* is defined as consumable tube, wire, or strip material supplied on coils with a maximum of one splice per coil that has been chemically analyzed to assure that the material conforms to the electrode manufacturer's chemical control limits for the specific type of electrode. Both ends of each coil shall be chemically analyzed, except those coils which are splice free need only be analyzed on one end of the coil.

(2) *Chemically controlled mixes of flux* are defined as flux material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the electrode manufacturer's standard for each chemical element for that type electrode. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending.

(e) A *heat of bare electrode, rod, wire, or consumable insert* is defined as the material produced from the same melt of metal.

(f) Alternatively, for carbon and low alloy steel bare electrode, rod, wire, or consumable inserts for use with SAW, OFW, GMAW, GTAW, PAW, and EGW processes, a *heat* may be defined as either the material produced from the same melt of metal, or the material produced from one type and size of wire when produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45360 kg), from chemically controlled wire, subject to requirements of (1), (2), and (3) below.

(1) For the chemical control of the product of the rod mill, coils shall be limited to a maximum of one splice prior to processing the wire. Chemical analysis shall be made from a sample taken from both ends of each coil of mill coiled rod furnished by mills permitting spliced coil practice of one splice maximum per coil. A chemical analysis need be taken from only one end of rod coils furnished by mills prohibiting spliced coil practice.

(2) Carbon, manganese, silicon, and other intentionally added elements shall be determined to identify the material to ensure that it conforms to the SFA or user's material specification.

(3) Each container of wire shall be coded for identification and traceability to the lot, production period, shift, line, and analysis of rod used to make the wire.

(g) A lot of submerged arc or electroslag flux is defined as the quantity of flux produced from the same combination of raw materials under one production schedule.

(h) A dry blend of supplementary powdered filler metal is defined as one or more mixes of material produced in a continuous period, not to exceed 24 hr and not to exceed 20,000 lb (9070 kg), from chemically controlled mixes of powdered filler metal, provided each container of powdered metal is coded for identification and traceable to the production period, the shift, and the mixing vessel. A chemically controlled mix of powdered filler metal is defined as powdered filler metal material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the powdered filler metal manufacturer's standard, for each chemical element, for that type of powdered filler metal. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending. The chemical analysis range of the supplemental powdered filler shall be the same as that of the welding electrode, and the ratio of powder to electrode used to make the test coupon shall be the maximum permitted for production welding.

NG-2430 WELD METAL TESTS

NG-2431 Mechanical Properties Test

Tensile and impact tests shall be made, in accordance with this paragraph, of welding material used to join P-Nos. 1, 3, 4, 5, 6, 7, 9, and 11 base materials in any combination, with the exceptions listed in (a) through (d) below:

- (a) austenitic stainless steel and nonferrous welding material used to join the listed P-Numbers;
- (b) consumable inserts (backing filler material);
- (c) welding material used for GTAW root deposits with a maximum of two layers;
- (d) welding material to be used for the welding of base material exempted from impact testing by NG-2300 shall likewise be exempted from the impact testing required by this paragraph.

NG-2431.1 General Test Requirements.

The welding test coupon shall be made in accordance with (a) through (f) below using each process with which the weld material will be used in production welding.

- (a) Test coupons shall be of sufficient size and thickness such that the test specimens required herein can be removed.
- (b) The weld metal to be tested for all processes except electroslag welding shall be deposited in such

Page 21

a manner as to eliminate substantially the influence of the base material on the results of the tests. Weld metal to be used with the electroslag process shall be deposited in such a manner as to conform to one of the applicable Welding Procedure Specifications (WPS) for production welding, Section IX, QW-201.1. The base material shall conform with the requirements of Section IX, QW-403.1 or QW-403.4, as applicable.

(c) The welding of the test coupon shall be performed within the range of preheat and interpass temperatures which will be used in production welding. Coupons shall be tested in the as-welded condition or they shall be tested in the applicable postweld heat treated condition when the production welds are to be postweld heat treated. The postweld heat treatment holding time⁶ shall be at least 80% of the maximum time to be applied to the weld metal in production application. The total time for postweld heat treatment of the test coupon may be applied in one heating cycle. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the component. In addition, weld coupons for weld metal to be used with the electroslag process that are tested in the as-welded condition, or following a postweld heat treatment within the holding temperature ranges of Tables NG-4622.1-1 or NG-4622.4(c)-1, shall have a thickness within the range of 0.5 to 1.1 times the thickness of the welds to be made in production. Electroslag weld coupons to be tested following a postweld heat treatment which will include heating the coupon to a temperature above the "Holding Temperature Range" of Table NG-4622.1-1 for the type of material being tested shall have a thickness within the range of 0.9 to 1.1 times the thickness of the welds to be made in production.

- (d)

(d) Regardless of the welding process or welding material being tested, the tensile specimens, and the C_v impact specimens where required, shall be located and prepared in accordance with the requirements of SFA-5.1, Specification for Mild Steel Covered Electrodes. Drop weight impact test specimens, where required, shall be oriented so that the longitudinal axis is transverse to the weld with the notch in the weld face or in a plane parallel to the weld face. For impact specimen preparation and testing, the applicable parts of NG-2321.1 and NG-2321.2 shall apply. The longitudinal axis of the specimen shall be at a minimum depth of $1/4$ from a surface, where t is the thickness of the test weld.

6 Any postweld heat treatment time which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

(e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the base material specification. When base materials of different specifications are to be welded, the tensile strength requirements shall conform to the specified minimum tensile strength requirements of either of the base material specifications.

(f) Impact specimens of the weld metal shall be tested where impact tests are required for either of the base materials of the production weld. The weld metal shall conform to the requirements of NG-2330 applicable to the base material. Where different requirements exist for the two base materials, the weld metal may conform to either of the two requirements.

NG-2431.2 Standard Test Requirements.

In lieu of the use of the General Test Requirements specified in NG-2431.1, tensile and impact tests may be made in accordance with this subparagraph where they are required for mild and low alloy steel covered electrodes. The material combinations to require weld material testing, as listed in NG-2431, shall apply for this Standard Test Requirements option. The limitations and testing under this Standard Test option shall be in accordance with (a) through (f) below.

(a) Testing to the requirements of this subparagraph shall be limited to electrode classifications included in Specification SFA-5.1 or SFA-5.5.

(b) The test assembly required by SFA-5.1 or SFA-5.5, as applicable, shall be used for test coupon preparation, except that it shall be increased in size to obtain the number of C_v specimens and the drop weight test specimens required by NG-2330, where applicable.

(c) The welding of the test coupon shall conform to the requirements of the SFA Specification for the classification of electrode being tested. Coupons shall be tested in the as-welded condition and also in the postweld heat treated condition. The postweld heat treatment temperatures shall be in accordance with Table NG-4622.1-1 for the applicable P-Number equivalent. The time at postweld heat treatment temperature shall be 8 hr (this qualifies postweld heat treatments of 10 hr or less). Where the postweld heat treatment of the production weld exceeds 10 hr or the PWHT temperature is other than that required above, the general test of NG-2431.1 shall be used.

(d) The tensile and C_v specimens shall be located and prepared in accordance with the requirements of SFA-5.1 or SFA-5.5, as applicable. Drop weight impact test specimens, where required, shall be located and oriented as specified in NG-2431.1(d).

**TABLE NG-2432.1-1
SAMPLING OF WELDING MATERIALS FOR
CHEMICAL ANALYSIS**

	GTAW/PAW	GMAW	All Other Processes
A-No. 8 filler metal	Filler metal or weld deposit	Weld deposit	Weld deposit
All other filler metal	Filler metal or weld deposit	Filler metal or weld deposit	Weld deposit

TABLE NG-2432.1-1 SAMPLING OF WELDING MATERIAL FOR CHEMICAL ANALYSIS

(e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirement of the SFA Specification for the applicable electrode classification.

(f) The requirements of NG-2431.1(f) shall be applicable to the impact testing of this option.

NG-2432 Chemical Analysis Test

Chemical analysis of filler metal or weld deposits shall be made in accordance with NG-2420 and as required by the following subparagraphs.

NG-2432.1 Test Method.

The chemical analysis test shall be performed in accordance with this subparagraph and Table NG-2432.1-1, and the results shall conform to NG-2432.2.

(a) A-No. 8 welding material to be used with GTAW and PAW processes and any other welding material to be used with any GTAW, PAW, or GMAW process shall have chemical analysis performed either on the filler metal or on a weld deposit made with the filler metal in accordance with (c) or (d) below.

(b) A-No. 8 welding material to be used with other than the GTAW and PAW processes and other welding material to be used with other than the GTAW, PAW, or GMAW process shall have chemical analysis performed on a weld deposit of the material or combination of materials being certified in accordance with (c) or (d) below. The removal of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c) below. As an alternative, the deposit shall be made in accordance with (d) below for material that will be used for corrosion resistant overlay cladding. Where the Welding Procedure Specification or the welding material specification specifies percentage

composition limits for analysis, it shall state that the specified limits apply for either the filler metal analysis or the undiluted weld deposit analysis or for *in situ* cladding deposit analysis in conformance with the above required certification testing.

(c) The preparation of samples for chemical analysis of undiluted weld deposits shall comply with the method given in the applicable SFA Specification. Where a weld deposit method is not provided by the SFA Specification, the sample shall be removed from a weld pad, groove, or other test weld⁷ made using the welding process that will be followed when the welding material or combination of welding materials being certified is consumed. The weld for A-No. 8 material to be used with the GMAW or EGW process shall be made using the shielding gas composition specified in the Welding Procedure Specifications that will be followed when the material is consumed. The test sample for ESW shall be removed from the weld metal of the Mechanical Properties Test coupon. Where a chemical analysis is required for a welding material which does not have a Mechanical Properties Test requirement, a chemical analysis test coupon shall be prepared as required by NG-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of NG-2431.1(c) do not apply.

(d) The alternative method provided in (b) above for the preparation of samples for chemical analysis of welding material to be used for corrosion-resistant overlay cladding shall require a test weld made in accordance with the essential variables of the Welding Procedure Specification that will be followed when the welding material is consumed. The test weld shall be made in conformance with the requirements of Section IX, QW-214.1. The removal of chemical analysis samples shall conform with QW-214.3 for the minimum thickness for which the Welding Procedure Specification is qualified.

NG-2432.2 Requirements for Chemical Analysis.

The chemical elements to be determined, the composition requirements of the weld metal, and the recording of results of the chemical analysis shall be in accordance with (a), (b), and (c) below.

(a) All welding material shall be analyzed for the elements listed in Table NG-2432.2-1 and for other elements specified either in the welding material specification referenced by the Welding Procedure Specification or in the Welding Procedure Specification.

⁷ The methods given in the Appendix of SFA 5.9, Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Rods and Bare Electrodes, shall be used to establish a welding and sampling method for the pad, groove, or other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution.

these composition limits of the Welding Procedure Specification shall apply for acceptability.

TABLE NG-2432.2-1 WELDING MATERIAL CHEMICAL ANALYSIS

Carbon and low alloy materials	C, Cr, Mo, Ni, Mn, Si, P, S, V, Cu
Chromium and Cr-Ni stainless material	C, Cr, Mo, Ni, Mn, Si, P, S, V, Cb + Ta, Ti, cu
Nickel and Ni-alloy materials	C, Cr, Mo, Ni, Mn, Si, S, Cb + Ta, Cu, Fe, Co

TABLE NG-2432.2-1 WELDING MATERIAL CHEMICAL ANALYSIS

(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition limits. Where the Welding Procedure Specification contains a modification of the composition limits of SFA or other referenced welding material specifications, or provides limits for additional elements,

(c) The results of the chemical analysis shall be reported in accordance with NCA-3867. Elements listed in Table NG-2432.2-1 but not specified in the welding material specification shall be reported for information only.

NG-2433 Delta Ferrite Determination

A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, QW-442) backing filler metal (consumable inserts); bare electrode, rod, or wire filler metal; or weld metal, except that delta ferrite determinations are not required for SFA-5.4, Type 16-8-2, or A-No. 8 weld filler metal to be used for weld metal cladding.

NG-2433.1 Method.

Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of chemical analysis of NG-2432 in conjunction with Fig. NG-2433.1-1.

(a) Calibration of magnetic instruments shall conform to AWS A4.2-91.

(b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with NG-2432.1(c).

(c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number (FN).

NG-2433.2 Acceptance Standards.

The minimum acceptable delta ferrite shall be 5FN. The results of the delta ferrite determination shall be included in the Certified Material Test Report of NG-2130 or NG-4120.

NG-2440 STORAGE AND HANDLING OF WELDING MATERIAL

Suitable storage and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by fluxes and cored, fabricated, and coated electrodes.

NG-2500 EXAMINATION AND REPAIR OF CORE SUPPORT STRUCTURE MATERIAL

NG-2510 EXAMINATION OF CORE SUPPORT STRUCTURE MATERIAL

Material for core support structures shall be examined by nondestructive methods applicable to the material and product form as required by the rules of this Subarticle.

NG-2520 EXAMINATION AFTER QUENCHING AND TEMPERING

Ferritic steel products that have their properties enhanced by quenching and tempering shall be examined by the methods specified in this Subarticle for each product form after the quenching and tempering phase of the heat treatment.

NG-2530 EXAMINATION AND REPAIR OF PLATE

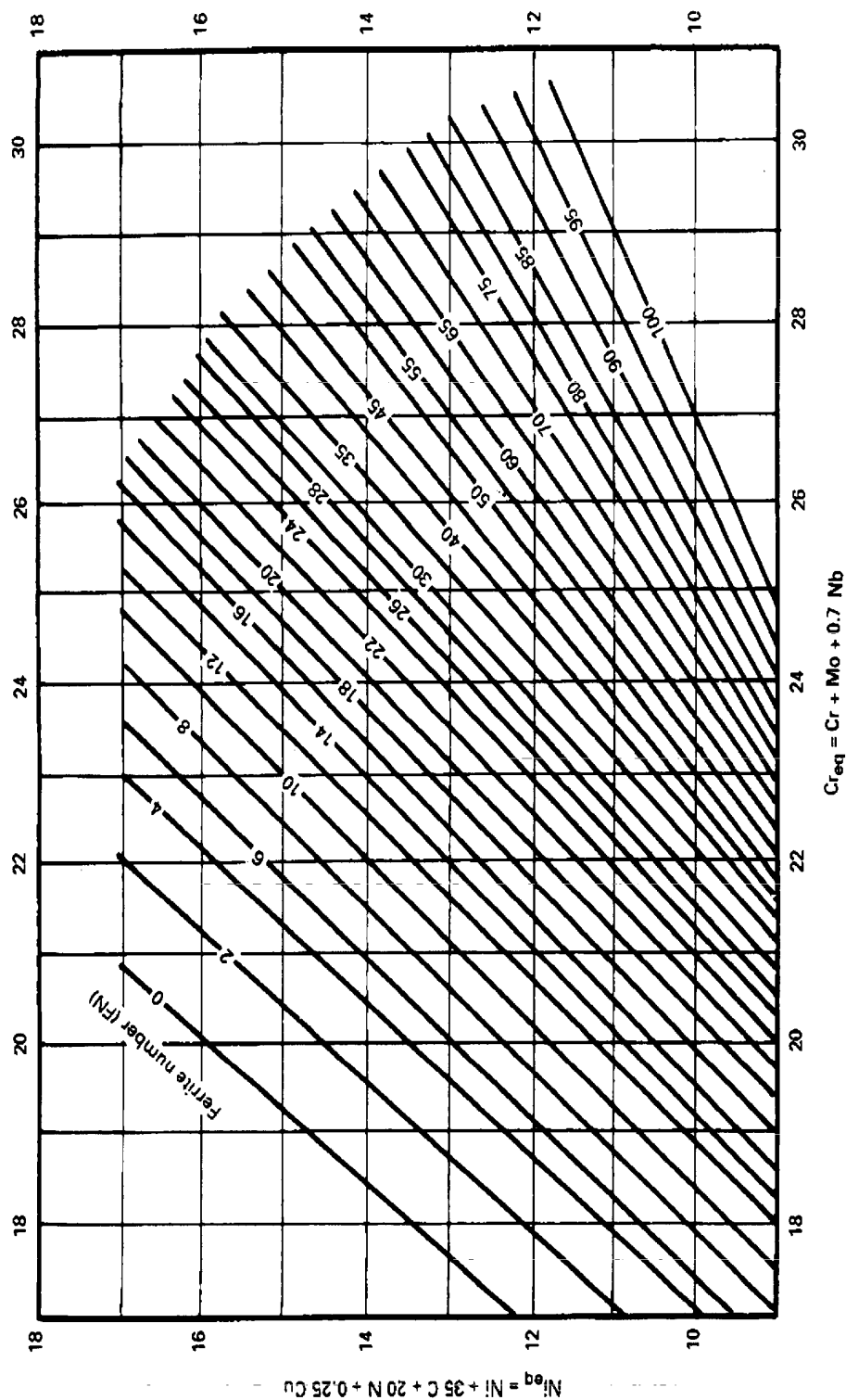
NG-2531 Required Examination

All plates for core support structures greater than $\frac{3}{4}$ in. thickness shall be examined by the straight beam ultrasonic method in accordance with NG-2532.1.

NG-2532 Examination Procedures

NG-2532.1 Straight Beam Examination.

The requirements for straight beam examination shall be in accordance with SA-578, as shown in Section V, except that the extent of examination and the acceptance standards to be applied are given in (a) and (b) below.



GENERAL NOTES:

- (a) The actual nitrogen content is preferred. If this is not available, the following applicable nitrogen value shall be used:
 (1) GMAW welds-0.06%, except that when self shielding flux cored electrodes are used-0.12%.
 (2) Welds made using other processes-0.06%.
 (b) This diagram is identical to the WRC-1992 Diagram, except that the solidification mode lines have been removed for ease of use.

FIG. NG-2433.1-1 WELD METAL DELTA FERRITE CONTENT

FIG. NG-2433.1-1 WELD METAL DELTA FERRITE CONTENT

(a) *Extent of Examination.* 100% of one major plate surface shall be covered by moving the search unit in parallel

paths with not less than a 10% overlap.

(b) Acceptance Standards

(1) Any area where one or more imperfections produce a continuous total loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed within a circle whose diameter is 3 in. or one-half of the plate thickness, whichever is greater, is unacceptable.

(2) In addition, two or more imperfections smaller than described in (1) above shall be unacceptable unless separated by a minimum distance equal to the greatest diameter of the larger imperfection, or unless they may be collectively encompassed by the circle described in (1) above.

NG-2532.2 Angle Beam Examination.

The requirements for angle beam examination shall be in accordance with SA-577, Specification for Ultrasonic Shear Wave Inspection of Steel Plates, as shown in Section V, as supplemented by this subparagraph. The calibration notch, extent of examination, and the acceptance standards to be applied are given in (a) through (c) below.

(a) Calibration. Angle beam examination shall be calibrated from a notch.

(b) Extent of Examination. 100% of one major plate surface shall be covered by moving the search unit in parallel paths with not less than 10% overlap.

(c) Acceptance Standards. Material which shows one or more imperfections which produce indications exceeding in amplitude the indication from the calibration notch is unacceptable.

NG-2537 Time of Examination

Acceptance examinations shall be performed at the time of manufacture as required in (a) through (c) below.

(a) Ultrasonic examination shall be performed after rolling to size and after heat treatment, except postweld heat treatment.

(b) Radiographic examination of repair welds, when required, may be performed prior to any required postweld heat treatment.

(c) Magnetic particle or liquid penetrant examination of repair welds in ferritic material shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment of P-No. 1 material 2 in. and less nominal thickness. All repair welds in austenitic and nonferrous material may be liquid penetrant examined prior to any required postweld heat treatment.

NG-2538 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining provided the requirements of (a) through (d) below are met.

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface with not less than a 3:1 taper.

(b) After defect elimination, the area is examined by the magnetic particle method in accordance with NG-2545 or the liquid penetrant method in accordance with NG-2546 to assure that the defect has been removed or reduced to an imperfection of an acceptable size.

(c) Areas ground to remove oxide scale or other mechanically caused impressions for appearance or to facilitate proper ultrasonic testing need not be examined by the magnetic particle or liquid penetrant test method.

(d) If the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of NG-3000, the product shall be repaired in accordance with NG-2539.

NG-2539 Repair by Welding

Material from which defects have been removed may be repaired by welding, provided the requirements of the following

subparagraphs are met. Prior approval of the Certificate Holder shall be obtained for any repair of plates to be used in the manufacture of core support structures.

NG-2539.1 Defect Removal.

The defect shall be removed or reduced to an imperfection of an acceptable size by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair (NG-4211.1).

NG-2539.2 Qualification of Welding Procedures and Welders.

The welding procedure and welders or welding operators shall be qualified in accordance with NG-4000 and Section IX.

NG-2539.3 Blending of Repaired Areas.

After repair, the surface shall be blended uniformly into the surrounding surface.

NG-2539.4 Examination of Repair Welds.

Each repair weld shall be examined by the magnetic particle method (NG-2545) or by the liquid penetrant method (NG-2546). In addition, when the depth of the repair cavity exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness, the repair weld shall be radiographed in accordance with NG-5000 and to the acceptance standards of NG-5320 or shall be ultrasonically

Page 26

examined after repair in accordance with NG-2532.2 or NG-2532.1.

NG-2539.5 Heat Treatment After Repairs.

The product shall be heat treated after repair in accordance with the heat treatment requirements of NG-4620.

NG-2539.6 Material Report Describing Defects and Repairs.

Each defect repair exceeding in depth the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness and, in addition, all repair welds exceeding an accumulated area of 20% of the area of the part or 15 sq in., whichever is less, shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart which shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographic film.

NG-2540 EXAMINATION AND REPAIR OF FORGINGS AND BARS

NG-2541 Required Examinations

(a) Forgings NG-2551 shall be examined by the ultrasonic method in accordance with NG-2542, except that forgings or sections of forgings which have coarse grains or configurations which do not yield meaningful examination results by ultrasonic methods shall be examined by radiographic methods in accordance with Section V, Article 2, and the acceptance standards of NG-5320. In addition, selected surfaces, as designated by the Certificate Holder, shall be liquid penetrant examined in accordance with NG-2546 or magnetic particle examined in accordance with NG-2545.

(b) Forged flanges and fittings, such as elbows, tees, and couplings, shall be examined in accordance with the requirements of NG-2550.

(c) Bar material used for threaded structural fasteners shall be examined in accordance with NG-2580.

NG-2542 Ultrasonic Examination

NG-2542.1 Examination Procedure.

All forgings in the rough forged or finished condition, and bars, shall be examined in accordance with one of the

following specifications: SA-745, Standard Practice for Ultrasonic Examination of Austenitic Steel Forgings; or SA-388, Recommended Practice for Ultrasonic Testing and Inspection of Heavy Steel Forgings, as shown in Section V, Article 23. Contact, immersion, or water column coupling is permissible. The techniques of (a) through (c) below are required, as applicable.

(a) All forgings and bars shall be examined by the ultrasonic method using the straight beam technique.

(b) Ring forgings and other hollow forgings shall, in addition, be examined using the angle beam technique in two circumferential directions, unless wall thickness or geometric configuration makes angle beam examination impractical.

(c) Forgings may be examined by the use of alternative ultrasonic methods which utilize distance amplitude corrections provided the acceptance standards are shown to be equivalent to those listed in NG-2542.2.

NG-2542.2 Acceptance Standards

(a) *Straight Beam General Rule.* A forging shall be unacceptable if the results of straight beam examinations show one or more reflectors which produce indications accompanied by a complete loss of back reflection not associated with or attributable to geometric configurations. Complete loss of back reflection is assumed when the back reflection falls below 5% of full calibration screen height.

(b) *Angle Beam Rule.* A forging shall be unacceptable if the results of angle beam examinations show one or more reflectors which produce indications exceeding in amplitude the indication from the appropriate calibration notches.

NG-2545 Magnetic Particle Examination

NG-2545.1 Examination Procedure.

The procedure for magnetic particle examination shall be in accordance with the methods of Section V, Article 7.

NG-2545.2 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication in excess of the NG-2545.3 acceptance standards which is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular

Page 27

or elliptical with the length equal to or less than three times the width.

NG-2545.3 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for material less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for material 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 sq in. (3871 mm²) of area whose major dimension is no more than 6 in. (152 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

NG-2546 Liquid Penetrant Examination

NG-2546.1 Examination Procedure.

The procedure for liquid penetrant examination shall be in accordance with the methods of Section V, Article 6.

NG-2546.2 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities such as may occur from machining marks or surface conditions may produce similar indications which are not relevant.

(b) Any indication in excess of the NG-2546.3 acceptance standards which is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NG-2546.3 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for material less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for materials 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 sq in. (3871 mm²) of area whose major dimension is no more than 6 in. (152 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

NG-2547 Time of Examination

Acceptance examinations, including those for repair welds, shall be performed at the time of manufacture as required in (a) and (b) below.

(a) Ultrasonic examination may be performed at any time after forging, and the maximum practical volume shall be examined after final heat treatment, excluding postweld heat treatment.

(b) Radiographic examination of repair welds, if required, may be performed prior to any required postweld heat treatment.

NG-2548 Elimination of Surface Defects

Elimination of surface defects shall be made in accordance with NG-2538.

NG-2549 Repair by Welding

Repair by welding shall be in accordance with NG-2539, except that:

(a) the depth of repair that is permitted is not limited; and

(b) for ferritic steel forgings, the completed repair may be examined by the ultrasonic methods in accordance with the requirements of NG-2542 in lieu of radiography.

Page 28

NG-2550 EXAMINATION AND REPAIR OF SEAMLESS AND WELDED TUBULAR PRODUCTS AND FITTINGS

NG-2551 Required Examination

(a) The examination performed shall be practical and yield meaningful pertinent information for the product form being examined. Certain examination methods are ineffective for some material conditions and product configuration. Some examples are:

(1) it may not be practical or meaningful to examine irregular shapes such as welding flanges and fittings by ultrasonic methods;

(2) ultrasonic examination employing special techniques is required on coarse-grained austenitic stainless steel or coarse-grained nickel-base alloy materials.

(b) Welded tubular products and fittings (including flanges and fittings) made from plate material greater than $\frac{3}{4}$ in. in thickness shall be ultrasonically or radiographically examined in accordance with NG-2552 or NG-2553.

(c) All welds in welded tubular products and fittings (including flanges and fittings) shall be ultrasonically or radiographically examined in accordance with NG-2552 or NG-2553. In addition, all welds shall be magnetic particle or liquid penetrant examined on all accessible surfaces in accordance with NG-2555 or NG-2556.

(d) Wrought seamless tubular products and fittings (including flanges and fittings machined from forgings and bars) greater than $\frac{3}{8}$ in. thickness shall be ultrasonically or radiographically examined in accordance with NG-2552 or NG-2553.

NG-2552 Ultrasonic Examination

NG-2552.1 Examination Procedure.

The procedure for ultrasonic examination shall provide a sensitivity which will consistently detect defects that produce indications equal to and greater than the indication produced by standard defects included in the reference specimen specified in NG-2552.2. Products with defects that produce indications in excess of the indications produced by the standard defects in the reference specimens are unacceptable unless the defects are eliminated or repaired in accordance with NG-2558 or NG-2559, as applicable.

NG-2552.2 Reference Specimens

(a) The reference specimen shall be of the same nominal diameter and thickness and of the same nominal composition and heat treated condition as the product which is being examined. The standard defects shall be axial notches or grooves on the outside and the inside surfaces of the reference specimen and shall have a length of approximately 1 in. (25 mm) or less, a width not to exceed $\frac{1}{16}$ in. (1.6 mm), and a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the nominal wall thickness. The reference specimen may be the product being examined.

(b) The reference specimen shall be long enough to simulate the handling of the product being examined through the examination equipment. When more than one standard defect is placed in a reference specimen, the defects shall be located so that indications from each defect are separate and distinct without mutual interference or amplification.

NG-2552.3 Checking and Calibration of Equipment.

The proper functioning of the examination equipment shall be checked and the equipment shall be calibrated by the use of the reference specimens, as a minimum:

- (a) at the beginning of each production run of a given size and thickness of a given material;
- (b) after each 4 hr or less during the production run;
- (c) at the end of the production run;
- (d) at any time that malfunctioning is suspected.

If during any check it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid equipment calibration shall be reexamined.

NG-2553 Radiographic Examination

The radiographic examination shall be performed in accordance with Section V, Article 2, as modified by NG-5111, using the acceptance requirements of NG-5320.

NG-2555 Magnetic Particle Examination

The magnetic particle examination shall be performed in accordance with the requirements of NG-2545.

NG-2556 Liquid Penetrant Examination

The liquid penetrant examination shall be performed in accordance with the requirements of NG-2546.

NG-2557 Time of Examination

Time of acceptance examination, including that of repair welds, shall be in accordance with NG-2537.

Page 29

NG-2558 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining provided the requirements of (a) through (c) below are met.

- (a) The depression, after defect elimination, is blended uniformly into the surrounding surface.
- (b) After defect elimination, the area is reexamined by the method which originally disclosed the defect to assure that the defect has been removed or reduced to an imperfection of acceptable size.
- (c) If the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of NG-3000, the product shall be repaired in accordance with NG-2559.

NG-2559 Repair by Welding

Repair welding of base material defects shall be in accordance with NG-2539. Repair welding of seam defects shall be made in accordance with NG-4450.

NG-2570 EXAMINATION AND REPAIR OF STATICALLY AND CENTRIFUGALLY CAST PRODUCTS

NG-2571 Required Examinations

NG-2571.1 General Requirements.

The portion of castings, as specified by the Design Specifications or drawings, used for core support structures shall be examined over the maximum feasible volume by radiographic methods, or ultrasonic methods, or a combination of both methods. Castings or sections of castings which have coarse grains or configurations which do not yield meaningful examination results by ultrasonic methods shall be examined by radiographic methods. In addition, the portion of castings used for core support structures shall be examined on accessible surfaces by either magnetic particle or liquid penetrant methods. Accessible machined surfaces, except threaded surfaces, of a cast product shall be examined by

either liquid penetrant or magnetic particle methods after machining.

NG-2571.2 Alternative General Requirements.

The portion of castings 2 in. (51 mm) thick and less, which are specified by the Design Specifications or drawings to be used for core support structures, may be utilized when the requirements of (a) through (d) below are met.

(a) The design stress intensity values in Tables 2A, 2B and 3, Section II, Part D, Subpart 1 are reduced by applying a quality factor of 0.75.

(b) A fatigue strength reduction factor of 2.0 is applied to the allowable S_a values when peak stresses are considered.

(c) The portions of castings used as core support structures are magnetic particle or liquid penetrant examined per NG-2575 or NG-2576 on all accessible as-cast or, if machined, machine-finished surfaces. The acceptance criteria of NG-2575 or NG-2576 shall be utilized except that no linear indications greater than $\frac{1}{16}$ in. are permitted.

(d) Five pilot castings⁸ made from a new or altered design of a production run⁹ shall be radiographically examined over the maximum feasible volume to the requirements of NG-2573.1. If all five pilot castings meet the radiographic acceptance criteria, a production run may be poured. The production run shall be examined using either of the sampling plans specified in (1) or (2) below. The five pilot castings, having passed examination, are not to be included in the following sampling examination programs.

(1) The production run shall be considered a single lot. Twenty castings shall be randomly selected from the production run and examined to the requirements of the pilot castings. The production run is accepted if all 20 castings meet the examination requirements and it is rejected if any one of the 20 castings does not meet the examination requirements. Acceptable castings may be retrieved from a rejected production run by examining all castings from that production run.

(2) The production run castings shall, in order of manufacture, be grouped into sublots with a maximum of 25 castings each. Five castings shall be randomly selected from each subplot and examined to the requirements of the pilot castings. The subplot is accepted if all five castings meet the examination requirements and it is rejected if any one of the five castings does not meet the examination requirements. In the event two sublots are rejected by the sampling examination, succeeding sublots shall have eight castings randomly selected for examination to the requirements of the pilot castings. In any event, acceptable castings may be retrieved from a rejected subplot by examining all castings from that subplot.

8 A pilot casting is a casting poured to a production run to prove the casting process. Pilot castings shall be made from the same pattern, poured of the same type or grade of material, and use the identical foundry procedure (risering, gating, pouring, and melting) as each casting in the production run.

9 A production run is a maximum of 100 castings made from the same pattern, poured of the same type or grade of material, and using the identical foundry procedure (risering, gating, pouring, and melting) as the pilot castings. All castings in a production run need not be made from the same heat of material.

Page 30

NG-2572 Ultrasonic Examination of Castings

The requirements for ultrasonic examination of statically and centrifugally cast products are given in the following subparagraphs.

NG-2572.1 Straight Beam Method.

When castings are to be examined ultrasonically, all sections, regardless of thickness, shall be examined in accordance with SA-609, Standard Method and Specification for Longitudinal Beam Ultrasonic Inspection of Carbon and Low Alloy Castings, as shown in Section V; however, supplementary angle beam examination in accordance with NG-2572.2 or radiographic examination in accordance with NG-2573 shall be performed in areas where a back reflection cannot be maintained during the straight beam examination, or where the angle between the two surfaces of the casting is more than 15 deg.

NG-2572.2 Angle Beam Method.

Examination shall be conducted in accordance with Section V, T-524 except that the acceptance standards in Section V do not apply.

NG-2572.3 Acceptance Standards

(a) The Quality Levels of SA-609 as shown in Section V shall apply for the casting thicknesses indicated:

- (1) Quality Level 1 for thicknesses up to 2 in. (51 mm).
- (2) Quality Level 3 for thicknesses 2 to 4 in. (51 mm to 102 mm).
- (3) Quality Level 4 for thicknesses greater than 4 in. (102 mm).

(b) In addition to the Quality Level requirements stated in (a) above, the requirements in (1) through (5) below shall apply for both straight beam and angle beam examination.

(1) Area imperfections producing indications exceeding the Amplitude Reference Line with any dimension longer than those specified in the following tabulation are unacceptable:

<u>UT Quality Level</u>	<u>Longest Dimension of Area¹⁻³</u>
1	1.5 in.
2	2.0 in.
3	2.5 in.
4	3.0 in.

TABLE

NOTES:

(1) The areas for the Ultrasonic Quality Levels in SA-609 as shown in Section V refer to the surface area on the casting over which a continuous indication exceeding the transfer-corrected distance-amplitude curve is maintained.

(2) Areas are to be measured from dimensions of the movement of the search unit, using the center of the search unit as the reference point.

(3) In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases, other criteria which incorporate a consideration of beam angles or beam spread must be used for realistic evaluation of the discontinuity.

(2) Quality Level 1 shall apply for the volume of castings within 1 in. (25 mm) of the surface regardless of the overall thickness.

(3) Imperfections indicated to have a change in depth equal to or greater than one-half the wall thickness or 1 in., whichever is less, are unacceptable.

(4) Two or more imperfections in the same plane with indication amplitudes exceeding the Amplitude Reference Line and separated by a distance less than the longest dimension of the larger of the adjacent imperfections are unacceptable if they cannot be encompassed within an area less than that of the Quality Level specified in (1) above.

(5) Two or more imperfections greater than permitted for Quality Level 1 for castings less than 2 in. in thickness, greater than permitted for Quality Level 2 for thickness 2 in. through 4 in., and greater than permitted for Quality

Level 3 for thickness greater than 4 in., separated by a distance less than the longest dimension of the larger of the adjacent imperfections, are unacceptable if they cannot be encompassed in an area less than that of the Quality Level requirements stated in (a) above.

NG-2573 Radiographic Examination

NG-2573.1 Extent, Methods, and Acceptance Standards.

Radiographic examination, where required, shall be performed on castings used for core support structures. The radiographic methods shall be in accordance with ASTM E 94-77, Recommended Practice for Radiographic Testing, and ASTM E 142-77, Controlling Quality of Radiographic Testing, and shall meet the acceptance requirements of Severity Level 3 for Category A and B defects and Severity Level 2 for Category C defects of ASTM E 446-78,¹⁰ Reference Radiographs for Steel Castings Up To 2 in. In Thickness, ASTM E 186-75,¹⁰ Reference Radiographs for Heavy-Walled (2 to 4½ in.) Steel Castings, or ASTM E 280-75,¹⁰ Reference Radiographs for Heavy-Walled (4½ to 12 in.) Steel Castings, as applicable for the thickness being radiographed, except that Category D, E, F, or G defects

¹⁰ The reference radiographs accompanying previous editions of ASTM E 186, E 280, and E 446 may be used with later editions of the specification, provided the text of the specified edition is used.

Page 31

are not acceptable. ASTM E 280-75¹⁰ shall also apply for castings over 12 in. in thickness.

NG-2573.2 Procedure.

The supplemental requirements in (a) through (d) below apply to the radiographic methods specified by ASTM E 94-77 and E 142-77.

(a) Type 4 film is not permitted.

(b) For those areas where relatively uniform thicknesses occur, the minimum film density shall be 1.5 for single viewing and 2.0 for composite viewing of multiple film exposures; each film of a composite set shall have a minimum density of 1.0, and the maximum film density permitted shall be 4.0.

(c) For those sections where the thickness varies sufficiently to cause difficulty in meeting the density requirements with one penetrometer, two penetrameters shall be used representing the thinnest and the thickest section in the area to be interpreted. Densities at or between the densities on the penetrameters shall be considered acceptable, except that the minimum density of the penetrometer image shall be 1.3 for single film viewing and 2.0 for composite film viewing of multiple film exposures; each film of a composite set shall have a minimum density of 1.0.

(d) The radiographic quality level shall be 2-4T for section thicknesses up to and including ¾ in. (19 mm) and 2-2T for section thicknesses greater than ¾ in. (19 mm) Radiographic quality is defined in Note 2 of ASTM E 94-77.

NG-2573.3 Film Identification

(a) Location markers, such as lead numbers or letters, which shall appear as radiographic images on the film, shall be placed on the casting and not on the film or film holder. Their locations shall be permanently stamped on the surface of the casting being radiographed in a manner permitting the area of interest on a radiograph to be accurately located on the casting and providing evidence on the radiograph that the extent of coverage required by NG-2573.1 has been obtained. On castings or sections of castings where stamping is not feasible, the radiographic procedure shall so state.

(b) In addition, each film of a casting being radiographed shall be identified with radiographic images of:

(1) name or symbol of the Material Organization, Certificate Holder, or subcontractor;

(2) job or heat number.

(c) Repairs (R_1 , R_2 , etc.), if applicable, date of radiography, and other indications may be made by a film imprinter, permanent ink, or imaged lead numbers.

NG-2575 Magnetic Particle Examination

The magnetic particle examination, when required, shall be performed in accordance with the requirements of NG-2545.

NG-2576 Liquid Penetrant Examination

The liquid penetrant examination, when required, shall be performed in accordance with the requirements of NG-2546.

NG-2577 Time of Examination

Acceptance examinations, including those for weld repairs, shall be performed as stipulated in the following subparagraphs.

NG-2577.1 Ultrasonic Examination.

Ultrasonic examination, if required, shall be performed at the stage of manufacture as required for radiography.

NG-2577.2 Radiographic Examination

(a) Radiography shall be performed after final heat treatment as required by the material specification, except radiography may be performed prior to postweld heat treatment. The examination shall be performed at the stage of manufacture defined in this subparagraph.

(b) Castings prior to finish machining shall be radiographed at the limiting thicknesses stipulated in (1) through (4) below.

(1) For thicknesses less than 2 in. (51 mm), castings shall be radiographed within 50% of the finished thickness. The penetrometer shall be based on the final thickness.

(2) For thicknesses less than 6 in. (152 mm) but greater than 2 in. (51 mm), castings shall be radiographed within 20% of the finished thickness. The penetrometer shall be based on the final thickness.

(3) For thicknesses 6 in. (152 mm) and greater, castings shall be radiographed within 10% of the finished thickness. The penetrometer shall be based on the final thickness.

(4) Where casting practices for core support structure sections require thickness to exceed the finished machined thickness limits of (2) and (3) above, radiography of the as-cast thickness is acceptable provided the acceptance reference radiographs of the next lesser thickness are met in those areas; for example, if the section being radiographed exceeds $4\frac{1}{2}$ in. (114 mm), use ASTM E 186-75¹⁰ reference radiographs. The penetrometer shall be based on the thickness of the section being radiographed.

Page 32

NG-2577.3 Magnetic Particle or Liquid Penetrant Examination.

Magnetic particle or liquid penetrant examination shall be performed after the final heat treatment required by the material specification. Repair weld areas shall be examined after postweld heat treatment when a postweld heat treatment is performed, except that repair welds in P-No. 1 material, 2 in. (51 mm) nominal thickness and less, may be examined prior to postweld heat treatment. For cast products with machined surfaces, all accessible finished machined surfaces, except threaded surfaces, shall also be examined by magnetic particle or liquid penetrant methods.

NG-2578 Elimination of Surface Defects

Elimination of surface defects shall be in accordance with NG-2538.

NG-2579 Repair by Welding

The Material Organization may repair castings by welding after removing the material containing defects. The depth of the repair is not limited. A cored hole or access hole may be closed by the Material Organization by welding in accordance with the requirements of this paragraph, provided the hole is closed by filler metal only. If the hole is closed by welding in a metal insert, the welding shall be in accordance with the requirements of NG-4000 by a Certificate of Authorization Holder.

NG-2579.1 Defect Removal.

The defect shall be removed or reduced to an imperfection of an acceptable size by suitable mechanical or thermal cutting or gouging methods, and the cavity prepared for repair. When thermal cutting is performed, consideration shall be given to preheating the material.

NG-2579.2 Qualification of Welding Procedures and Welders.

The welding procedure and welders or welding operators shall be qualified in accordance with NG-4000 and Section IX.

NG-2579.3 Blending of Repaired Areas.

After welding, the surface shall be blended uniformly into the surrounding surface.

NG-2579.4 Examination of Repair Welds.

Each repair weld shall be examined by the magnetic particle method (NG-2545) or by the liquid penetrant method (NG-2546). In addition, repair welds in cavities the depth of which exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness shall be radiographed in accordance with NG-2573. The radiographic method and acceptance standards of NG-2573 shall apply except that weld slag, including elongated slag, shall be considered as inclusions under Category B of the applicable reference radiographs. The total area of all inclusions, including slag inclusions, shall not exceed the limits of the applicable severity level of Category B of the reference radiographs.

NG-2579.5 Heat Treatment After Weld Repair.

After repair, the casting shall be heat treated in accordance with NG-4620, except that the heating and cooling limitations of NG-4623 do not apply.

NG-2579.6 Material Report Describing Defects and Repairs.

Each repair weld exceeding in depth either $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness shall be described in the Certified Material Test Report. The Certified Material Test Report shall include a chart for each repaired casting which shows the location and size of the repaired cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographic film.

NG-2580 EXAMINATION OF THREADED STRUCTURAL FASTENERS

NG-2581 Required Examinations

Threaded structural fasteners shall be visually examined in accordance with NG-2582. Externally threaded structural fasteners $\frac{3}{8}$ in. (10 mm) and greater and nuts greater than 1 in. shall be examined by either the magnetic particle or liquid penetrant method. In addition, nominal sizes greater than $\frac{1}{2}$ in. (13 mm) but not over 4 in. (102 mm) shall be examined by ultrasonic methods as required by NG-2584, and nominal sizes greater than 4 in. (102 mm) shall be examined by ultrasonic methods as required by NG-2585.

NG-2582 Visual Examination

Externally threaded structural fasteners less than $\frac{3}{8}$ in. (10 mm) and nuts 1 in. (25 mm) and smaller shall be visually examined in the areas of threads, shanks, and heads of final machined parts prior to plating or other surface protection type treatments. Harmful discontinuities such as laps, seams, or cracks that would be detrimental to the intended service are unacceptable.

NG-2583 Magnetic Particle or Liquid Penetrant Examination

Externally threaded structural fasteners $\frac{3}{8}$ in. (10 mm) and greater and nuts greater than 1 in. (25 mm) shall be examined by a magnetic particle method

(NG-2545) or a liquid penetrant method (NG-2546). Such examination shall be performed on the finished threaded structural fastener after threading and prior to plating or other surface protection type treatments. On threaded surfaces no relevant indications are permitted. Relevant indications include any linear indications or rounded indications greater than $\frac{1}{16}$ in. (1.6 mm). Indications, caused by a particular manufacturing method, that may appear to be relevant, such as the crest of rolled threads or root of cut threads, may be shown to be nonrelevant and acceptable by prior process qualification or destructive metallographic examination. On all other accessible surfaces, no linear indications or rounded indications greater than $\frac{1}{16}$ in. (1.6 mm) are permitted, except that linear axial indications the smaller of one diameter or 1 in. (25 mm) in length are permitted.

NG-2584 Ultrasonic Examination for Sizes Greater Than $\frac{1}{2}$ in. (13 mm)

All threaded structural fasteners greater than $\frac{1}{2}$ in. (13 mm) nominal bolt size shall be ultrasonically examined over the entire surface prior to threading, in accordance with the requirements of the following subparagraphs.

NG-2584.1 Ultrasonic Method.

Examination shall be carried out by the straight beam, radial scan method.

NG-2584.2 Examination Procedure.

Examination shall be performed at a nominal frequency of 2.25 MHz unless variables such as production material grain structure necessitate the use of a 1 MHz frequency in order to assure adequate penetration, with a search unit not to exceed 1 sq in. (645 mm²) area.

NG-2584.3 Calibration of Equipment.

Calibration sensitivity shall be established by adjustment of the instrument so that the first back reflection is 75%-90% of full screen height.

NG-2584.4 Acceptance Standards.

Any imperfection which causes an indication in excess of 20% of the height of the first back reflection or any imperfection which prevents the production of a first back reflection of 50% of the calibration amplitude is not acceptable.

NG-2585 Ultrasonic Examination for Sizes Over 4 in.

In addition to the requirements of NG-2584, all threaded structural fasteners over 4 in. nominal size shall be ultrasonically examined over an entire end surface before or after threading in accordance with the requirements of the following subparagraphs.

NG-2585.1 Ultrasonic Method.

Examination shall be carried out by the straight beam, longitudinal mode scan method.

NG-2585.2 Examination Procedure.

Examination shall be performed at a nominal frequency of 2.25 MHz unless variables such as production material grain structure necessitate the use of a 1 MHz frequency in order to assure adequate penetration with a search unit having a circular cross section with a diameter not less than $\frac{1}{2}$ in. (13 mm) nor more than $1\frac{1}{8}$ in. (29 mm)

NG-2585.3 Calibration of Equipment.

Calibration shall be established on a test bar of the same nominal composition and diameter as the production part and a minimum of one-half of the length. A $\frac{3}{8}$ in. (10 mm) diameter $\times$ 3 in. (76 mm) deep flat bottom hole shall be drilled in one end of the bar and plugged to full depth. A distance-amplitude correction curve shall be established by scanning

from both ends of the test bar.

NG-2585.4 Acceptance Standards.

Any imperfection which causes an indication in excess of 50% of that produced by the calibration hole in the reference specimen, as corrected by the distance-amplitude correction curve, is not acceptable.

NG-2586 Elimination of Surface Defects

Surface defects may be eliminated by grinding or machining, provided the final dimension of the affected portion meets the requirements of the design and the area is reexamined by the magnetic particle or liquid penetrant method in accordance with NG-2583.

NG-2600 MATERIAL ORGANIZATIONS' QUALITY SYSTEM PROGRAMS

NG-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS

(a) Except as provided in (b) below, Material Organizations shall have a Quality System Program or an Identification and Verification Program, as applicable, which meets the requirements of NCA-3800.

(b) The requirements of NCA-3862 shall be met as required by NG-2130. The other requirements of NCA-3800 need not be used by Material Organizations for small products, as defined in (c) below, and for material which is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Assurance Program (NCA-4000) shall include measures to provide assurance

Page 34

that the material is furnished in accordance with the material specification and with the applicable special requirements of this Subsection.

(c) For the purpose of this paragraph, small products are defined as given in (1) through (5) below:

- (1) pipe, tube (except heat exchanger tube), pipe fittings, and flanges 2 in. nominal pipe size (DN 50) and less;
- (2) bolting material, including studs, nuts, and bolts of 1 in. (25 mm) nominal diameter and less;
- (3) bars with a nominal cross-sectional area of 1 sq in. (645 mm²) and less.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NG-3000

ARTICLE NG-3000 DESIGN

Page 35

NG-3100 GENERAL DESIGN

NG-3110 LOADING CRITERIA

NG-3111 Loading Conditions

The loadings that shall be taken into account in designing core support structures include, but are not limited to, those in (a) through (k) below:

- (a) pressure differences due to coolant flow;
- (b) weight of the core support structure;
- (c) superimposed loads such as those due to other structures, the reactor core, steam separating equipment, flow

distributors and baffles, thermal shields, and safety equipment;

- (d) earthquake loads or other loads which result from motion of the reactor vessel;
- (e) reactions from supports, restraints, or both;
- (f) loads due to temperature effects, thermal gradients and differential expansion, or both;
- (g) loads resulting from the impingement or flow of reactor coolant, or other contained or surrounding fluids;
- (h) transient pressure difference loads, such as those which result from rupture of the main coolant pipe;
- (i) vibratory loads;
- (j) loads resulting from the operation of machinery, such as snubbing of control rods;
- (k) handling loads experienced in preparation for or during refueling or in-service inspection.

NG-3112 Design Loadings

The Design Loadings are the pressure differences, temperatures, and various forces applicable to the design of core support structures as defined in the following subparagraphs.

NG-3112.1 Design Pressure Difference

(a) The specified internal and external Design Pressure Difference shall not be less than the maximum difference in pressure between the inside and outside of the core support structure which exists under the specified normal service conditions. It shall be used in the computations made to show compliance with the stress intensity limits of NG-3221, NG-3227.1, NG-3227.2, NG-3227.4, NG-3228.1, NG-3228.2, and NG-3231. The actual service pressure difference at the appropriate time shall be used in the computations made to show compliance with the stress intensity limits of NG-3222, NG-3228.3, and NG-3232. When the occurrence of different pressure differences during service can be predicted for different zones of a structure, the Design Pressure Difference of the different zones may be based on their predicted pressure difference.

(b) The Design Pressure Difference shall include allowances for pressure difference surges.

NG-3112.2 Design Temperature.

The Design Temperature shall be established in accordance with NCA-2142.1(b). It shall be used in computations involving the Design Pressure Difference and coincidental Design Mechanical Loads. The actual metal temperature at the point under consideration shall be used in all computations where the use of the actual service pressure difference is required.

(a) All temperatures referred to in this Subsection are the metal temperatures expressed in degrees Fahrenheit (°F), unless otherwise stated.

(b) Where a core support structure is heated by tracing, induction coils, jacketing, or internal heat generation, the effect of such heating shall be incorporated in the establishment of the Design Temperature.

NG-3112.3 Design Mechanical Loads.

The specific combinations and values of mechanical loadings which must be considered in conjunction with the Design Pressure Difference and Design Temperature in evaluating the requirements of NG-3221.1 and NG-3221.2 shall be those identified in the Design Specifications (NCA-3250) and designated as the Design Mechanical Loads in accordance with NCA-2142.1(c). The actual mechanical loads at the appropriate time shall be used in the computations made to show compliance with

Page 40

the stress intensity limits of NG-3222.2 and NG-3222.4. The requirements of (a), (b), and (c) below shall also apply.

(a) Impact forces caused by either external or internal conditions shall be considered.

(b) The effects of earthquake shall be considered in the design of core support structures. The loadings, movements, and number of cycles to be used in the analysis shall be part of the Design Specifications. The stresses resulting from these earthquake effects shall be included with pressure differences or other applied loads.

(c) Core support structures shall be arranged and supported so that vibration will be minimized.

NG-3112.4 Design Stress Intensity Values.

Design stress intensity values for materials are listed in Tables 2A, 2B, and 4, Section II, Part D, Subpart 1. The material shall not be used at metal temperatures and Design Temperatures above those for which stress intensity values are listed. The values in the Table may be interpolated for intermediate temperatures.

NG-3113 Service Loadings

Each loading to which the structure may be subjected shall be classified in accordance with NCA-2142 and Service Limits [NCA-2142.4(b)] designated in the Design Specifications in such detail as will provide a complete basis for design, construction, and inspection in accordance with these rules.

NG-3120 SPECIAL CONSIDERATIONS

NG-3121 Corrosion

Material subject to thinning by corrosion, erosion, mechanical abrasion, or other environmental effects shall have provision made for these effects during the design or specified life of the structure by a suitable increase in or addition to the thickness of the base metal over that determined by the design formulas. Material added or included for these purposes need not be of the same thickness for all areas of the structure if different rates of attack are expected for the various areas. It should be noted that the tests on which the design fatigue curves (Figs. I-9.0) are based did not include tests in the presence of corrosive environments which might accelerate fatigue failure.

NG-3122 Cladding

The rules of this paragraph apply to the design analysis of clad structures constructed of material permitted in Tables 2A, 2B, and 4, Section II, Part D, Subpart 1.

NG-3122.1 Primary Stresses.

No structural strength shall be attributed to the cladding in satisfying NG-3221.1 and NG-3221.3.

NG-3122.2 Design Dimensions.

The dimensions given in (a) and (b) below shall be used in the design of the component.

(a) For structures subjected to internal pressure difference, the inside diameter shall be taken at the nominal inner face of the cladding.

(b) For structures subjected to external pressure difference, the outside diameter shall be taken at the outer face of the base metal.

NG-3122.3 Secondary and Peak Stresses.

In satisfying NG-3222.2 and NG-3222.4(b), the presence of the cladding shall be considered with respect to both the thermal analysis and the stress analysis. The stresses in both materials shall be limited to the values specified in NG-3222.2 and NG-3222.4(b). However, when the cladding is of the integrally bonded type and the nominal thickness of the cladding is 10% or less of the total thickness of the structure, the presence of the cladding may be neglected.

NG-3122.4 Bearing Stresses.

In satisfying NG-3227.1, the presence of cladding shall be included.

NG-3123 Welds Between Dissimilar Metals

In satisfying the requirements of this Subarticle, caution should be exercised in design and construction involving dissimilar metals having different coefficients of thermal expansion in order to avoid difficulties in service.

NG-3124 Environmental Effects

Changes in material properties may occur due to environmental effects. In particular, fast (> 1 MeV) neutron irradiation above a certain level may result in significant increase in the brittle fracture transition temperature and deterioration in the resistance to fracture at temperatures above the transition range (upper shelf energy). Therefore, structural discontinuities in ferritic structures should preferably not be placed in regions of high neutron flux.

Page 41

NG-3130 GENERAL DESIGN RULES

NG-3131 Scope

Design rules generally applicable to core support structures are provided in the following paragraphs.

NG-3132 Reinforcement for Openings

The rules for reinforcing applicable to Class 1 vessels and piping may be used in the design of core support structures if stipulated in the Design Specifications.

NG-3133 External Pressure Difference

NG-3133.1 General.

Rules are given in this paragraph for determining the stresses under external pressure difference loading in spherical shells, cylindrical shells with or without stiffening rings, and tubular products consisting of pipes, tubes, and fittings. Charts for determining the stresses in shells, hemispherical heads, and tubular products are given in Appendix VII.

NG-3133.2 Nomenclature.

The symbols used in this paragraph are defined as follows:

A	= factor determined from Fig. G, Section II, Part D, Subpart 3 and used to enter the applicable material chart in Section II, Part D, Subpart 3. For the case of cylinders having D_o/T values less than 10, see NG-3133.3(b). Also, factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a stiffening ring, corresponding to the factor B and the design metal temperature for the shell under consideration.
A_s	= cross-sectional area of a stiffening ring, sq in.
B	= factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a shell or stiffening ring at the design metal temperature, psi
D_o	= outside diameter of the cylindrical shell course or tube under consideration, in.
E	= modulus of elasticity of material at Design Temperature, psi (for this value, see Table TM, Section II, Part D, Subpart 2. Use the curve with this value on the material/temperature line of the applicable chart in Section II, Part D, Subpart 3.

I	= available moment of inertia of the combined ring-shell section about its neutral axis, parallel to the axis of the shell, in. ⁴ The width of the shell which is taken as contributing to the combined moment of inertia shall not be greater than $1.10 \sqrt{D_o} \bar{T}_n$ and shall be taken as lying one-half on each side of the centroid of the ring. Portions of shell plates shall not be considered as contributing area to more than one stiffening ring.
I_s	= required moment of inertia of the combined ring-shell section about its neutral axis parallel to the axis of the shell, in. ⁴
L	= total length of a tube between tubesheets, or the design length of a cylindrical section, taken as the largest of the following: (1) the distance between head tangent lines plus one-third of the depth of each head if there are no stiffening rings (2) the greatest center-to-center distance between any two adjacent stiffening rings, or (3) the distance from the center of the first stiffening ring to the head tangent line plus one-third of the depth of the head, all measured parallel to the axis of the cylinder, in.
L_s	= one-half of the distance from the center line of the stiffening ring to the next line of support on one side, plus one-half of the center line distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the component, in. A line of support is: (1) a stiffening ring that meets the requirements of this paragraph (2) a circumferential line on a head at one-third the depth of the head from the head tangent line, or (3) a circumferential connection to a jacket for a jacketed section of a cylindrical shell
P	= external design pressure, psi (gage or absolute, required)
P_2	= allowable external pressure, psi (gage or absolute, as required)
R	= inside radius of spherical shell, in.
S	= the lesser of 1.5 times the stress intensity at design metal temperature from Tables 2A, 2B, and 4, Section II, Part D, Subpart 1 or 0.9 times the tabulated yield strength at design metal temperature from Tables Y-1, Section II, Part D, Subpart 2, psi
T	= minimum required thickness of cylindrical shell or tube, or spherical shell, in.
T_n	= nominal thickness used, less corrosion allowance, of a cylindrical shell or tube, in.

NG-3133.3 Cylindrical Shells and Tubular Products

(a) The minimum thickness of cylindrical shells or tubular products under external pressure difference having D_o/T values equal to or greater than 10 shall

Page 42

be determined by the procedure given in Steps 1 through 8.

Step 1: Assume a value for T . Determine the ratios L/D_o and D_o/T .

Step 2: Enter Fig. G, Section II, Part D, Subpart 3 at the value of L/D_o determined in Step 1. For values of L/D_o greater than 50, enter the chart at a value of L/D_o of 50. For values of L/D_o less than 0.05, enter the chart at a value of L/D_o of 0.05.

Step 3: Move horizontally to the line for the value of D_o/T determined in Step 1. Interpolation may be made for intermediate values of D_o/T . From this intersection move vertically downwards and read the value of factor A .

Step 4: Using the value of A calculated in Step 3, enter the applicable material chart in Section II, Part D, Subpart 3 for the material/temperature under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material line, see Step 7.

Step 5: From the intersection obtained in Step 4 move horizontally to the right and read the value of B .

Step 6: Using this value of B , calculate the maximum allowable pressure difference P_a by the following formula:

$$P_a = \frac{4B}{3D_o/T}$$

Step 7: For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following formula:

$$P_a = \frac{2AE}{3(D_o/T)}$$

Step 8: Compare P_a with P . If P_a is smaller than P , select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P .

(b) The minimum thickness of cylindrical shells or tubular products under external pressure difference having D_o/T values less than 10 shall be determined by the procedure given in Steps 1 through 4.

Step 1: Using the same procedure as given in (a) above, obtain the value of B . For values of D_o/T less than 4, the value of factor A can be calculated using the following formula:

$$A = \frac{1.1}{(D_o/T)^2}$$

For values of A greater than 0.10 use a value of 0.10.

Step 2: Using the value of B obtained in Step 1, calculate a value P_{a1} using the following formula:

$$P_{a1} = \left[\frac{2.167}{(D_o/T)} - 0.0833 \right] B$$

Step 3: Calculate a value P_{a2} using the following formula:

$$P_{a2} = \frac{2S}{D_o/T} \left[1 - \frac{1}{D_o/T} \right]$$

Step 4: The smaller of the values of P_{a1} calculated in Step 2 or P_{a2} calculated in Step 3 shall be used for the maximum allowable external pressure P_a . Compare P_a with P . If P_a is smaller than P , select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P .

NG-3133.4 Spherical Shells.

The minimum required thickness of a spherical shell under external pressure, either seamless or of built-up construction with butt joints, shall be determined by the procedure given in Steps 1 through 6.

Step 1: Assume a value for T and calculate the value of factor A using the following formula:

$$A = \frac{0.125}{(R/T)}$$

Step 2: Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection

Page 43

with the material/temperature line for the design temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values at A falling to the left of the material/temperature line, see Step 5.

Step 3: From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B .

Step 4: Using the value of B obtained in Step 3, calculate the value of the maximum allowable external pressure P_a using the following formula:

$$P_a = \frac{B}{(R/T)}$$

Step 5: For values of A falling to the left of the applicable material/temperature line for the Design Temperature, the value of P_a can be calculated using the following formula:

$$P_a = \frac{0.0625 E}{(R/T)^2}$$

Step 6: Compare P_a obtained in Steps 4 or 5 with P . If P_a is smaller than P , select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P .

NG-3133.5 Stiffening Rings for Cylindrical Shells

(a) The required moment of inertia of the combined ring-shell section is given by the formula:

$$I_s = \frac{D_o^2 L_s (T + A_s / L_s) A}{10.9}$$

The available moment of inertia I for a stiffening ring shall be determined by the procedure given in Steps 1 through 6.

Step 1: Assuming that the shell has been designed and D_o , L_s , and T_n are known, select a member to be used for the stiffening ring and determine its area A_s and the value of I defined in NG-3133.2. Then calculate B by the formula:

$$B = \frac{3}{4} \left[\frac{PD_o}{T_n + A_s / L_s} \right]$$

Step 2: Enter the right-hand side of the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration at the value of B determined in Step 1. If different materials are used for the shell and stiffening ring, then use the material chart resulting in the larger value for factor A in Step 4 or 5 below.

Step 3: Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5.

Step 4: Move vertically to the bottom of the chart and read the value of A .

Step 5: For values of B falling below the left end of the material/temperature line for the Design Temperature, the value of A can be calculated using the following formula:

$$A = 2B/E$$

Step 6: If the required I_s is greater than the computed moment of inertia I for the combined ring-shell section selected in Step 1, a new section with a larger moment of inertia must be selected and a new I_s determined. If the required I_s is smaller than the computed I for the section selected in Step 1, that section should be satisfactory.

(b) Stiffening rings may be attached to either the outside or the inside of the component by continuous welding.

NG-3133.6 Cylinders Under Axial Compression.

The maximum allowable compressive stress to be used in the design of cylindrical shells and tubular products subjected to loadings that produce longitudinal compressive stresses in the shell or wall shall be the lesser of the values given in (a) or (b) below:

(a) the S_m value for the applicable material at Design Temperature given in Tables 2A, 2B, and 4, Section II, Part D, Subpart 1;

(b) the value of the factor B determined from the applicable chart contained in Section II, Part D, Subpart 3, using the following definitions for the symbols on the charts:

T = minimum required thickness of the shell or tubular product, exclusive of the corrosion allowance, in.

R = inside radius of the cylindrical shell or tubular product, in.

The value of B shall be determined from the applicable chart contained in Section II, Part D, Subpart 3 in the manner given in Steps 1 through 5.

Step 1: Using the selected values of T and R , calculate the value of factor A using the following formula:

$$A = 0.125/(R/T)$$

Step 2: Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 4.

Step 3: From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B . This is the maximum allowable compressive stress for the values of T and R used in Step 1.

Step 4: For values of A falling to the left of the applicable material/temperature line, the value of B shall be calculated using the following formula:

$$B = AE/2$$

Step 5: Compare the value of B determined in Step 3 or 4 with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of T and R . If the value of B is smaller than the computed compressive stress, a greater value of T must be selected and the design procedure repeated until a value of B is obtained which is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

NG-3200 DESIGN BY ANALYSIS

NG-3210 DESIGN CRITERIA

NG-3211 Requirements for Acceptability

The requirements for the acceptability of a design by analysis are those set forth in (a) through (d) below.

(a) The design shall be such that stress intensities will not exceed the limits of NG-3200 using the design stress intensity values S_m as tabulated in Tables 2A, 2B, and 4, Section II, Part D, Subpart 1.

(b) The design details shall conform to the rules given in NG-3100 and NG-3350.

(c) For configurations where compressive stresses occur, in addition to the requirements in (a) and (b) above, the critical buckling stress shall be taken into account; see NG-3133. (For the special case of external pressure difference, see NG-3133.1. Where dynamic pressure differences are involved, the permissible external pressure difference shall satisfy the requirements of NG-3133 or be limited to 25% of the dynamic instability pressure difference for normal service conditions.)

(d) Protection against nonductile fracture shall be provided. An acceptable procedure for nonductile failure prevention is given in Appendix G.

NG-3212 Basis for Determining Stresses

The theory of failure used in the rules of this Subsection for combining stresses is the maximum shear stress theory. The maximum shear stress at a point is equal to one-half the difference between the algebraically largest and the algebraically smallest of the three principal stresses at the point.

NG-3213 Terms Relating to Stress Analysis

Terms used in this Subsection relating to stress analysis are defined in the following subparagraphs.

NG-3213.1 Stress Intensity.¹

Stress intensity is the equivalent intensity of combined stress, or, in short, the stress intensity is defined as twice the maximum shear stress. In other words, the stress intensity is the difference between the algebraically largest and the algebraically smallest principal stress at a given point. Tensile stresses are considered positive, and compressive stresses are considered negative.

¹ This definition of stress intensity is not related to the definition of stress intensity applied in the field of Fracture Mechanics.

Page 45

NG-3213.2 Gross Structural Discontinuity.

Gross structural discontinuity is a geometric or material discontinuity which affects the stress or strain distribution through the entire wall thickness of the shell-type member. Gross-discontinuity type stresses are those portions of the actual stress distributions that produce net bending and membrane force resultants when integrated through the wall thickness. Examples of gross structural discontinuities are head-to-shell and flange-to-shell junctions, nozzles, and junctions between shells of different diameters or thicknesses.

NG-3213.3 Local Structural Discontinuity.

Local structural discontinuity is a geometric or material discontinuity which affects the stress or strain distribution through a fractional part of the wall thickness. The stress distribution associated with a local discontinuity causes only very localized types of deformation or strain and has no significant effect on the shell-type discontinuity deformations. Examples are small fillet radii, small attachments, and partial penetration welds.

NG-3213.4 Normal Stress.

Normal stress is the component of stress normal to the plane of reference. This is also referred to as direct stress. Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to be made up in turn of two components, one of which is uniformly distributed and equal to the average value of stress across the thickness under consideration, and the other of which varies from this average value with the location across the thickness.

NG-3213.5 Shear Stress.

Shear stress is the component of stress tangent to the plane of reference.

NG-3213.6 Membrane Stress.

Membrane stress is the component of normal stress which is uniformly distributed and equal to the average of stress across the thickness of the section under consideration.

NG-3213.7 Bending Stress.

Bending stress is the variable component of normal stress described in NG-3213.4. The variation may or may not be linear across the thickness.

NG-3213.8 Primary Stress.

Primary stress is any normal stress or a shear stress developed by an imposed loading which is necessary to satisfy the laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses which considerably exceed the yield strength will result in failure or, at least, in gross distortion. A thermal stress is not classified as a primary stress. A general primary membrane stress is one which is so distributed in the structure that no redistribution of load occurs as a result of yielding. Examples of primary stresses are:

(a) general membrane stress in a circular cylindrical or a spherical shell due to internal pressure difference or to distributed live loads;

(b) bending stress in the central portion of a flat head due to pressure difference.

NG-3213.9 Secondary Stress.

Secondary stress is a normal stress or a shear stress developed by the constraint of adjacent material or by self-constraint of the structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions which cause the stress to occur, and failure from one application of the stress is not to be expected. Examples of secondary stresses are:

(a) general thermal stress [NG-3213.12(a)];

(b) bending stress at a gross structural discontinuity.

NG-3213.10 Peak Stress.

Peak stress is that increment of stress which is additive to the primary plus secondary stresses by reason of local discontinuities or local thermal stress [NG-3213.12(b)], including the effects of stress concentrations. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture. A stress which is not highly localized falls into this category if it is of a type which cannot cause noticeable distortion. Examples of peak stresses are:

(a) the thermal stress in the austenitic steel cladding of a carbon steel component;

(b) certain thermal stresses which may cause fatigue but not distortion;

(c) the stress at a local structural discontinuity;

(d) surface stresses produced by thermal shock.

NG-3213.11 Load Stress.

Load stress is the stress resulting from the application of a load, such as pressure difference or the effects of gravity as distinguished from thermal stress.

NG-3213.12 Thermal Stress.

Thermal stress is a self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally should under a change in temperature. For the purpose of establishing allowable stresses, two types of thermal stress are recognized, depending on the volume or area in which distortion takes place, as described in (a) and (b) below.

Page 46

(a) General thermal stress is associated with distortion of the structure in which it occurs. If a stress of this type, neglecting stress concentrations, exceeds twice the yield strength of the material, the elastic analysis may be invalid and successive thermal cycles may produce incremental distortion. Therefore this type is classified as secondary stress in Table NG-3217-1. Examples of general thermal stresses are:

(1) stress produced by an axial temperature distribution in a cylindrical shell;

(2) stress produced by the temperature difference between a nozzle and the shell to which it is attached;

(3) the equivalent linear stress² produced by the radial temperature distribution in a cylindrical shell.

(b) Local thermal stress is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses shall be considered only from the fatigue standpoint and are therefore classified as local stresses in Table NG-3217-1. In evaluating local thermal stresses the procedures of NG-3227.6(b) shall be used.

Examples of local thermal stresses are:

- (1) the stress in a small hot spot in a vessel wall;
- (2) the difference between the actual stress and the equivalent linear stress resulting from a radial temperature distribution in a cylindrical shell;
- (3) the thermal stress in a cladding material which has a coefficient of expansion different from that of the base metal.

NG-3213.13 Total Stress.

Total stress is the sum of the primary, secondary, and peak stress contributions. Recognition of each of the individual contributions is essential to establishment of appropriate stress limitations.

NG-3213.14 Operational Cycle.

Operational cycle is defined as the initiation and establishment of new conditions followed by a return to the conditions which prevailed at the beginning of the cycle. The types of operating conditions which may occur are further defined in NG-3113.

NG-3213.15 Stress Cycle.

Stress cycle is a condition in which the alternating stress difference [NG-3222.4(e)] goes from an initial value through an algebraic maximum value and an algebraic minimum value, then returns to the initial value. A single operational cycle may result in one or more stress cycles. Dynamic effects shall also be considered as stress cycles.

2 Equivalent linear stress is defined as the linear stress distribution which has the same net bending moment as the actual stress distribution.

NG-3213.16 Fatigue Strength Reduction Factor.

Fatigue strength reduction factor is a stress intensification factor which accounts for the effect of a local structural discontinuity (stress concentration) on the fatigue strength. In the absence of experimental data, the theoretical stress concentration factor may be used.

NG-3213.17 Shakedown.

Shakedown is the absence of a continuing cycle of plastic deformation. A structure shakes down if after a few cycles of load application, the deformation stabilizes and subsequent structural response is elastic, excluding creep effects.

NG-3213.18 Free End Displacement.

Free end displacement consists of the relative motions that would occur between an attachment and connected structure or equipment if the two members were separated. Examples of such motions are those that would occur because of relative thermal expansion of piping, equipment, and equipment supports or because of rotations imposed upon the equipment by sources other than the piping.

NG-3213.19 Expansion Stresses.

Expansion stresses are those stresses resulting from restraint of free end displacement of piping which may act as a core support structure.

NG-3213.20 Limit Analysis - Collapse Load.

The methods of limit analysis are used to compute the maximum load or combination of loads a structure made of ideally plastic (nonstrain-hardening) material can carry. The deformations of an ideally plastic structure increase without bound at this load, which is termed the *collapse load*. Among the methods used in limit analysis is a technique which assumes elastic, perfectly plastic, material behavior and a constant level of moment or force in those redundant structural elements in which membrane yield, plastic hinge, or critical buckling load has been reached. Any increase in load must be accompanied by a stable primary structure until a failure mechanism defined by the lower bound theorem of limit analysis is reached in the primary structure.

analysis is reached in the primary structure.

NG-3213.21 Collapse Load - Lower Bound.

If, for a given load, any system of stresses can be found which everywhere satisfies equilibrium and nowhere exceeds the material yield strength, the load is at or below the collapse load. This is the lower bound theorem of limit analysis which permits calculations of a lower bound to the collapse load.

NG-3213.22 Stress Ratio Method.

The methods of plastic analysis which utilize the stress ratio combinations are used to compute the maximum load a strain-hardened

Page 47

material can carry (A-9000). Stress ratio combinations are useful since the actual shape factor (function of cross section) and the type and magnitude of different stress fields may be considered in determining the load.

NG-3214 Stress Analysis

A detailed stress analysis of all major structural components shall be prepared in sufficient detail to show that each of the stress limitations of NG-3220 and NG-3230 is satisfied when the core support structure is subjected to the loadings of NG-3110. As an aid to the evaluation of these stresses, formulas and methods for the solution of certain recurring problems have been placed in Appendix A.

NG-3215 Derivation of Stress Intensities

One requirement for the acceptability of a design (NG-3210) is that the calculated stress intensities shall not exceed specified allowable limits. These limits differ depending on the stress category (primary, secondary, etc.) from which the stress intensity is derived. This paragraph describes the procedure for the calculation of the stress intensities which are subject to the specified limits. The steps in the procedure are stipulated in (a) through (e) below.

(a) At the point on the component which is being investigated, choose an orthogonal set of coordinates, such as tangential, longitudinal, and radial, and designate them by the subscripts t , l , and r . The stress components in these directions are then designated σ_t , σ_l , and σ_r for direct stresses and τ_{lt} , τ_{lr} , and τ_{rt} for shear stresses.

(b) Calculate the stress components for each type of loading to which the part will be subjected and assign each set of stress values to one or a group of the following categories:³

- (1) general primary membrane stress P_m (NG-3213.8)
- (2) primary bending stress P_b (NG-3213.7 and NG-3213.8)
- (3) expansion stress P_e (NG-3213.19)
- (4) secondary stress Q (NG-3213.9)
- (5) peak stress F (NG-3213.10)

(c) For each category, calculate the algebraic sum of the values of σ_i which result from the different types of loadings, and similarly for the other five stress components. Certain combinations of the categories must also be considered.

³ See Table NG-3217-1 and Fig. NG-3221-1, Note (4).

(d) Translate the stress components for the t , l , and r directions into principal stresses σ_1 , σ_2 , and σ_3 . In many pressure component calculations, the t , l , and r directions may be so chosen that the shear stress components are zero and σ_1 , σ_2 , and σ_3 are identical to σ_t , σ_l , and σ_r .

(e) Calculate the stress differences S_{12} , S_{23} , and S_{31} from the relations:

$$S_{12} = \sigma_1 - \sigma_2$$

$$S_{23} = \sigma_2 - \sigma_3$$

$$S_{31} = \sigma_3 - \sigma_1$$

The stress intensity S is the largest absolute value of S_{12} , S_{23} , and S_{31} .

NOTE: Membrane stress intensity is derived from the stress components averaged across the thickness of the section. The averaging shall be performed at the component level in (b) or (c) above.

NG-3216 Derivation of Stress Differences and Alternating Stress Intensities

If the specified operation of the structure does not meet the conditions of NG-3222.4(d), the ability of the structure to withstand the specified cyclic service without fatigue failure shall be determined as provided in NG-3222.4(e). The determination shall be made on the basis of the stresses at a point of the structure, and the allowable stress cycles shall be adequate for the specified service at every point. Only the stress differences due to cyclic service loadings as specified in the Design Specifications need be considered.

NG-3216.1 Constant Principal Stress Direction.

For any case in which the directions of the principal stresses at the point being considered do not change during the cycle, the steps stipulated in (a), (b), and (c) below shall be taken to determine the alternating stress intensity.

(a) *Principal Stresses.* Consider the values of the three principal stresses at the point versus time for the complete stress cycle, taking into account both the gross and local structural discontinuities and the thermal effects which vary during the cycle. These are designated as σ_1 , σ_2 , and σ_3 for later identification.

(b) *Stress Differences.* Determine the stress differences $S_{12} = \sigma_1 - \sigma_2$; $S_{23} = \sigma_2 - \sigma_3$; $S_{31} = \sigma_3 - \sigma_1$ versus time for the complete cycle. In what follows,

Page 48

the symbol S_{ij} is used to represent any one of these three stress differences.

(c) *Alternating Stress Intensity.* Determine the extremes of the range through which each stress difference S_{ij} fluctuates and find the absolute magnitude of this range for each S_{ij} . Call this magnitude S_{rij} and let $S_{alt\ ij} = 0.5S_{rij}$. The alternating stress intensity S_{alt} is the largest of the $S_{alt\ ij}$ values.

NG-3216.2 Varying Principal Stress Direction.

For any case in which the directions of the principal stresses at the point being considered do change during the stress cycle, it is necessary to use the more general procedure of (a) through (e) below.

(a) Consider the values of the six stress components σ_p , σ_{lp} , σ_{lp} , τ_{lp} , τ_{lp} , τ_{rt} versus time for the complete stress cycle, taking into account both the gross and local structural discontinuities and the thermal effects which vary during the cycle.

(b) Choose a point in time when the conditions are one of the extremes for the cycle (either maximum or minimum, algebraically) and identify the stress components at this time by the subscript i . In most cases it will be possible to choose at least one time during the cycle when the conditions are known to be extreme. In some cases it may be necessary to try different points in time to find the one which results in the largest value of alternating stress intensity.

(c) Subtract each of the six stress components σ_{lp} , σ_{lp} , etc., from the corresponding stress components σ_p , σ_p , etc., at each point in time during the cycle and call the resulting components σ'_p , σ'_p , etc.

(d) At each point in time during the cycle, calculate the principal stresses σ'_1 , σ'_2 , σ'_3 derived from the six stress components σ'_p , σ'_p , etc. Note that the directions of the principal stresses may change during the cycle but each principal stress retains its identity as it rotates.

(e) Determine the stress differences $S'_{12} = \sigma'_1 - \sigma'_2$, $S'_{23} = \sigma'_2 - \sigma'_3$, $S'_{31} = \sigma'_3 - \sigma'_1$ versus time for the complete cycle and find the largest absolute magnitude of any stress difference at any time. The alternating stress intensity S_{alt} is one-half of this magnitude.

NG-3217 Classification of Stress

Table NG-3217-1 provides assistance in the determination of the category to which a stress should be assigned.

NG-3220 STRESS LIMITS FOR OTHER THAN THREADED STRUCTURAL FASTENERS

NG-3221 Design Loadings

The stress intensity limits which must be satisfied for the Design Loadings (NG-3112) stated in the Design Specifications are the three limits of this paragraph and the special stress limits of NG-3227. The provisions of NG-3228 may provide relief from certain of these stress limits if plastic analysis techniques or tests are applied. The design stress intensity values S_m are given by NG-3229. The limits are summarized by Fig. NG-3221-1.

NG-3221.1 General Primary Membrane Stress Intensity.

(Derived from P_m in Fig. NG-3221-1.) This stress intensity is derived from the average value across the thickness of a section of the general primary stresses (see NG-3213.8) produced by design internal pressure difference and other specified Design Mechanical Loads, but excluding all secondary and peak stresses. Averaging is to be applied to the stress components prior to determination of the stress intensity values. The allowable value of the stress intensity is S_m at the Design Temperature.

NG-3221.2 Primary Membrane Plus Primary Bending Stress Intensity.

(Derived from $P_m + P_b$ in Fig. NG-3221-1.) This stress intensity is derived from the highest value across the thickness of a section of the general primary membrane stresses plus primary bending stresses produced by Design Pressure Difference and other specified Design Mechanical Loads, but excluding all secondary and peak stresses. The allowable value of this stress intensity is $1.5S_m$.

NG-3221.3 External Pressure Difference.

The provisions of NG-3133 apply.

NG-3222 Level A Service Limits

The Level A Service Limits must be satisfied for the Service Conditions [NCA-2142.2(a)] for which these limits are designated in the Design Specifications and are the four limits of this paragraph and NG-3227. The provisions of NG-3228 may provide relief from certain of these stress limits if plastic analysis techniques are applied. The design stress intensity values S_m are given by NG-3229. The limits are summarized by Fig. NG-3221-1.

NG-3222.1 Primary Membrane and Bending Stress Intensities.

The stresses due to primary loads presented

Page 49

during normal service must be computed and satisfy the limits of NG-3221. Pages 50-50

**TABLE NG-3217-1
CLASSIFICATION OF STRESS INTENSITIES FOR SOME TYPICAL CASES**

Core Support Structure	Location	Origin of Stress	Type of Stress	Classification	Discontinuity	
					Gross	Local
Cylindrical or spherical shell	Shell plate remote from discontinuities	Pressure difference	General membrane Gradient through plate thickness	P_m Q	No Yes	No No
		Axial thermal gradient	Membrane Bending	Q Q	Yes Yes	No No
	Junction with head or flange	Pressure difference	Membrane Bending	Q Q	Yes Yes	No No
Any shell or head	Any section across entire shell	External load or moment, or pressure difference	General membrane averaged across full section. Stress component perpendicular to cross section.	P_m	No	No
		External load or moment	Bending across full section. Stress component perpendicular to cross section.	P_m	No	No
	Near nozzle or other opening	External load or moment, or pressure difference	Membrane Bending Peak (fillet or corner)	Q Q F	Yes Yes Yes	No No Yes
	Any location	Temp. difference between shell and head	Membrane Bending	Q Q	Yes Yes	No No
Dished head or conical	Crown	Pressure difference	General membrane Bending	P_m P_b	No No	No No
	Knuckle of junction to shell	Pressure difference	Membrane Bending	$Q(1)$ Q	Yes Yes	No No
Flat head	Center region	Pressure difference	General membrane Bending	P_m P_b	No No	No No
	Junction to shell	Pressure difference	Membrane Bending	Q Q	Yes Yes	No No
Perforated head or shell	Typical ligament in a uniform pattern	Pressure difference or external load	General membrane (avg. through cross section) Bending (avg. through width of ligament, but gradient through plate) Peak	P_m P_b F	No No No	No No Yes
	Isolated or atypical ligament	Pressure difference	Membrane Bending Peak	Q F F	Yes Yes Yes	No Yes Yes

(Table NG-3217-1 continues on next page)

TABLE NG-3217-1 CLASSIFICATION OF STRESS INTENSITIES FOR SOME TYPICAL CASES

TABLE NG-3217-1 (CONT'D)
CLASSIFICATION OF STRESS INTENSITIES FOR SOME TYPICAL CASES

Core Support Structure	Location	Origin of Stress	Type of Stress	Classification	Discontinuity	
					Gross	Local
Nozzle	Cross section perpendicular to nozzle axis	Pressure difference or external load or moment	General membrane avg. across full section. Stress component perpendicular to section.	P_m	No	No
		External load or moment	Bending across nozzle section	P_m	No	No
	Nozzle wall	Pressure difference	General membrane	P_m	No	No
			Membrane	Q	Yes	No
			Bending	Q	Yes	No
			Peak	F	Yes	Yes
	Differential expansion	Membrane	Q	Yes	No	
		Bending	Q	Yes	No	
		Peak	F	Yes	Yes	
Cladding	Any	Differential expansion	Membrane Bending	F F	Yes Yes	Yes Yes
Any	Any	Radial thermal gradient through plate thickness(2)	Stress due to equivalent bending portion Stress due to nonlinear portion	$Q(3)$ F	Yes Yes	No Yes
Any	Any	Any	Stress concentration (notch effect)	F	Yes	Yes

NOTES:

- (1) Consideration must also be given to the possibility of wrinkling and excessive deformation in shells with large diameter-to-thickness ratio.
(2) Consider the possibility of thermal stress ratchet.
(3) Equivalent linear stress is defined as the linear stress distribution which has the same net bending moment as the actual stress distribution.

TABLE NG-3217-1 (CONT'D) CLASSIFICATION OF STRESS INTENSITIES FOR SOME TYPICAL CASES

4 The concept of stress differences discussed in NG-3216 is essential to determination to the maximum range, since algebraic signs must be retained in the computation. Note that this limitation on range is applicable to the entire history of normal Service Loadings, not just to the stresses resulting from each individual transient.

NG-3222.2 Primary Plus Secondary Stress Intensity.⁴

This stress intensity is derived from the highest value at any point across the thickness of a section of the general or local primary membrane stresses, plus primary bending stresses, plus secondary stresses, produced by the specified service pressure differences and other specified mechanical loads and by general thermal effects associated with normal service loadings. The effects of gross structural discontinuities but not of local structural discontinuities (stress concentrations) shall be included. The allowable value for the maximum range of this stress intensity is $3S_m$ [Fig. NG-3221-1, Note (1)], except for certain cyclic events which may exceed the $3S_m$ limit during the design life of the plant. For this exception, in lieu of meeting the $3S_m$ limit, an elastic-plastic fatigue analysis in accordance with NG-3228.3 may be performed to demonstrate that the cumulative fatigue usage attributable to the combination of these low cycle events plus all other cyclic events does not exceed a value of 1.0 when calculated in accordance with NG-3222.4.

NG-3222.3 Expansion Stress Intensity.⁴

This stress intensity is the highest value of stress, neglecting local structural discontinuities, produced at any point across the thickness of a section by the loadings which result from restraint of free end displacement and the effect of

anchor point motions. The allowable value of the maximum range of this stress intensity when combined with all other primary and secondary stress intensities is $3S_m$.

[98]
NG-3222.4 Analysis for Cyclic Operation

(a) *Suitability for Cyclic Condition.* The suitability of a structure for specified Service Loadings involving

cyclic application of loads and thermal conditions shall be determined by the methods described herein, except that the suitability of high strength threaded structural fasteners shall be determined by the methods of NG-3232.3(b) and the possibility of thermal stress ratchet shall be investigated in accordance with NG-3222.5. If the specified Service Loadings of the structure meet all of the conditions of (d) below, no analysis for cyclic service is required, and it may be assumed that the peak stress limit discussed in (b) below has been satisfied by compliance with the applicable requirements for material, design, fabrication, examination, and testing of this Subsection. If the Service Loadings do not meet all the conditions of (d) below, a fatigue analysis shall be made in accordance with (e) below or a fatigue test shall be made in accordance with II-1200. Pages 52-52

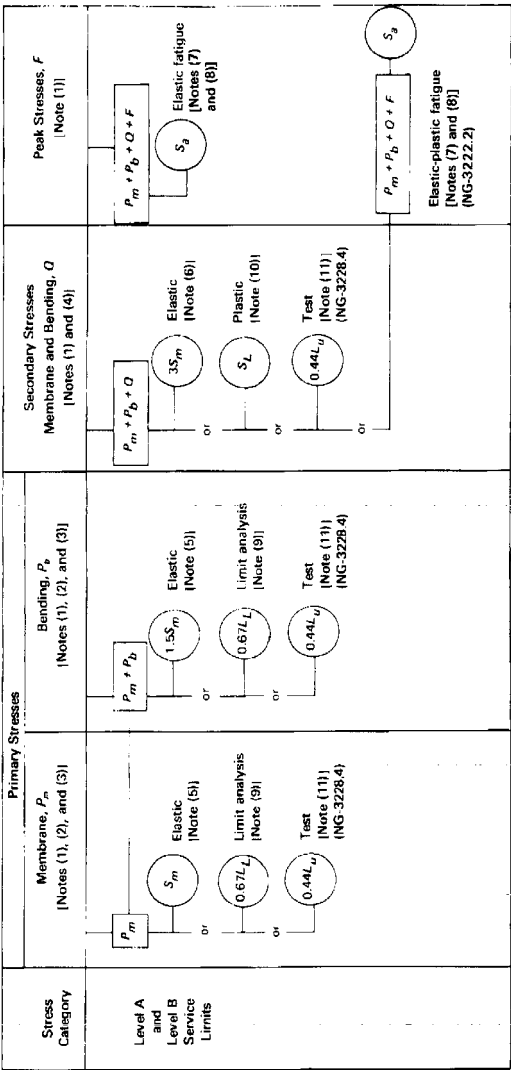


FIG. NG-3221-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITIES FOR SERVICE LEVELS A AND B

NOTES:

- (1) The symbols P_m , P_b , Q , and F do not represent single quantities, but rather sets of six quantities representing the six stress components σ_1 , σ_2 , σ_3 , τ_{12} , τ_{13} , and τ_{23} .
- (2) For configurations where compressive stresses occur, the stress limits shall be reviewed to take into account critical buckling stresses [NG-3211(c)].
- (3) When loads are transiently applied, consideration should be given to the use of dynamic load amplification.
- (4) The stresses in Category Q are those parts of the total stress which are produced by thermal gradients, structural discontinuities, etc., and do not include primary stresses which may also exist at the same point. It should be noted, however, that a detailed stress analysis frequently gives the combination of primary and secondary stresses directly and, when appropriate, this calculated value represents the total of $P_m + P_b + Q$, and not Q alone. Similarly, if the stress in Category F is produced by a stress concentration, the quantity F is the additional stress produced by the notch, over and above the nominal stress. For example, if a plate has a nominal stress intensity, $P_m = S$, $P_b = 0$, $Q = 0$, and a notch with a stress concentration K is introduced, then $F = P_m(K - 1)$ and the peak stress intensity equals $P_m + P_m(K - 1) = KP_m$.
- (5) The triaxial stresses represent the algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) for the combination of stress components. Where uniform tension loading is present, triaxial stresses are limited to $4S_m$.
- (6) This limitation applies to the range of stress intensity. When the secondary stress is due to a temperature excursion at the point at which the stresses are being analyzed, the value of S_m shall be taken as the average of the S_m values tabulated in Tables 2A, 2B and 4, Section II, Part D, Subpart 1 for the highest and the lowest temperature of the metal during the transient. When part or all of the secondary stress is due to mechanical load, the value of S_m shall be taken as the S_m value for the highest temperature of the metal during the transient.
- (7) S_e is obtained from the fatigue curves, Figs. I-9.0. The allowable stress intensity for the full range of fluctuation is $2S_e$.
- (8) Values of S_{sh} , calculated on an elastic basis, shall not exceed the S_e value associated with 10 cycles when using the fatigue curves of Figs. I-9.0.
- (9) L_L = lower bound limit load with yield point equal to $1.5 S_m$ (where S_m is the value of allowable stress intensity at temperature as contained in Tables 2A, 2B and 4, Section II, Part D, Subpart 1. The lower bound limit load is here defined as that produced from the analysis of an ideally plastic (nonstrain-hardening) material where deformations increase with no further increase in applied load. The lower bound load is one in which the material everywhere satisfies equilibrium and nowhere exceeds the defined material yield strength using either a shear theory or a strain energy of distortion theory to relate multiaxial yielding to the uniaxial case.
- (10) S_s denotes the structural action of shakedown load as defined in NG-3213.17, calculated on a plastic basis as applied to a specific location on the structure.
- (11) L_s is defined in NG-3228.4.

FIG. NG-3221.1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITIES
FOR SERVICE LEVELS A AND B (CONT'D)

FIG. NG-3221-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITIES FOR SERVICE LEVELS A AND B (CONT'D)

(b) *Peak Stress Intensity.* This stress intensity is derived from the highest value at any point across the thickness of a section of all primary, secondary, and peak stresses produced by specified service pressure differences and other mechanical loads, and by general and local thermal effects associated with normal Service Conditions and including the effects of gross and local structural discontinuities.

(c) *Conditions and Procedures.* The conditions and procedures of NG-3222.4 are based on a comparison of peak stresses with strain cycling fatigue data. The strain cycling fatigue data are represented by design fatigue strength curves of Figs. I-9.0. These curves show the allowable amplitude S_a of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles. This stress intensity amplitude is calculated on the assumption of elastic behavior and, hence, has the dimensions of stress, but it does not represent a real stress when the elastic range is exceeded. The fatigue

curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable stress intensity amplitude directly comparable. As an exception to the use of strain controlled test data, Fig.

I-9.2.2, Curves B and C, are based on load controlled fatigue data. The curves have been adjusted, where necessary, to include the maximum effects of mean stress, which is the condition where the stress fluctuates about a mean value which is different from zero. As a consequence of this procedure, it is essential that the requirements of (b) above be satisfied at all times with transient stresses included, and that the calculated value of the alternating stress intensity be proportional to the actual strain amplitude. To evaluate the effect of alternating stresses of varying amplitudes, a linear damage relation is assumed in (e)(4) below.

(d) Components Not Requiring Analysis for Cyclic Service. An analysis for cyclic service is not required, and it may be assumed that the peak stress limit discussed in (b) above has been satisfied for a structure by compliance with the applicable requirements for material, design, fabrication, examination, and testing of this Subsection, provided the specified Service⁵ Loadings of the structure or portion thereof meets all the conditions stipulated in (1) through (4) below.

(1) Temperature Difference - Startup and Shutdown. The temperature difference in degrees Fahrenheit between any two adjacent points⁶ of the structure during normal service does not exceed $S_a/(2E\alpha)$, where S_a is the value obtained from the applicable design fatigue curves for the specified number of startup-shutdown cycles, α is the value of the instantaneous coefficient of thermal expansion at the mean value of the temperatures at the two points as given by Table TE, Section II, Part D, Subpart 2, and E is taken from Table TM, Section II, Part D, Subpart 2 at the mean value of the temperature at the two points.

5 As stated in NG-3223, for structures operating within the temperature limits of this Subsection, Service Loadings for which Level B Limits are designated must be considered as though Level A Limits were designated in evaluating exemptions from fatigue analysis.

6 Adjacent points are defined as points which are spaced less than the distance $(2\sqrt{Rt})$ from each other, where R and t are the mean radius and thickness, respectively, of the shell of revolution. In configurations other than a shell of revolution, either the allowable distance between adjacent points must be determined in appropriate configurations or a fatigue analysis shall be accomplished.

(2) Temperature Difference - Normal Service. The temperature difference in degrees Fahrenheit between any two adjacent points⁶ does not change⁷ during normal service by more than the quantity $S_a/(2E\alpha)$, where S_a is the value obtained from the applicable design fatigue curve of Figs. I-9.0 for the total specified number of significant temperature difference fluctuations. A temperature difference fluctuation shall be considered to be significant if its total algebraic range exceeds the quantity $S/2E\alpha$, where S is defined as follows.

(a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(3) Temperature Difference - Dissimilar Materials. For structures fabricated from materials of differing moduli of elasticity and coefficients of thermal expansion or both, the total algebraic range of temperature fluctuation in degrees Fahrenheit experienced by the component during normal service does not exceed the magnitude $S_a/2(E_1\alpha_1 - E_2\alpha_2)$, where S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature fluctuations, E_1 and E_2 are the moduli of elasticity, and α_1 and α_2 are the values of the instantaneous coefficients of thermal expansion at the mean temperature value involved for the two materials of construction (Tables TE and TM, Section II, Part D, Subpart 1). A temperature fluctuation shall be considered to be significant if its total excursion exceeds the quantity $S/2(E_1\alpha_1 - E_2\alpha_2)$, where S is defined as follows:

(a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve. If the two materials used have different applicable design fatigue curves, the lower value of S_a shall be used in applying the rules of this paragraph.

7 The algebraic range of the difference shall be used.

(4) Mechanical Loads. The specified full range of mechanical loads, including pipe reactions and pressure differences, does not result in load stresses whose range exceeds the S_a value obtained from the applicable design

fatigue curve of Figs. I-9.0 for the total specified number of significant^a load fluctuations. If the total specified number of significant load fluctuations exceeds 10^6 , the S_a value at $N = 10^6$ may be used. A load fluctuation shall be considered to be significant if the

total excursion of load stress exceeds the value of S_a , where S is defined as follows.

(a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(e) *Procedure for Analysis for Cyclic Loading.* If the specified service loadings for the structure do not meet the conditions of (d) above, the ability of the structure to withstand the specified cyclic service without fatigue failure shall be determined as provided herein. The determination shall be made on the basis of the stresses at a point and the allowable stress cycles shall be adequate for the specified Service Loadings at every point. Only the stresses due to service cycles as specified in the Design Specifications need be considered. Compliance with these requirements means only that the structure is suitable from the standpoint of possible fatigue failure; complete suitability for the specified Service Loadings is also dependent on meeting the general stress limits of NG-3222 and any applicable special stress limits of NG-3227.

(1) *Stress Differences.* For each condition of normal service, determine the stress differences and the alternating stress intensity S_a in accordance with NG-3216.

(2) *Local Structural Discontinuities.* These effects shall be evaluated by the use of theoretical stress concentration factors for all conditions, except that experimentally determined fatigue strength reduction factors may be used when stated herein or when determined in accordance with the procedures of II-1600. Except for the case of cracklike defects and specific piping geometries for which specific values are given in NB-3680, no fatigue strength reduction factor greater than 5 need be used.

(3) *Design Fatigue Curves.* Figures I-9.0 contain the applicable fatigue design curves for the materials permitted by this Subsection. When more than one curve is presented for a given material, the applicability of each curve to material of various strength levels is identified. Linear interpolation may be used for intermediate strength levels of these materials. As used herein the strength level is the specified minimum room temperature value. The design fatigue curves of Figs. I-9.0 are defined over a cyclic range of 10 to 10^6 cycles, except that for austenitic steels, nickel-chromium alloys, and nickel-copper alloys, the design fatigue curves are extended to 10^{11} cycles in Fig. I-9.2.2. Criteria for the use of the latter curves are given in Fig. I-9.2.2 and are also presented graphically by the flow chart in Fig. I-9.2.3.

(4) *Effect of Elastic Modulus.* Multiply S_{alt} (NG-3216.1 or NG-3216.2) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve of Figs. I-9.0 at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the service cycle being considered is the only one which produces significant fluctuating stresses, this is the allowable number of cycles.

(5) *Cumulative Damage.* If there are two or more types of stress cycle which produce significant stresses, their cumulative effect shall be evaluated as stipulated in Steps 1 through 6 below.

Step 1: Designate the specified number of times each type of stress cycle of types 1, 2, 3, etc., will be repeated during the life of the component as $n_1, n_2, n_3, \dots, n_r$ respectively.

NOTE: In determining $n_1, n_2, n_3, \dots, n_r$ consideration shall be given to the superposition of cycles of various origins which produce a total stress difference range greater than the stress difference ranges of the individual cycles. For example, if one type of stress cycle produces 1000 cycles of a stress difference variation from zero to +60,000 psi and another type of stress cycle produces 10,000 cycles of a stress difference variation from zero to -50,000 psi, the two types of cycle to be considered are defined by the following parameters:

$$\text{Type 1 cycle: } n_1 = 1000, S_{alt1} = (60,000 + 50,000)/2 = 55,000 \text{ psi}$$

Type 2 cycle: $n_2 = 9000$, $S_{alt2} = (50,000 + 0)/2 = 25,000$ psi

Step 2: For each type of stress cycle, determine the alternating stress intensity S_{alt} by the procedures of NG-3216.1 or NG-3216.2 above. Call these quantities S_{alt1} , S_{alt2} , S_{alt3} , ..., S_{altn}

Step 3: For each value S_{alt1} , S_{alt2} , S_{alt3} , ..., S_{altn} , use the applicable design fatigue curve to determine the maximum number of repetitions which would be allowable if this type of cycle were the only one acting. Call these values N_1 , N_2 , N_3 , ..., N_n

Step 4: For each type of stress cycle, calculate the usage factors U_1 , U_2 , U_3 , ..., U_n from $U_1 = n_1/N_1$, $U_2 = n_2/N_2$, $U_3 = n_3/N_3$, ..., $U_n = n_n/N_n$

Step 5: Calculate the cumulative usage factor U from $U = U_1 + U_2 + U_3 + \dots + U_n$

Step 6: The cumulative usage factor U shall not exceed 1.0.

[98]

NG-3222.5 Thermal Stress Ratchet.

It should be noted that under certain combinations of steady state

Page 55

and cyclic loadings there is a possibility of large distortions developing as the result of ratchet action; that is, the deformation increases by a nearly equal amount for each cycle. Examples of this phenomenon are treated in this subparagraph and in NG-3227.3.

(a) The limiting value of the maximum cyclic thermal stress permitted in a portion of an axisymmetric shell loaded by steady-state internal pressure difference in order to prevent cyclic growth in diameter is as follows:

Let y'	= maximum allowable range of thermal stress computed on an elastic basis divided by the yield strength S_y^8
x	= maximum general membrane stress due to pressure difference divided by the yield strength S_y^8

(1) Case 1 - linear variation of temperature through the wall:

$$y' = \frac{1}{x} \text{ for } 0 < x < 0.5$$

$$y' = 4(1 - x) \text{ for } 0.5 < x < 1.0$$

(2) Case 2 - parabolic constantly increasing or constantly decreasing variation of temperature through the wall:

y'	= 5.2(1 - x) for 0.615 < x < 1.0 and approximately for x < 0.615 as follows:
for x	= 0.3, 0.4, 0.5
y'	= 4.65, 3.55, 2.70

(b) Use of yield strength S_y in the above relations instead of the proportional limit allows a small amount of growth during each cycle until strain hardening raises the proportional limit to S_y . If the yield strength of the material is higher than the endurance limit⁹ for the material, the latter value shall be used if there is to be a large number of cycles because strain softening may occur.

NG-3222.6 Deformation Limits.

Any deformation limits prescribed by the Design Specifications shall be satisfied.

⁸ It is permissible to use $1.5S_m$ whenever it is greater than S_y .

⁹ The endurance limit shall be taken as two times the S_a value at 10^6 cycles in the applicable fatigue curve of Figs. 1-9.0, except that for the curves of Figs. 1-9.2.1 and 1-9.2.2 the endurance limit shall be taken as two times the S_a value at 10^{11} cycles obtained from Curve A.

NG-3223 Level B Service Limits

For components operating within the temperature limits of this Section the requirements of (a) and (b) below apply.

(a) The values of Level A Service Limits (NB-3222) shall apply for Level B Service Limits. In addition, if a pressure for which Level B Limits are designated exceeds the Design Pressure Difference, the stress limits of Fig. NG-3221-1 shall apply using allowable stress intensity values of 110% of those given on Fig. NG-3221-1 and the loadings.

(b) The Design Specifications shall be satisfied.

NG-3224 Level C Service Limits

Level C Service Limits must be satisfied for Service Loadings for which they are designated by the Design Specifications and are those of one of the five methods permitted in NG-3224.1. These stress intensity limits are summarized by Fig. NG-3224-1. Dynamic instability shall be considered in meeting the load, stress, and deformation limits. The requirements of NG-3224.2 through NG-3224.6 shall also be met.

NG-3224.1 Stress Intensity Limits

(a) Elastic Analysis Method

(1) The general primary membrane stress intensity (NG-3213.6, NG-3213.8, and NG-3221.1) shall not exceed 1.5 times the allowable stress intensity S_m as given in Tables 2A and 2B, Section II, Part D, Subpart 1.

(2) The primary membrane plus primary bending stress intensity (NG-3213.7, NG-3213.8, and NG-3221.3) shall not exceed 2.25 times the allowable stress intensity S_m as given in Tables 2A and 2B, Section II, Part D, Subpart 1.

(b) Limit Load Analysis. Instead of the elastic analysis of (a) above, a limit load analysis may be performed as set forth below.

(1) The lower bound limit load L_L is determined with material yield point equal to 1.5 times the allowable stress intensity S_m at temperatures where S_m is given in Tables 2A and 2B, Section II, Part D, Subpart 1. The lower bound limit load (NG-3213.21) is that load, determined from the analysis (NG-3213.20) of an ideally plastic (nonstrain-hardening) material, which produces increasing deformations with no further increase in applied load. The lower bound load is one in which the material everywhere satisfies equilibrium and nowhere exceeds the defined material yield strength, using either the maximum shear stress theory or a strain energy of distortion theory to relate multiaxial yielding to the uniaxial case.

Page 56

Page 57

Stress Category	Primary Stresses		Secondary Stresses Membrane and Bending, Q	Peak Stresses
	Membrane, P_m (Notes (1), (2), and (3))	Bending, P_b (Notes (1), (2), and (3))		
Level C (Note (4))	P_m	$P_m + P_b$		
	1.5 S_m Elastic analysis (Note (5))	2.25 S_m Elastic analysis (Note (5))		
	L_L Limit analysis (Note (6))	L_L Limit analysis (Note (6))	Evaluation not required	Evaluation not required
	1.5 S_m Plastic analysis (Note (7))	2.25 S_m Plastic analysis (Notes (7) and (8))		
	0.6 L_u Test (Note (9))	0.6 L_u Test (Note (9))		
	S_E Stress-ratio analysis (Note (10))	$K S_E$ Stress-ratio analysis (Note (10))		

NOTES:

- (1) The symbols P_m , P_b , Q, and F do not represent single quantities, but rather sets of six quantities representing the six stress components $\sigma_1, \sigma_2, \sigma_3, \sigma_4, \sigma_5, \sigma_6$ and $\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6$.
- (2) For configurations where compressive stresses occur, the stress limits shall be revised to take into account critical buckling stresses (NG-3224.2).
- (3) When loads are transiently applied, consideration should be given to the use of dynamic load amplification and possible change in modulus of elasticity.
- (4) Where deformation is of concern in a structure, the deformation shall be limited to two-thirds the value given in Design Specifications for Level C Service Limits.
- (5) The triaxial stresses represent the algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) for the combination of stress components. Where uniform tension loading is present, triaxial stresses should be limited to $6S_m$.
- (6) L_L - lower bound limit load with yield point equal to 1.5 S_m (where S_m is the value of allowable stress intensity at temperature as contained in Tables 2A and 2B, Section II, Part D, Subpart 1. The lower bound limit load is here defined as that produced from the analysis of an ideally plastic (nonstrain-hardening) material where deformations increase with no further increase in applied load. The lower bound load is one in which the material everywhere satisfies equilibrium and nowhere exceeds the defined material yield strength using either a shear theory or a strain energy of distortion theory to relate multiaxial yielding to the uniaxial case.
- (7) Elastic-plastic evaluated nominal primary stress. Strain hardening of the material may be used for the actual monotonic stress-strain curve at the temperature of loading or any approximation to the actual stress-strain curve which everywhere has a lower stress for the same strain as the actual monotonic curve may be used. Either the shear or strain energy of distortion flow rule shall be used to account for multiaxial effects.
- (8) S_u = ultimate strength at temperature. Multiaxiality effect on the ultimate strength shall be considered.
- (9) L_u is defined in NG-3224.1(a).
- (10) Stress ratio is a method of plastic analysis which uses the stress ratio combinations [combination of stresses that consider the ratio of the actual stress to the allowable plastic or elastic stress, NG-3224.1(d)] to compute the maximum load strain-hardening material can carry.

FIG. NG-3224-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITIES FOR SERVICE LEVEL C

FIG. NG-3224-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITIES FOR SERVICE LEVEL C

(2) For Service Loadings for which Level C Limits are designated, the general primary membrane stress intensity shall not exceed the lower bound limit load L_L .

(3) For Service Loadings for which Level C Limits are designated, the general primary membrane plus primary bending stress intensities shall not exceed the lower bound limit load L_L .

(c) *Plastic Analysis*. Instead of the elastic analysis of (a) above, a plastic analysis may be performed as set forth in (1) and (2) below.

(1) For Service Loadings for which Level C Limits are designated, general primary membrane stress intensity values shall not exceed 1.5 times the allowable stress intensity S_m at temperatures where S_m is given in Tables 2A and 2B, Section II, Part D, Subpart 1.

(2) For Service Loadings for which Level C Limits are designated, the general primary membrane plus primary bending stress intensities shall not exceed the greater of either one-half of the ultimate strength values at temperature or 2.25 times the allowable stress intensity values S_m at temperature as given in Tables 2A and 2B, Section II, Part D, Subpart 1.

(d) *Stress Ratio Analysis*. Instead of the elastic analysis of (a) above, a stress ratio analysis (NG-3213.23) may be performed, in which event the limits of (1) and (2) below shall be met.

(1) Service loads producing primary membrane stresses shall not result in stress intensities exceeding S_E where $S_E \leq 2.0S_m$.

(2) The stress intensity limits for other stress fields shall be as specified in A-9000. For example, for bending:

$$P_B \leq S_E \left[1 - \left(\frac{P_m}{S_E} \right)^2 \right]$$

for rectangular sections, where

$$n = 2 \quad \text{or} \quad P_B \leq \sqrt{K^2 S_E (S_E - P_m)}$$

where K is the Section Factor for $n = 1$ as determined by the method of A-9000.

(e) *Prototype or Model Tests.* For Service Loadings for which Level C Limits are designated, the limits of (a) above need not be satisfied if it can be shown from the test of a prototype or model that the specified loads (dynamic or static equivalent) do not exceed 60% of L_e , where L_e is the ultimate load or the maximum load or load combination used in the test. In using this method, account shall be taken of the size effect and dimensional tolerances which exist between the actual part and the test part or parts, as well as differences which may exist in the ultimate strength or other governing material properties of the actual part and the tested parts, to assure that the loads obtained from the test are a conservative representation of the load carrying capability of the actual structure under postulated Service Loadings for which Level C Limits are designated.

NG-3224.2 External Pressure.

The permissible equivalent static external pressure shall be taken as 150% of that permitted by the rules of NG-3133. Where dynamic pressures are involved, the permissible external pressure shall satisfy the preceding requirements or be limited to one-half the dynamic instability pressure.

NG-3224.3 Special Stress Limits.

The permissible values for special stress limits shall be taken as 150% of the values given in NG-3227 and NG-3228.1.

NG-3224.4 Secondary and Peak Stresses.

The requirements of NG-3222.2, NG-3222.4(b), NG-3222.5, and NG-3227.3 need not be satisfied.

NG-3224.5 Fatigue Requirements.

Service Loadings for which Level C Limits are designated need not be considered when applying the procedures of NG-3222.4(a) to determine whether or not a fatigue analysis is required.

NG-3224.6 Deformation Limits.

Any deformation limits prescribed by the Design Specifications shall be considered [Fig. NG-3224-1, Note (9)].

NG-3225 Level D Service Limits

If the Design Specifications specify any Service Loadings for which Level D Limits are designated [NCA-2142.4(d)], the rules contained in Appendix F may be used in evaluating these loadings, independently of all other Design and Service Loadings. In addition, when the special stress limits of NG-3227 are applicable for Level D Limits, the calculated stresses shall not exceed twice the stress limits given in NG-3227 as applied for Level A and Level B Service Limits.

NG-3227 Special Stress Limits

The following deviations from the basic stress limits are provided to cover special Service Loadings or configurations. Some of these deviations are more restrictive and some are less restrictive than the basic stress limits. Rules governing

respectively. In cases of conflict between these requirements and the basic stress limits, the rules of NG-3227 take precedence for the particular situations to which they apply. NG-3227 does not apply to threaded structural fasteners (NG-3230).

[98]

NG-3227.1 Bearing Loads

(a) The average bearing stress for resistance to crushing under the maximum load, experienced as a result of Design Loadings or of Service Loadings for which Level A Limits are designated, shall be limited to S_y at temperature, except that when the distance to a free edge is larger than the distance over which the bearing load is applied, a stress of $1.5S_y$ at temperature is permitted. For clad surfaces the yield strength of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.

(b) When bearing loads are applied near free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. In the case of load stress only, the average shear stress shall be limited to $0.6S_m$. In the case of load stress plus secondary stress, the average shear stress shall not exceed (1) or (2) below:

(1) for material to which Tables 2A and 2B, Section II, Part D, Subpart 1, Note (2) applies, the lower of $0.5S_y$ at 100°F (38°C) and $0.675 S_y$ at temperature;

(2) for all other material, $0.5S_y$ at temperature.

(c) For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

(d) When considering bearing stresses in pins and similar members, the S_y at temperature value is applicable, except that a value of $1.5S_y$ may be used if no credit is given to bearing area within one pin diameter from a plate edge.

[98]

NG-3227.2 Pure Shear

(a) The average primary shear stress across a section loaded in pure shear, experienced as a result of Design Loadings or Service Loadings for which Level A Limits are designated (for example, keys, shear rings), shall be limited to $0.6S_m$.

(b) The maximum primary shear, experienced as a result of Design Loadings or Service Loadings for which Level A Limits are designated exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.8S_m$. Primary plus secondary and peak shear stresses shall be converted to stress intensities (equal to two times pure shear stress) and as such shall not exceed the basic stress limits of NG-3222.2 and NG-3222.4(b).

NG-3227.3 Progressive Distortion of Nonintegral Connections.

Screwed on caps, screwed in plugs, shear ring closures, and breechlock closures are examples of nonintegral connections which are subject to failure by bell mousing or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore, primary plus secondary stress intensities (NG-3222.2) which result in slippage between the parts of a nonintegral connection in which disengagement could occur as a result of progressive distortion shall be limited to the value S_y (Table Y-1, Section II, Part D, Subpart 2).

NG-3227.4 Triaxial Stresses.

The algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) shall not exceed four times the tabulated value of S_m .

NG-3227.5 Nozzle Piping Transition.

The P_m classification of stresses in nozzle resulting from pressure difference, external loads, and moments is applicable for that length of nozzle which lies within the limits of reinforcement given by NG-3132, whether or not nozzle reinforcement is provided. Beyond the limits of reinforcement, a P_m classification shall be applied to the general primary membrane stress intensity averaged across the section (not thickness) resulting from combined pressure difference and external mechanical loads; $P_m + P_b$ classification shall be applied to primary membrane plus primary bending stress intensities that result from Design Pressure Difference and external mechanical loads; and a $P_m + P_b + Q$ classification shall be applied to primary plus secondary stress intensities resulting from all loads including external load or moment attributable to restrained free end displacement of the attached pipe. Beyond the limits of reinforcement, the $3S_m$ limit on the range of primary plus secondary stress intensity may be exceeded as provided in NG-3228.3 except that in the evaluation of NG-3228.3(a), stresses from attached pipe thermal expansion loads and moments may also be excluded. The range of membrane plus bending stress intensity attributable solely to thermal

Page 59

expansion of the attached piping shall be $\leq 3S_m$. The nozzle, outside the reinforcement limit, shall not be thinner than the larger of the pipe thickness or the quantity $t_p (S_{mp}/S_{mn})$ where t_p is the nominal thickness of the mating pipe, S_{mp} is the allowable stress intensity value for the pipe material, and S_{mn} is the allowable stress intensity value for the nozzle material.

NG-3227.6 Applications of Elastic Analysis for Stresses Beyond the Yield Strength.

Certain of the allowable stresses permitted in the design criteria are such that the maximum stress calculated on an elastic basis may exceed the yield strength of the material. The limit on primary plus secondary stress intensity of $3S_m$ (NG-3222.2) has been placed at a level which assures shakedown to elastic action after a few repetitions of the stress cycle except in regions containing significant local structural discontinuities or local thermal stresses. These last two factors are considered only in the performance of a fatigue evaluation. Therefore:

(a) in evaluating stresses for comparison with the stress limits on other than fatigue allowables, stresses shall be calculated on an elastic basis;

(b) in evaluating stresses for comparison with fatigue allowables, all stresses except those which result from local thermal stresses [(NG-3213.12(b))] shall be evaluated on an elastic basis. In evaluating local thermal stresses, the elastic equations shall be used except that the numerical value substituted for Poisson's ratio shall be determined from the expression:

$$\nu = 0.5 - 0.2 \frac{S_y}{S_a} \text{ but not less than } 0.3$$

where

S_y

= the yield strength of the material at the mean value of the

S_a

temperature of the cycle

= the value obtained from the applicable design fatigue curve (Figs. I-9.0) for the specified number of cycles of the condition being considered

NG-3228 Applications of Plastic Analysis

The following subparagraphs provide guidance in the application of plastic analysis and some relaxation of the basic stress limits which are allowed if plastic analysis is used.

NG-3228.1 Plastic Analysis.

The limits on primary plus secondary stress intensity (NG-3222.2), thermal stress ratchet in shell (NG-3222.5), and progressive distortion of nonintegral connections (NG-3227.3) need not be satisfied at a specific location if, at the location, the procedures of (a) through (c) below are used.

(a) In evaluating stresses for comparison with the remaining stress limits, the stresses are calculated on an elastic basis.

(b) In lieu of satisfying the specific requirements of NG-3222.2, NG-3222.5, and NG-3227.3 at a specific location, the structural action is calculated on a plastic basis, and the design shall be considered to be acceptable if shakedown occurs (as opposed to continuing deformation) and if the deformations which occur prior to shakedown do not exceed specified limits. However, this shakedown requirement need not be satisfied provided the following conditions are met.

(1) The requirements on primary plus secondary stress intensity (NG-3222.2), thermal stress ratchet in shell (NG-3222.5), and progressive distortion of non-integral connections (NG-3227.3) need not be satisfied at a specific location, provided that at the location the evaluation of stresses for comparison with all the other design, service, testing, and special limits specified in NG-3220 is calculated on an elastic basis.

(2) The maximum accumulated strain at any point, as a result of cyclic operations to which plastic analysis is applied, does not exceed 5.0%.

(3) The maximum deformations do not exceed specified limits.

(4) In evaluating stresses for comparison with fatigue allowables, the numerically maximum principal total strain range shall be multiplied by one-half the modulus of elasticity of the material (Table TM, Section II, Part D, Subpart 2) at the mean value of temperature of the cycle.

(5) The material shall have a minimum specified yield strength to specified minimum ultimate strength ratio of less than 0.80.

(c) In evaluating stresses for comparison with fatigue allowables, the numerically maximum principal total strain range which occurs after shakedown shall be multiplied by one-half of the modulus of elasticity of the material (Table TM, Section II, Part D, Subpart 2) at the mean value of the temperature of the cycle.

NG-3228.2 Limit Analysis.

The limits on primary membrane stress intensity (NG-3221.1) and primary membrane plus primary bending stress intensity (NG-3221.2) need not be satisfied at a specific location if it can be shown by means of limit analysis or by tests that the specified loadings do not exceed two-thirds of the lower bound collapse load, except for those materials of Tables 2A and 2B, Section II, Part D, Subpart 1 to which Note (2) of that table is applicable. For these latter materials, the specified loading shall not exceed

Page 60

the product of the applicable permanent strain limiting factor of Table Y-2, Section II, Part D, Subpart 2 times the lower bound collapse load.

NG-3228.3 Simplified Elastic-Plastic Analysis.

The $3S_m$ limit on the range of primary plus secondary stress intensity (NG-3222.2) may be exceeded, provided that the

requirements of (a) through (f) below are met.

(a) The range of primary plus secondary membrane plus bending stress intensity, excluding thermal bending stresses, shall be $\leq 3S_m$.

(b) The value of S_a used for entering the design fatigue curve is multiplied by the factor K_e where:

$$K_e = 1.0 \text{ for } S_n \leq 3S_m$$

$$= 1.0 + \frac{(1 - n)}{n(m - 1)} \left(\frac{S_n}{3S_m} - 1 \right) \text{ for}$$

$$3S_m < S_n < 3mS_m$$

$$= 1/n \text{ for } S_n \geq 3mS_m$$

S_n

= range of primary plus secondary stress intensity

The values of the material parameters m and n for the various classes of permitted materials are as follows:

	m	n	$T_{\max}, ^\circ\text{F}$
Low alloy steel	2.0	0.2	700
Martensitic stainless steel	2.0	0.2	700
Carbon steel	3.0	0.2	700
Austenitic stainless steel	1.7	0.3	800
Nickel-chromium-iron	1.7	0.3	800
Nickel-copper	1.7	0.3	800

(c) The rest of the fatigue evaluation stays the same as required in NG-3222.4, except that the procedure of NG-3227.6 need not be used.

(d) The structure meets the thermal ratcheting requirement of NG-3222.5.

(e) The temperature does not exceed those listed in the above table for the various classes of materials.

(f) The material shall have a specified minimum yield strength to specified minimum tensile strength ratio of less than 0.80.

NG-3228.4 Tests for Level A and Level B Service Limits.

For Level A and Level B Service Limits, the limits on primary membrane plus primary bending need not be satisfied in a structure if it can be shown from the test of a prototype or model that the specified loads (dynamic or static equivalent) do not exceed 44% of L_u , where L_u is the ultimate load or the maximum load or load combination used in the test. In using this method, account shall be taken of the size effect and dimensional tolerances which may exist between the actual part and test part or parts, as well as differences which may exist in the ultimate strength or other governing material properties of the actual part and the tested parts to assure that the loads obtained from the test are a conservative representation of the load-carrying capability of the actual structure under the postulated Service Loading.

NG-3229 Design Stress Values

The design stress intensity values S_m are given in Tables 2A and 2B, Section II, Part D, Subpart 1 for core support structure material. Values for intermediate temperatures may be found by interpolation. These form the basis for the various stress limits. Values of yield strength are given in Table Y-1, Section II, Part D, Subpart 2. Values of the coefficient of thermal expansion are in Table TE, Section II, Part D, Subpart 2, and values of the modulus of elasticity are in Table TM, Section II, Part D, Subpart 2. The basis for establishing stress values is given in Appendix III. The design fatigue curves used in conjunction with NG-3222.4 are those of Figs. I-9.0.

NG-3230 STRESS LIMITS FOR THREADED STRUCTURAL FASTENERS

NG-3231 Design Conditions

(a) The rules of this paragraph apply to mechanical connections joining parts in core support structures located within a pressure retaining boundary. Devices which are used to assemble structural elements of core support structures are referred to as threaded structural fasteners. The design stress intensity values S_m and yield strength values S_y for threaded structural fasteners shall be the values given in Tables 2A and 2B, Section II, Part D, Subpart 1 and in Table Y-1, Section II, Part D, Subpart 2, respectively.

(b) The special stress limits of NG-3227 do not apply to threaded structural fasteners. For connections joining parts of pressure retaining boundaries see NB-3230.

NG-3232 Level A Service Limits

The number and cross-sectional area of threaded structural fasteners shall be such that the stress intensity limits of this paragraph are satisfied for the Service Loadings for which Level A Limits are designated in the Design Specifications. The stress intensity limits are summarized in Fig. NG-3232-1. Any deformation

Page 61

Page 62

limit prescribed in the Design Specifications shall be considered. The total axial load transferred through the fastener threads shall not go to or through zero during the specified Service Loadings.

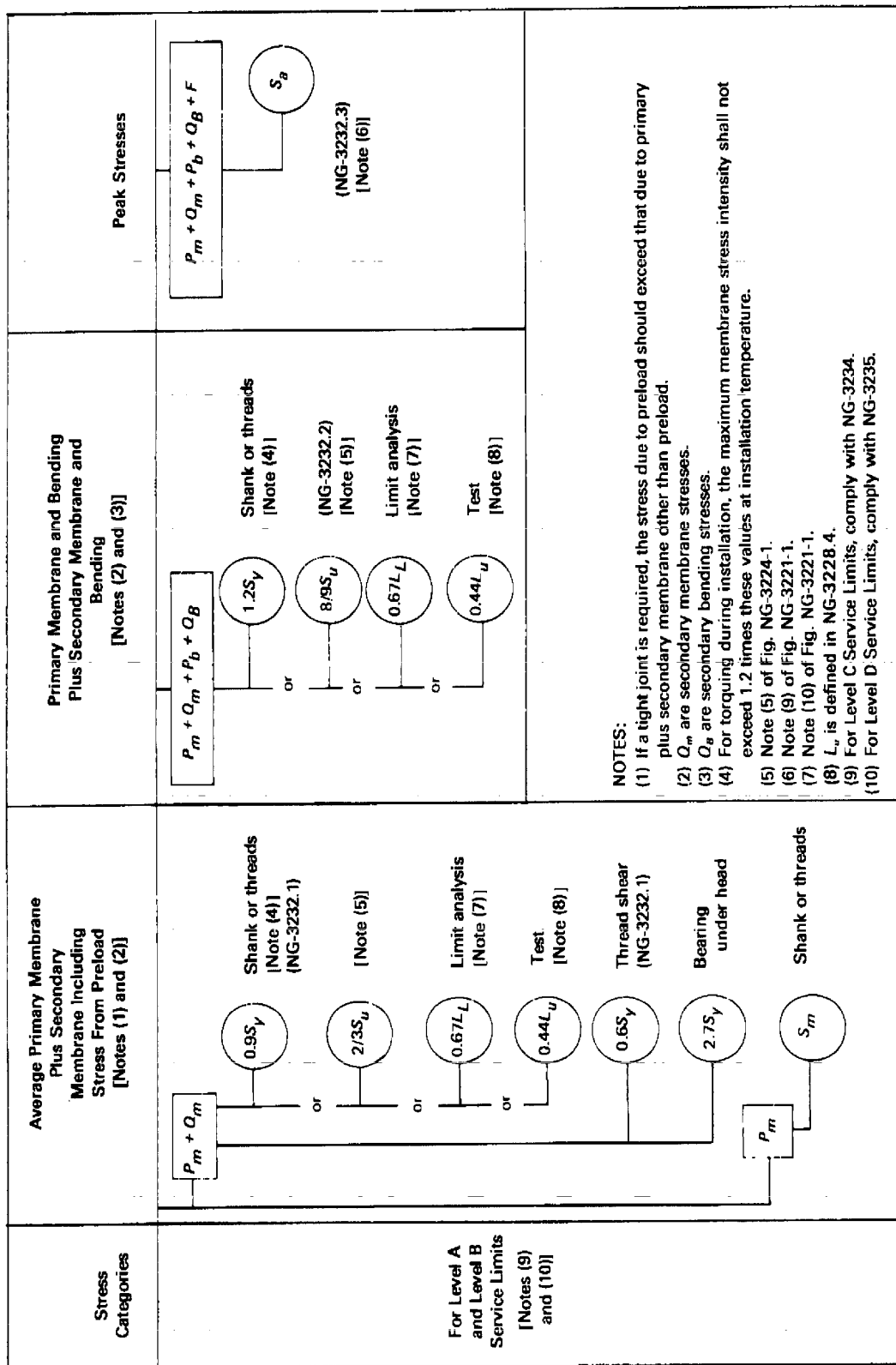


FIG. NG-3232-1 STRESS INTENSITY LIMITS FOR DESIGN OF THREADED STRUCTURAL FASTENERS

FIG. NG-3232-1 STRESS INTENSITY LIMITS FOR DESIGN OF THREADED STRUCTURAL FASTENERS

NG-3232.1 Average Stress.

Elastic analysis of specified conditions shall show that the average primary plus secondary membrane stress including stress from preload meets the requirements of (a) through (f) below.

(a) The maximum value of the membrane stress intensity averaged across either the area of the fastener shank or the tensile stress area of the threads shall be no greater than the lesser of either $0.9S_y$ or $\frac{2}{3}S_u$, where S_y and S_u are determined at service temperature.

(b) The average shear stress across the threads when loaded in pure shear shall be no greater than $0.6S_y$, where S_y is determined at service temperature.

(c) The average value of bearing stress under the fastener head shall be no greater than $2.7S_y$, where S_y is determined at service temperature.

(d) The primary membrane stress intensity P_m due only to Design Mechanical Loads applied to the fastener shall be no greater than S_m , where S_m is determined at service temperature.

(e) If a tight joint is required, the stress due to preload shall be greater than that due to primary and secondary membrane stress excluding preload.

(f) The primary shear stress across the threads when loaded in pure shear due only to Design Mechanical Loads applied to the fastener shall be no greater than $0.6S_m$, where S_m is determined at service temperature.

NG-3232.2 Maximum Stress

(a) The maximum primary membrane and bending plus secondary membrane and bending stress intensities, produced by the combination of all primary loads and secondary loads but excluding effects of stress concentrations, shall be no greater than 1.33 times the limits of NG-3232.1(a).

(b) For torquing during installation of fasteners, the maximum value of membrane stress intensity shall be no greater than 1.2 times the limits of NG-3232.1(a) and the maximum value of membrane plus bending stress intensity shall be no greater than 1.2 times the limits of NG-3232.2(a) at installation temperature.

NG-3232.3 Fatigue Analysis of Threaded Structural Fasteners.

Unless threaded structural fasteners meet the conditions of NG-3222.4(d) and thus require no fatigue analysis, the suitability of threaded structural fasteners for cyclic service shall be determined in accordance with the procedures of (a) through (e) below.

(a) *Threaded Structural Fasteners Having Less Than 100.0 ksi (689 MPa) Tensile Strength.* Fasteners made of material which has specified minimum tensile strength of less than 100.0 ksi (689 MPa) shall be evaluated for cyclic service by the methods of NG-3222.4(e), using the applicable design fatigue curves of Figs. I-9.0 and an appropriate fatigue strength reduction factor [NG-3232.3(c)].

(b) *High Strength Threaded Structural Fasteners.* High strength fasteners may be evaluated for cyclic service by the methods of NG-3222.4(e) using the applicable design fatigue curve of Figs. I-9.0, provided:

(1) the maximum value of primary and secondary stresses, including preload, at the periphery of the fastener cross section (resulting from direct tension plus bending and neglecting stress concentrations) shall not exceed $0.9S_y$, where S_y is determined at service temperature;

(2) threads shall have a minimum thread root radius no smaller than 0.003 in. (0.076 mm);

(3) fillet radii at the end of the shank shall be such that the ratio of fillet radius to shank diameter is not less than 0.060.

(c) *Fatigue Strength Reduction Factor (NG-3213.16).* Unless it can be shown by analysis or tests that a lower value is

appropriate, the fatigue strength reduction factor used in the fatigue evaluation of threaded members shall not be less than 4.0. However, when applying the rules of (b) above for high strength fasteners, the value used shall not be less than 4.0.

(d) *Effect of Elastic Modulus.* Multiply S_{alt} (NG-3216.1 or NG-3216.2) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the service cycle being considered is the only one which produces significant fluctuating stresses, this is the allowable number of cycles.

(e) *Cumulative Damage.* The fasteners shall be acceptable for the specified cyclic application of loads and thermal stress provided the cumulative usage factor U as determined in NG-3222.4(e)(5) does not exceed 1.0.

NG-3233 Level B Service Limits

Level A Service Limits (NG-3232) apply.

NG-3234 Level C Service Limits for Threaded Structural Fasteners

The number and cross-sectional area of threaded structural fasteners shall be such that the requirements

Page 63

of NG-3224 are satisfied for the Service Loadings for which Level C Limits are designated in the Design Specifications. For high strength structural fasteners ($S_u > 100.0$ ksi) (689 MPa), the limits of NG-3232 also apply for these Service Loadings. Any deformation limit prescribed in the Design Specifications shall be considered.

NG-3235 Level D Service Limits for Threaded Structural Fasteners

The number and cross-sectional area of threaded structural fasteners shall be such that the requirements of NG-3225 are satisfied for the Service Loadings for which Level D Limits are designated [NCA-2142.2(d)] in the Design Specifications. Any deformation limit prescribed in the Design Specifications shall be considered.

NG-3300 CORE SUPPORT STRUCTURE DESIGN

NG-3310 GENERAL REQUIREMENTS

NG-3311 Acceptability

The requirements for acceptability of a core support structure design are given in (a) through (c) below.

(a) The design shall be such that the requirements of NG-3100 and NG-3200 are satisfied.

(b) The requirements of NG-3300 are satisfied. In case of conflict between NG-3200 and NG-3300, the requirements of NG-3300 shall govern.

(c) The requirements of this Subarticle apply to internal structures, NG-1122, only as specifically stipulated by the Certificate Holder; however, the Certificate Holder shall certify that the design used for the internal structures shall not adversely affect the integrity of the core support structure.

NG-3320 DESIGN CONSIDERATIONS

NG-3321 Design and Service Loadings

The provisions of NG-3110 apply.

NG-3322 Special Considerations

The provisions of NG-3120 apply.

NG-3323 General Design Rules

The provisions of NG-3130 apply, except when they conflict with rules of this Subarticle. In case of conflict, this Subarticle governs in the design of core support structures.

NG-3350 DESIGN FOR WELDED CONSTRUCTION

NG-3351 Welded Joint Categories

(a) The term *category* as used herein defines the location of a joint. The categories established by this paragraph are for use elsewhere in this Subsection to identify special restrictions regarding type of joint permitted for the location. Figures NG-3351(a)-1 and NG-3351(a)-2 illustrate locations of some typical welded joints in each category. Joints whose design functions are neither to restrain nor support the core do not fall into any category.

(b) The *types* of joints which may be used at the various locations are defined in NG-3352.

NG-3351.1 Joints of Category A.

Joints of Category A are longitudinal joints in cylindrical members. Category A joints may be of Type I, II, or, with the following restriction, Type IV. When a Type IV joint is used in Category A, the quality factor shall be one-half that permitted for Type I or II by Table NG-3352-1 for the examination used.

NG-3351.2 Joints of Category B.

Joints of Category B are girth welds in cylindrical members. Category B joints may be of Type I, II, or, with the following restriction, Type IV or V. When Type IV or V joints are used in Category B, the quality factor shall be one-half that permitted for Type I or II by Table NG-3352-1 for the examination used.

NG-3351.3 Joints of Category C.

Joints of Category C are primarily for joining flanges to cylinders. Category C joints may be of Type I, II, III, or, with the following restriction, Type IV or V. When Type IV or V joints are used in Category C, the quality factor shall be one-half that permitted for Type I or II by Table NG-3352-1 for the examination used.

NG-3351.4 Joints of Category D.

Joints of Category D are primarily for attaching nozzles to other members. Category D joints may be of Type I, II, III, IV, V, VI, or VII.

NG-3351.5 Joints of Category E.

Joints of Category E are for joints at the ends of webs of beams. Category E joints may be of Type I, II, III, IV, V, VI, VII, or VIII.

Page 64

Page 65

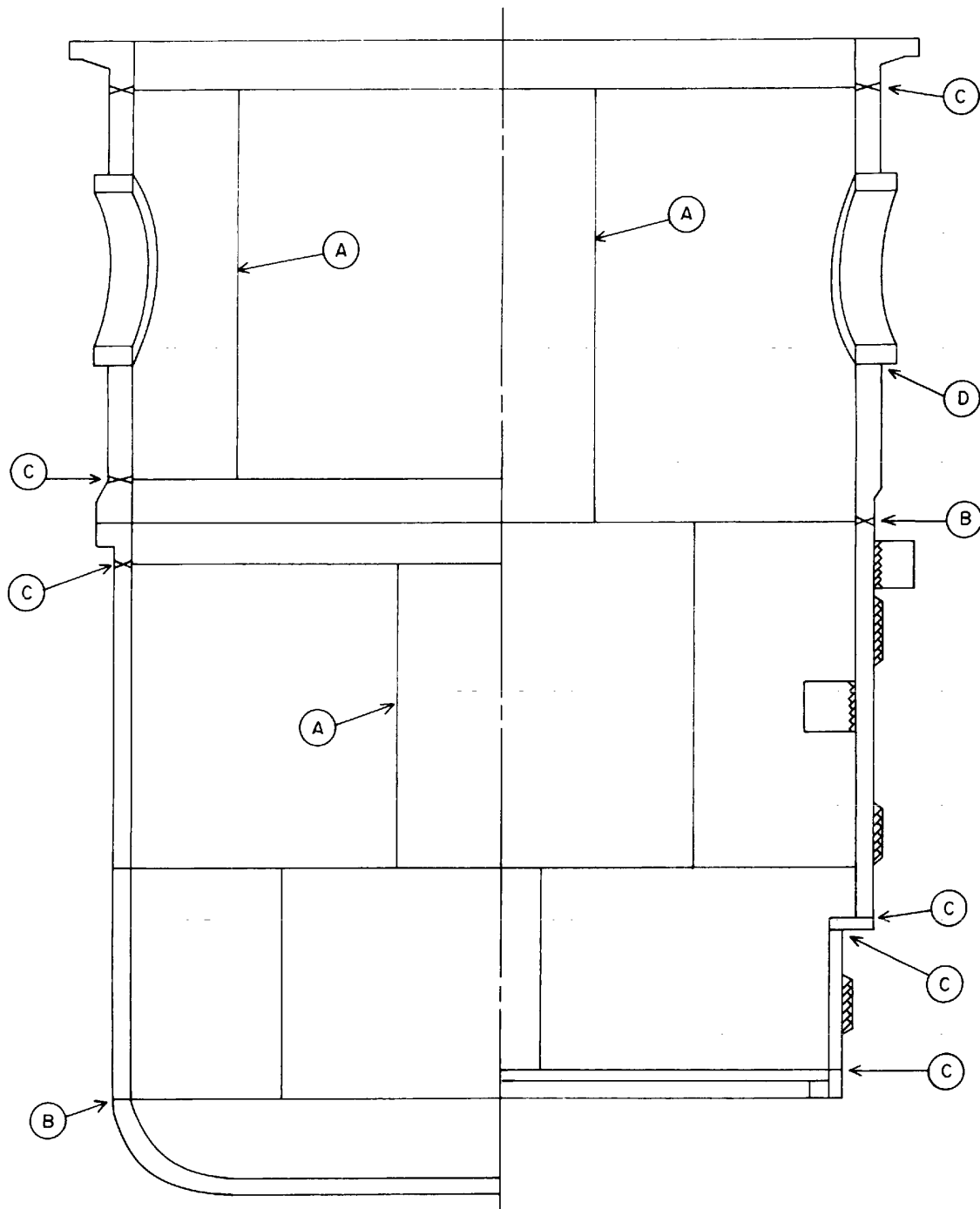


FIG. NG-3351(a)-1 TYPICAL LOCATIONS OF JOINTS OF SEVERAL CATEGORIES

FIG. NG-3351(a)-1 TYPICAL LOCATIONS OF JOINT OF SEVERAL CATEGORIES

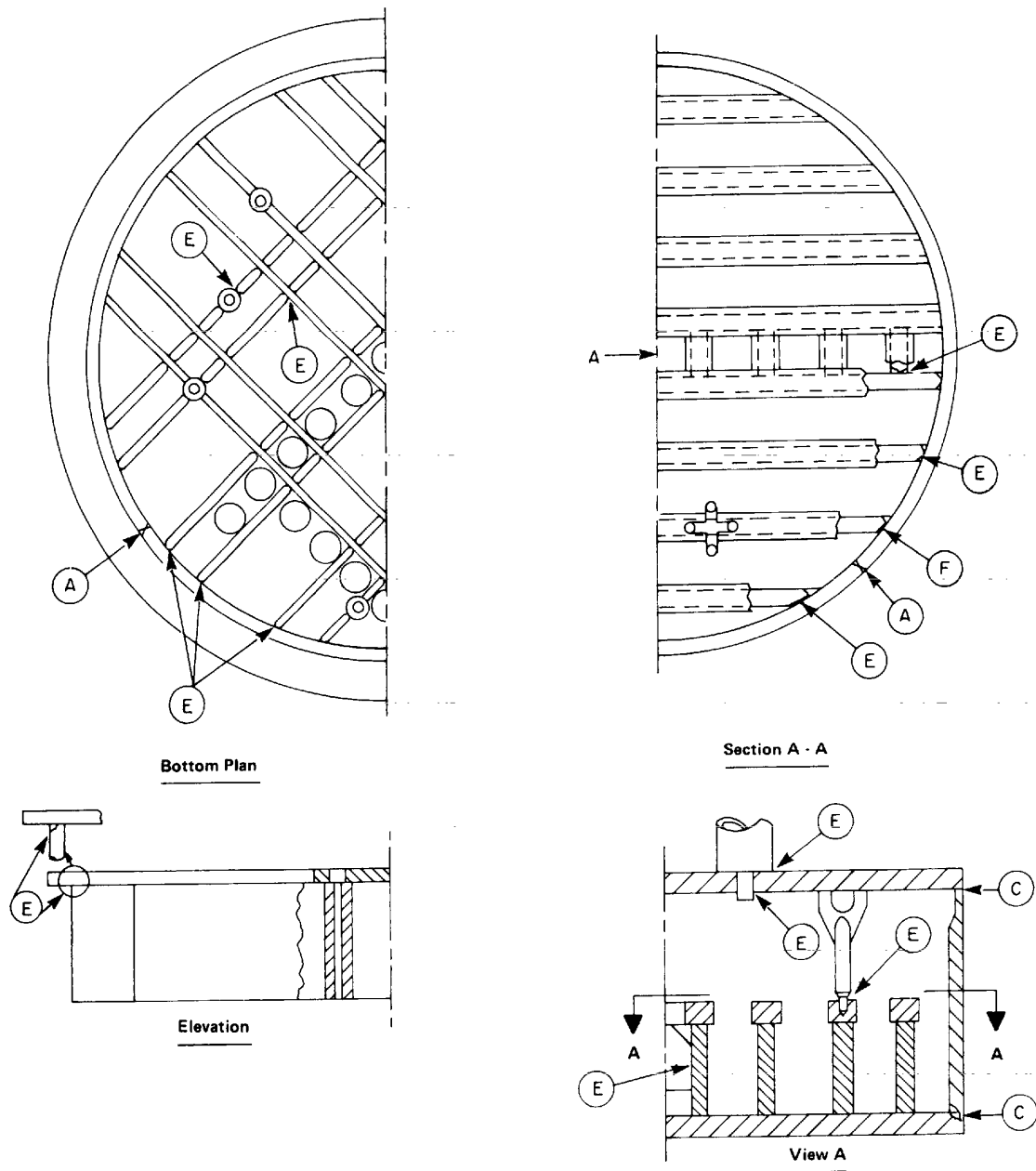


FIG. NG-3351(a)-2 TYPICAL WELDED JOINT CATEGORY LOCATIONS

FIG. NG-3351(a)-2 TYPICAL WELDED JOINT CATEGORY LOCATIONS

TABLE NG-3352-1
PERMISSIBLE WELDED JOINTS AND DESIGN FACTORS

Quality Factor and Fatigue Factor ¹						
Type of Welded Joint	Permissible for Category Shown Below	RT or UT ² and PT or MT Examination NG-5220	Progressive PT or MT Examination NG-5231	Root and Final PT or MT Examination NG-5232	Surface PT or MT Examination NG-5233	Surface Visual Examination NG-5260
I. Full penetration	A,B,C,D,E	$n = 1.0$ $f = 1$	$n = 0.9$ $f = 1$	$n = 0.75$ $f = 1$	$n = 0.65$ $f = 1$	$n = 0.5$ $f = 1$
II. Full penetration	A,B,C,D,E	$n = 1.0$ $f = 2$	$n = 0.9$ $f = 2$	$n = 0.75$ $f = 2$	$n = 0.65$ $f = 2$	$n = 0.5$ $f = 2$
III. Full penetration	C,D,E	$n = 1.0$ $f = 1$	$n = 0.9$ $f = 1^3$	$n = 0.75$ $f = 1^3$	$n = 0.65$ $f = 1^3$	$n = 0.5$ $f = 1^3$
IV. Double groove (RT not applicable)	A,B,C	$n = 0.5$ $f = 4$	$n = 0.45$ $f = 4$	$n = 0.4$ $f = 4$	$n = 0.35$ $f = 4$	$n = 0.25$ $f = 4$
	D,E	$n = 0.9$ $f = 4$	$n = 0.8$ $f = 4$	$n = 0.7$ $f = 4$	$n = 0.6$ $f = 4$	$n = 0.4$ $f = 4$
V. Double fillet (RT not applicable)	B,C	$n = 0.5$ $f = 4$	$n = 0.45$ $f = 4$	$n = 0.4$ $f = 4$	$n = 0.35$ $f = 4$	$n = 0.25$ $f = 4$
	D,E	$n = 0.9$ $f = 4$	$n = 0.8$ $f = 4$	$n = 0.7$ $f = 4$	$n = 0.6$ $f = 4$	$n = 0.4$ $f = 4$
VI. Single groove (RT not applicable)	D,E	$n = 0.6$ $f = 4$	$n = 0.55$ $f = 4$	$n = 0.45$ $f = 4$	$n = 0.4$ $f = 4$	$n = 0.35$ $f = 4$
VII. Single fillet (RT not applicable)	D,E	$n = 0.6$ $f = 4$	$n = 0.55$ $f = 4$	$n = 0.45$ $f = 4$	$n = 0.4$ $f = 4$	$n = 0.35$ $f = 4$
VIII. Intermittent fillet or plug	E	Not applicable	$n = 0.45$ $f = 4$	$n = 0.4$ $f = 4$	$n = 0.35$ $f = 4$	$n = 0.3$ $f = 4$

NOTES:

- (1) See NG-3352 for definitions.
- (2) Electroslag butt welds shall be examined by radiography. Electroslag welds in ferritic material shall also be examined for their full length by the ultrasonic method after a grain refining heat treatment, when performed, or after a postweld heat treatment.
- (3) A minimum fatigue strength reduction factor of 1.0 is permitted when both sides of weld are examined; otherwise a factor of 2.0 must be used in analysis for cyclic operation.

TABLE NG-3352-1 PERMISSIBLE WELDED JOINTS AND DESIGN FACTORS

[98]

NG-3352 Permissible Types of Welded Joints

Subject to the limitations given in NG-3351, core support structures may use any of the types of joints described in the following subparagraphs, providing the quality factor n and fatigue factor f used in the analysis meet the requirements of Table NG-3352-1 for the method of examination employed. The quality factor is used by multiplying the allowable stress limit for primary and secondary categories times the quality factor in evaluating the design. The use of weld quality factor n is for static, not fatigue applications. In performing a fatigue analysis, use the fatigue factor f , designated in Table NG-3352-1, and the applicable fatigue curve in Tables I-9.0.

[98]

NG-3352.1 Type I Joints.

Full penetration welds between plates or other elements that lie approximately in the same plane or have an offset angle not greater than 30 deg. meet the intent of this subparagraph when made either as double welded butt joints, or with consumable inserts or gas backup, or with metal backing strips that are later removed, provided the backface of such joints meets the requirements of NG-4424.

NG-3352.2 Type II Joints.

Full penetration welds between plates or other elements meet the intent of this subparagraph when made either according to NG-3352.1 or with edges of the joint prepared with opposing lips to form an integral backing strip, or with metal backing strips which are not later removed, except that the suitability for cyclic operation shall be analyzed by the method of NG-3222.4 (when used, backing strips shall be continuous and any splices shall be full penetration welded).

NG-3352.3 Type III Joints.

Full penetration welds between plates or other elements that may have an offset angle up to 90 deg. meet the intent of this subparagraph when either made according to NG-3352.2 or are corner welds. Attachment of connections using deposited weld metal as reinforcement and oblique connections meet the intent of this subparagraph.

NG-3352.4 Type IV Joints.

Partial penetration welds of double groove design (minimum depth of each groove equals one-eighth times the thickness of the thinnest element) meet the intent of this subparagraph when the area of the connection is determined by the product of the throat thickness times the length of welds.

NG-3352.5 Type V Joints.

Double fillet welds meet the intent of this subparagraph when the area of the connection is determined by the product of the theoretical throat thickness times the length of the welds (Fig. NG-4427-1). Joints made having one side a single fillet and the other side a single groove meet the intent of this subparagraph.

NG-3352.6 Type VI Joints.

Partial penetration welds of single groove design meet the intent of this subparagraph when the area of the connection is determined as the product of the weld throat thickness times the length of weld.

NG-3352.7 Type VII Joints.

Single fillet welds meet the intent of this subparagraph when the area of the connection is determined as the product of the theoretical throat thickness of the fillet welds times the length of weld (Fig. NG-4427-1).

NG-3352.8 Type VIII Joints.

Intermittent fillet or plug welds meet the intent of this subparagraph when the area of the intermittent fillet weld connection is determined as the product of the theoretical throat thickness times the sum of weld lengths and the area of plug weld connection is determined as the product of the number of plug welds times the area of the minimum cross section.

NG-3352.9 Limitations on Types of Joints.

The type of joint used for service shall be one of those permitted for the Category of the joint (NG-3351). Reduced quality factors must be used for certain types of joints when used in Categories A, B, and C (Table NG-3352-1).

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NG-4000

ARTICLE NG-4000 FABRICATION AND INSTALLATION

Page 69

Page 70

NG-4100 GENERAL REQUIREMENTS

NG-4110 INTRODUCTION

(a) Core support structures (NG-1121) shall be manufactured and installed in accordance with the requirements of this Article and shall be manufactured from materials which meet the requirements of NG-2000.

(b) The rules of this Article apply to the internal structures (NG-1122) only as specifically implemented by the Certificate Holder; however, the Certificate Holder shall certify that each internal structure has been fabricated so as to avoid creating an adverse effect on the integrity of the core support structure.

NG-4120 CERTIFICATION OF MATERIAL AND FABRICATION BY CERTIFICATE HOLDER

NG-4121 Means of Certification

The Certificate Holder for an item shall certify, by application of the appropriate Code symbol and completion of the appropriate data report in accordance with NCA-8000, that the materials used comply with the requirements of NG-2000 and that the fabrication and installation comply with the requirements of this Article.

NG-4121.1 Certification of Treatments, Tests, and Examinations.

If the Certificate Holder performs treatments, tests, repairs, or examinations required by other Articles, he shall certify that he has fulfilled such requirements. Reports of all required treatments and of the results of all required tests, repairs, and examinations performed shall be available to the Inspector.

NG-4121.2 Repetition of Tensile or Impact Tests.

If during the fabrication or installation of the item the material is subjected to heat treatment that has not been covered by treatment of the test coupons (NG-2200), and that may reduce either tensile or impact properties below the required values, the tensile and impact tests shall be repeated by the Certificate Holder on test specimens taken from test coupons which have been taken and treated in accordance with the requirements of NG-2000.

NG-4122 Material Identification

Material for core support structures shall carry identification markings which will remain distinguishable until the core support structure is fabricated or installed. If the original identification markings are cut off or the material is divided, the

marks shall be accurately transferred to the parts or a coded marking shall be used to assure identification of each piece of material during subsequent fabrication or installation, unless otherwise provided by NG-2150. Material supplied with a Certificate of Compliance and welding and brazing material shall be identified and controlled so that they can be traced to the core support structure, or else a control procedure shall be employed which ensures that the specified material is used.

NG-4123 Examinations

Visual examination activities that are not referenced for examination by other specific Code paragraphs, and are performed solely to verify compliance with requirements of NG-4000, may be performed by the persons who perform or supervise the work. These visual examinations are not required to be performed by personnel and procedures qualified to NG-5500 and NG-5100, respectively, unless so specified.

NG-4125 Testing of Welding Material

All welding material shall meet the requirements of NG-2400.

Page 74

NG-4130 REPAIR OF MATERIAL

NG-4131 Elimination and Repair of Defects

Material originally accepted on delivery in which defects exceeding the limits of NG-2500 are known or discovered during the process of fabrication or installation is unacceptable. The material may be used provided the condition is corrected in accordance with the requirements of NG-2500 for the applicable product form, except:

- (a) the limitation on the depth of the weld repair does not apply;
- (b) the time of examination of the weld repairs to weld edge preparations shall be in accordance with NG-5130.

NG-4132 Documentation of Repair Welds of Base Material

The Certificate Holder who makes a repair weld, exceeding in depth the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness, shall prepare a report which shall include a chart which shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results of repair welds. In addition, all repair welds exceeding an accumulated area of 20% of the area of the part or 15 sq in. (9677 mm²), whichever is less, shall require the same documentation as welds exceeding the minimum depth.

NG-4200 FORMING, FITTING, AND ALIGNING

NG-4210 CUTTING, FORMING, AND BENDING

NG-4211 Cutting

Materials may be cut to shape and size by mechanical means such as machining, shearing, chipping, or grinding, or by thermal cutting.

NG-4211.1 Preheating Before Thermal Cutting.

When thermal cutting is performed to prepare weld joints or edges, to remove attachments or defective material, or for any other purpose, consideration shall be given to preheating the material, using preheat schedules such as suggested in Appendix D.

NG-4211.2 Material Preparation After Thermal Cutting for P-No. 8 Material.

When metal is to be removed by thermal cutting methods, additional material shall be removed by mechanical means to the extent required in the Design Specifications.

NG-4212 Forming and Bending Processes

Any process may be used to hot or cold form or bend core support structure material, including weld metal, provided the required dimensions are attained (see NG-4214 and NG-4220), and provided the specified impact properties of the material, when required, are not reduced below the minimum specified values or they are effectively restored by heat treatment following the forming operation. *Hot forming* is defined as forming with the material temperature higher than 100°F (38°C) below the lower transformation temperature of the material. When required, the process shall be qualified for impact properties as outlined in NG-4213.

NG-4213 Qualification of Forming Processes for Impact Property Requirements

A procedure qualification test shall be conducted using specimens taken from material of the same specification, grade or class, heat treatment, and with similar impact properties as required for the material in the structure. These specimens shall be subjected to the equivalent forming or bending process and heat treatment as the material in the structure. Applicable tests shall be conducted to determine that the required impact properties of NG-2300 are met after straining.

NG-4213.1 Exemptions.

Procedure qualification tests are not required for materials listed in (a) through (f) below:

(a) hot formed material, such as forgings, in which the hot forming is completed by the Material Organization prior to removal of the impact test specimens;

(b) hot formed material represented by test coupons required in either NG-2211 or NG-4121.2 which has been subjected to heat treatment representing the hot forming procedure and the heat treatments to be applied to the parts;

(c) material which does not require impact tests in accordance with NG-2300;

(d) material which has a final strain less than 0.5%;

(e) material where the final strain is less than that of a previously qualified procedure for that material;

(f) material from which the impact testing required by NG-2300 is performed on each heat and lot, as applicable, after forming.

NG-4213.2 Procedure Qualification Test.

The procedure qualification test shall be performed in the manner stipulated in (a) through (f) below.

Page 75

(a) The tests shall be performed on three different heats of material both before and after straining to establish the effects of the forming and subsequent heat treatment operations.

(b) Specimens shall be taken in accordance with the requirements of NG-2000 and shall be taken from the tension side of the strained material.

(c) The percent strain shall be established by the following formulas:

For cylinders:

$$\% \text{ strain} = 50t/R_f [1 - (R_f/R_o)]$$

For spherical or dished surfaces:

$$\% \text{ strain} = 75t/R_f [1 - (R_f/R_o)]$$

For pipe:

$$\% \text{ strain} = 100r/R$$

where

t = nominal thickness, in.

R_f	= final radius to center line of shell, in.
R_o	= original radius (equal to infinity for a flat part), in.
R	= nominal bending radius to the center line of the pipe, in.
r	= nominal radius of the pipe, in.

(d) The procedure qualification shall simulate the maximum percent surface strain, employing a bending process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient C_v specimens shall be taken from each of the three heats of material to establish a transition curve showing both the upper and lower shelves. On each of the three heats, tests consisting of three impact specimens shall be conducted at a minimum of five different temperatures distributed throughout the transition region. The upper and lower shelves may be established by the use of one test specimen each. Depending on the product form, it may be necessary to plot the transition curves using both lateral expansion and energy level data (NG-2300). In addition, drop weight tests shall be made when required by NG-2300.

(f) Using the results of the impact test data from each of three heats, taken both before and after straining, determine either:

(1) the maximum change in NDT temperature along with:

(a) the maximum change of lateral expansion and energy at the temperature under consideration; or

(b) the maximum change in temperature at the lateral expansion or energy levels under consideration; or

(2) where lateral expansion is the acceptance criterion (NG-2300), either the maximum change in temperature or the maximum change in lateral expansion.

NG-4213.3 Acceptance Criteria for Formed Material.

To be acceptable, the formed material used in the component shall have impact properties before forming sufficient to compensate for the maximum loss of impact properties due to the qualified forming procedure used.

NG-4213.4 Requalification.

A new procedure qualification test is required when any of the following changes are made:

(a) the actual postweld heat treatment time at temperature is greater than previously qualified considering NG-2211. If the material is not postweld heat treated, the procedure must be qualified without postweld heat treatment.

(b) the maximum calculated strain of the material exceeds the previously qualified strain by more than 0.5%;

(c) preheat over 250°F (121°C) is used in the forming or bending operation but not followed by a subsequent postweld heat treatment.

NG-4214 Minimum Thickness of Fabricated Material

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of NG-3000, the material may be repaired in accordance with NG-4130.

NG-4230 FITTING AND ALIGNING

NG-4231 Fitting and Aligning Methods

Parts that are to be joined by welding may be fitted, aligned, and retained in position during the welding operation by the use of bars, jacks, clamps, tack welds, or temporary attachments.

NG-4231.1 Tack Welds.

Tack welds used to secure alignment shall either be removed completely, when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified welders using qualified welding procedures. When tack welds are to become part of

Page 76

the finished weld, they shall be visually examined in accordance with NG-5261 and defective tack welds removed.

NG-4232 Maximum Offset of Aligned Sections

Alignment of sections shall be such that the maximum offset of the finished welded joint will not be greater than $\frac{1}{2}t$, where t is the nominal thickness of the thinner section at the joint. Alternatively, smaller alignment tolerances may be specified by the Design Specifications.

NG-4232.1 Fairing of Offsets.

Any offset within the allowable limit provided shall be faired to at least a 3:1 taper, length to offset, over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld. In addition, offsets greater than those stated in NG-4232 are acceptable provided the requirements of NG-3200 are met.

NG-4300 WELDING QUALIFICATIONS

NG-4310 GENERAL REQUIREMENTS

NG-4311 Types of Processes Permitted

Only those welding processes which are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Subsection may be used for welding core support structure material or attachments thereto. Any process used shall be such that the records required by NG-4320 can be prepared. Stud welds are not permitted.

NG-4311.2 Capacitor Discharge Welding.

Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments provided that:

- (a) temporary attachments are removed in accordance with the provisions of NG-4435(b);
- (b) the energy output for permanent nonstructural attachments such as strain gages and thermocouples is limited to 125 W-sec and the minimum thickness of the material to which the attachment is made is greater than 0.09 in. (2.3 mm); and
- (c) a Welding Procedure Specification is prepared describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required.

NG-4311.3 Inertia and Continuous Drive Friction Welding.

Inertia and continuous drive friction welding shall not be used for the fabrication of core support structures.

NG-4320 WELDING QUALIFICATIONS, RECORDS, AND IDENTIFYING STAMPS

NG-4321 Required Qualifications

(a) Each Certificate Holder is responsible for the welding done by his organization, and he shall establish the procedure and conduct the tests required by this Article and by Section IX in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures.

(b) Procedures, welders, and welding operators used to join permanent or temporary attachments to core support

structure parts and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Article.

(c) When making procedure test plates for butt welds, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. This applies particularly to material and weld metal of 80.0 ksi (552 MPa) tensile strength or higher and heavy sections of both low and high tensile strength material. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

NG-4322 Maintenance and Certification of Records

The Certificate Holder shall maintain a record of their qualified welding procedures and of the welders and welding operators qualified by them, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and signed by any authorized individual assigned by the Certificate Holder, and they shall be accessible to the Owner and to the Inspector.

NG-4322.1 Identification of Joints by Welder or Welding Operator

(a) Each welder or welding operator shall apply the identification mark assigned to him by the Certificate Holder on or adjacent to all permanent welded joints or series of joints on which he welds. The marking shall be at intervals of 3 ft (0.9 m) or less and shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps. As an alternative, the Certificate Holder shall keep a record of permanent welded joints in each item and of the welders and welding operators used in making each of the joints.

Page 77

(b) When a multiple number of permanent structural attachment welds, nonstructural welds, fillet welds, socket welds, welds of specially designed seals, weld metal cladding, hard surfacing, and tube-to-tubesheet welds are made on an item, the Certificate Holder need not identify the welder or welding operator who welded each individual joint, provided:

(1) the Certificate Holder maintains a system that will identify the welders or welding operators that made such welds on each item so that the Inspector can verify that the welders or welding operators were all properly qualified;

(2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification.

(c) The identification of welder or welding operator is not required for tack welds.

NG-4323 Welding Prior to Qualification

No welding shall be undertaken until after the welding procedures which are to be used have been qualified. Only welders and welding operators who are qualified in accordance with NG-4320 and Section IX shall be used.

NG-4324 Transferring Qualifications

The welding procedure qualifications and the performance qualification tests for welders and welding operators conducted by one Certificate Holder shall not qualify welding procedures and shall not qualify welders or welding operators to weld for any other Certificate Holder except as provided in Section IX, QW-201 and QW-300.2.

NG-4330 GENERAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION TESTS

NG-4331 Conformance to Section IX Requirements

All welding procedure qualification tests shall be in accordance with the requirements of Section IX as supplemented by the requirements of this Article.

NG-4333 Heat Treatment of Qualification Welds for Ferritic Material

Postweld heat treatment of procedure qualification welds shall conform to the applicable requirements of NG-4600 and Section IX

Section IX. The postweld heat treatment time at temperature shall be at least 80% of the maximum time to be applied to the weld material. The postweld heat treatment total time may be applied in one heating cycle.

NG-4334 Preparation of Test Coupons and Specimens

(a) Removal of test coupons from the test weld and the dimensions of specimens made from them shall conform to the requirements of Section IX, except that the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with (b) below.

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test specimens. When each process cannot be included in the full-size impact test specimen at the $\frac{1}{4}t$ location required by this Section, additional full-size specimens shall be obtained from locations in the test weld that will ensure that at least a portion of each process has been included in full-size test specimens. As an alternative, additional test welds can be made with each process so that full-size specimens can be tested for each process.

NG-4334.1 Coupons Representing the Weld Deposits.

Impact test specimens and testing methods shall conform to NG-2321. The impact specimen shall be located so that the longitudinal axis of the specimen is at least $\frac{1}{4}t$ and, where the thickness of the test assembly permits, not less than $\frac{3}{8}$ in. (10 mm) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified in NG-4620 and the test assembly is cooled at an accelerated rate, the longitudinal axis of the specimen shall be a minimum of t from the edge of the test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the weld. The length of the notch of the Charpy V-notch specimen shall be normal to the surface of the weld. Where drop weight specimens are required, the tension surface of the specimen shall be oriented parallel to the surface of the test assembly.

NG-4334.2 Coupons Representing the Heat Affected Zone.

Where impact tests of the heat affected zone are required by NG-4335.2, specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through (c) below.

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be

Page 78

oriented in the direction parallel to the principal direction of rolling or forging.

(b) The heat affected zone impact test specimens and testing methods shall conform to the requirements of NG-2321.2. The specimens shall be removed from a location as near as practical to a depth midway between the surface and center thickness. The coupons for heat affected zone impact specimens shall be taken transverse to the axis of the weld and etched to define the heat affected zone. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much heat affected zone as possible in the resulting fracture. Where the material thickness permits, the axis of a specimen may be inclined to allow the root of the notch to align parallel to the fusion line. When a grain-refining heat treatment is not performed on welds made by the electroslag or electrogas welding process, the notch for the impact specimens shall be located in the grain-coarsened region.

(c) For the comparison of heat affected zone values with base material values [NG-4335.2(b)], Charpy V-notch specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the heat affected zone specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the heat affected zone specimens, and the axis of the notch shall be normal to the surface of the base material. When required by NG-4335.2(b)(4), drop weight specimens shall be removed from a depth as near as practical to midway between the surface and center thickness of the unaffected base material and shall be tested in accordance with the requirements of NG-2321.1.

NG-4335 Impact Test Requirements

When materials are required to be impact tested per NG-2300, impact tests of the weld metal and heat affected zone shall be performed in accordance with the following subparagraphs. The weld procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of NG-2330 and NG-4334. Retests in accordance with the provisions of NG-2350 are permitted.

accordance with the provisions of NG-2350 are permitted.

NG-4335.1 Impact Tests of Weld Metal

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding $\frac{5}{8}$ in. (16 mm) in thickness when the weld will be made on the surface or will penetrate the base material that requires impact testing in accordance with NG-2310. In addition, such testing of the weld metal is required for the welding procedure qualification tests for any weld repair to base material that requires impact testing in accordance with NG-2310, regardless of the depth of the repair.

(b) The impact test requirements and acceptance standards for welding procedure qualification weld metal shall be the same as specified in NG-2330 for the base material to be welded or repaired. Where two materials are to be joined by welding and have different fracture toughness requirements, the test requirements and acceptance standards of either material may be used for the weld metal except where otherwise specified by NCA-1280 or other parts of this Section.

NG-4335.2 Impact Tests of Heat Affected Zone

(a) Charpy V-notch tests of the heat affected zone of the welding procedure qualification test assembly are required whenever the thickness of the weld exceeds $\frac{5}{8}$ in. (16 mm) and either of the base materials requires impact testing in accordance with the rules of NG-2310. The only exceptions to the requirements are the following:

(1) the qualification for welds in P-Nos. 1 and 3 and SA-336 F12 materials that are postweld heat treated and are made by any process other than electroslog, electrogas, or thermit;

(2) the qualification for weld deposit cladding or hard-facing on any base material.

(b) Impact testing of the procedure qualification test heat affected zone, where required by this paragraph, shall be conducted in accordance with (1) through (3) below, or (4) through (6) below, and (c) below, if applicable.

(1) For tests of welding procedure qualifications for materials that require testing in accordance with NG-2331, the three Charpy V-notch heat affected zone specimens and three Charpy V-notch unaffected base material specimens shall be tested at a temperature in accordance with NG-2331(a). The Charpy V-notch impact test of the unaffected base material shall meet the requirements of Table NG-2331(a)-1. If the average lateral expansion value of the three heat affected zone specimens is equal to or greater than the average value of the unaffected base material Charpy V-notch specimens, the test shall be considered acceptable. The values and testing temperature shall be recorded on the Welding Procedure Qualification Record.

(2) If the heat affected zone Charpy V-notch average lateral expansion value of (b)(1) above is less than the unaffected base material value, and the qualification test meets the other criteria of acceptance, the Charpy V-notch test results may be recorded on the Welding Procedure Qualification Record. Data shall then be

Page 79

obtained as specified in (b)(3) below to provide an additive temperature for the adjustment of the lowest service temperature (LST) of the base material that is to be welded in production with the welding procedure that is being qualified. Alternatively, the welding procedure qualification may be rewelded and retested.

(3) The data for use in (b)(2) above shall be developed by performing additional Charpy V-notch tests on either the welding procedure qualification test heat affected zone or the unaffected base material, or both, at temperatures which provide lateral expansion values that meet or exceed those required for the thickness of the material to be welded in production [Table NG-2331(a)(1)]. The average lateral expansion data for the heat affected zone and unaffected base material shall be plotted on a lateral expansion-temperature chart. The temperature at which these two sets of data exhibit a common acceptable value of lateral expansion for the production thickness involved shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the heat affected zone. This difference, if a positive number, shall be used in (b)(2) above as the adjustment temperature. The welding procedure adjustment temperature shall be added to the highest LST established by the tests of NG-2331 for all of the base material to be welded by this procedure in production. If the temperature difference is zero or a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by the tests for NG-2331 will still apply as stated in (b)(1) above. Where the actual LST is not required for the production material to be welded [for example, where a testing temperature is established

by the Design Specification to determine that the material has adequate lateral expansion to meet the requirements of Table NG-2331(a)-1 at the specified test temperature], the adjustment temperature determined by the curves shall be used to establish a reduction in the specified testing temperature for the production material. The adjustment temperature shall be used to lower the specified testing temperature for any production material on which the procedure will be used.

(4) For tests of welding procedure qualification for material that requires tests in accordance with NG-2332, the T_{NDT} of the unaffected base material shall be determined to establish the test temperature for the Charpy V-notch tests. The Charpy V-notch specimens representing the heat affected zone material and the unaffected base material shall be tested at the ($T_{NDT} + 60^{\circ}\text{F}$) temperature of the unaffected base material. The Charpy V-notch impact tests of the unaffected base material shall meet the requirements of NG-2332(a). If the average lateral expansion value of the three heat affected zone specimens is equal to or greater than the average value for the unaffected base material Charpy V-notch specimens, the qualification test shall be considered acceptable, and the values and testing temperature shall be recorded on the Welding Procedure Qualification Record.

(5) If the average Charpy V-notch lateral expansion for the heat affected zone of (b)(4) above is less than that for the unaffected base material, and the qualification test meets the other criteria of acceptance, the Charpy V-notch test results may be recorded on the Welding Procedure Qualification Record. Data of (b)(6) below, which will provide an additive temperature for any base material for which the welding procedure is being qualified, shall be included. Alternatively, the welding procedure qualification may be rewelded and retested.

(6) The data for use in (b)(5) above shall be developed by performing additional Charpy V-notch tests on either the welding procedure qualification heat affected zone or the unaffected base material, or both, at temperatures which provide lateral expansion values equal to or greater than 35 mils (0.89 mm). The lateral expansion data for the heat affected zone and the unaffected base material shall be plotted on a lateral expansion-temperature chart. The temperatures at which these two sets of data exhibit a common lateral expansion value equal to or greater than 35 mils (0.89 mm) shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the heat affected zone. This difference, if a positive number, shall be used in (b)(5) above as the adjustment temperature. The adjustment temperature shall be added to the highest RT_{NDT} temperature established by the tests of NG-2332 for all of the base material to be welded by this procedure in production.

If the temperature difference is zero or a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by the tests for NG-2332 will still apply as stated in (b)(4) above.

Where actual RT_{NDT} is not required for the production material to be welded (for example, where a testing temperature is established by the Design Specification to determine that the RT_{NDT} is at or below the specified temperature) the additive temperature determined by the curves shall be used to establish a reduction in the specified testing temperature for the production material. The additive temperature shall be used to lower the

Page 80

specified testing temperature for any production material upon which the procedure will be used.

(c) Should the unaffected base material Charpy V-notch impact test results fail to meet the applicable requirements referenced in (b)(1) or (b)(4) above, additional unaffected base material Charpy V-notch impact tests shall be tested at higher temperatures until the applicable requirements are met. Charpy V-notch impact tests of the heat affected zone shall be tested at the same temperature at which acceptable unaffected base material properties were achieved. The rules governing the average lateral expansion of the heat affected zone relative to the average lateral expansion of the unaffected base material shall be followed as in (b)(1) through (3) or (b)(4) through (6) above, as applicable, to determine the data which are to be recorded on the Welding Procedure Qualification Record.

NG-4336 Qualification Requirements for Built-Up Weld Deposits

Built-up weld deposits for base metal reinforcement shall be qualified in accordance with the requirements of NG-4331 to NG-4335, inclusive.

NG-4400

NG-4400 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS

NG-4410 PRECAUTIONS TO BE TAKEN BEFORE WELDING

NG-4411 Identification, Storage, and Handling of Welding Material

Each Certificate Holder is responsible for control of the welding electrodes and other material which is used in the fabrication and installation of core support structures (NG-4120). Suitable identification, storage, and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by electrodes and flux.

NG-4412 Cleanliness and Protection of Welding Surfaces

The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

NG-4420 RULES FOR MAKING WELDED JOINTS

NG-4421 Backing Rings

Backing rings shall conform to the requirements of NG-3350. The material for backing rings, when used, shall be compatible with the base metal. Permanent backing rings, when permitted by NG-3350, shall be continuous, and any splices shall be made by full penetration welds. Spacer pins shall not be incorporated into the welds.

NG-4422 Peening

Controlled peening may be performed to minimize distortion. Peening shall not be used on the initial layer, root of the weld metal, nor on the final layer unless the weld is postweld heat treated.

NG-4423 Double Welded Joints

Before applying weld metal on the second side to be welded, the root of full penetration double welded joints shall be prepared by suitable methods such as chipping, grinding, or thermal gouging, except for those processes of welding by which proper fusion and penetration are otherwise obtained and demonstrated to be satisfactory by welding procedure qualification.

NG-4424 Surfaces of Welds

As-welded surfaces are permitted. However, the surface of welds shall be sufficiently free from coarse ripples, grooves, overlaps, abrupt ridges, and valleys to meet the requirements of (a) through (e) below.

(a) The surface condition of the finished weld shall be suitable for the proper interpretation of radiographic and any other required nondestructive examinations of the welds. In those cases where there is a question regarding the surface condition on the interpretation of a radiographic film, the film shall be compared to the actual weld surface for interpretation and determination of acceptability.

(b) Reinforcements are permitted in accordance with NG-4426.

(c) Undercuts shall not exceed $\frac{1}{32}$ in. (0.8 mm) and shall not encroach on the required section thickness.

(d) Concavity on the root side of a single welded circumferential butt weld is permitted when the resulting

thickness of the weld meets the requirements of NG-3000.

(e) If the surface of the weld requires grinding to meet the above criteria, care shall be taken to avoid reducing the weld or base material below the required thickness.

NG-4425 Welding Items of Different Diameters

When items of different diameters are welded together, there shall be a gradual transition between the two surfaces. The length of the transition may include the weld. The slope of the transition shall be such that the length-offset ratio shall not be less than 3:1, unless greater slopes are shown to be acceptable by analysis in accordance with NG-3200.

NG-4426 Reinforcement of Welds

The surface of the reinforcement of all butt welded joints in core support structures may be flush with the base material or may have uniform crowns. The height of reinforcement on each face of the weld shall not exceed the following thickness:

Nominal Thickness, in.	Maximum Reinforcement, in.
Up to 1, incl.	$\frac{3}{32}$
Over 1 to 2, incl.	$\frac{1}{8}$
Over 2 to 3, incl.	$\frac{5}{32}$
Over 3 to 4, incl.	$\frac{7}{32}$
Over 4 to 5, incl.	$\frac{1}{4}$
Over 5	$\frac{5}{16}$

NG-4427 Shape and Size of Fillet Welds

Fillet welds may vary from convex to concave. The shape and size of the weld shall be in accordance with the requirements of Fig. NG-4427-1. A fillet weld in any single continuous weld may be less than the specified fillet weld dimension by not more than $\frac{1}{16}$ in. (1.6 mm), provided that the total underrun portion of the weld does not exceed 10% of the length of the weld. Individual underrun weld portions shall not exceed 2 in. (51 mm) in length. On web-to-flange welds on girders, no underrun is permitted at the ends for a length equal to twice the width of the flange. In making socket welds, a gap as shown in Fig. NG-4427-1 shall be provided prior to welding. The gap need not be present nor be verified after welding.

NG-4429 Welding of Clad Parts¹

The joint types and welding procedures used for cladding shall be such as to prevent the formation of brittle weld composition. Any such weld deposited cladding shall be examined by a liquid penetrant method in accordance with the requirements of NG-5110 and meet the acceptance standards of NG-5350. Parts welded to clad items shall be welded directly to the base metal and not to the cladding, except in the case of weld overlay cladding.

NG-4430 WELDING OF TEMPORARY ATTACHMENTS AND THEIR REMOVAL

(a) Temporary attachments (NG-1123) may be noncertified material and may be welded to the core support structure or its parts with continuous or intermittent fillet or partial penetration welds, provided the requirements of (1) through (5) below are met:

- (1) the welding procedure and the welders have been qualified in accordance with NG-4321;
- (2) the material is identified and is suitable for welding;
- (3) the material is compatible with the material to which it is attached;
- (4) the welding material is identified and compatible with the materials joined;
- (5) the welds are postweld heat treated when required by NG-4620.

(b) Removal of temporary attachments shall be accomplished as follows:

(1) the immediate area around the temporary attachment is marked in a suitable manner so that after removal the area can be identified until after it has been examined in accordance with (3) below;

(2) the temporary attachment is completely removed in accordance with the procedures of NG-4211;

(3) after the temporary attachment has been removed, the marked area is examined by the liquid penetrant or magnetic particle method in accordance with the requirements of NG-5110 and meets the acceptance standards of NG-5340 or NG-5350, whichever is applicable; this examination is not required if more than $\frac{1}{8}$ in. (3.2 mm) of material will be removed by any subsequent machining operations;

1 Welds that are exposed to corrosive action should have a resistance to corrosion that is not substantially less than that of the cladding. The use of filler metal that will deposit weld metal which is similar to the composition of the cladding material is recommended. If weld metal of different composition is used, it should have properties compatible with the application.

Page 82

Page 83

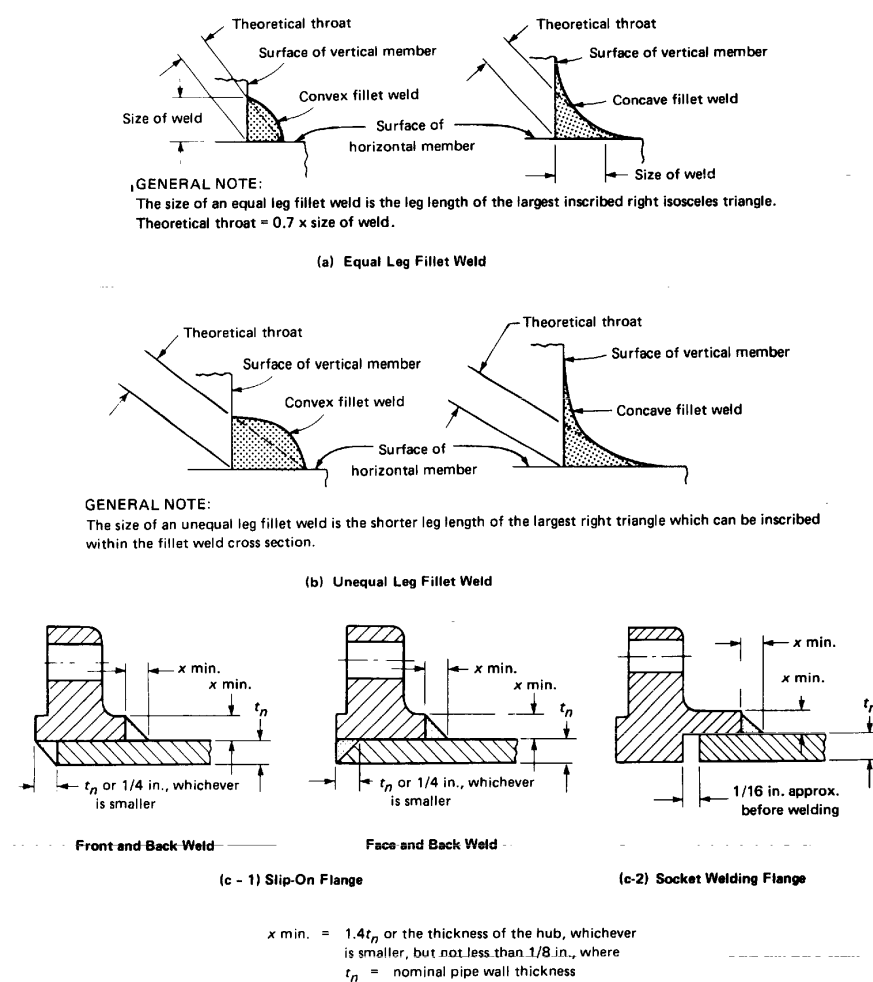


FIG. NG-4427-1 FILLET AND SOCKET WELD DETAILS AND DIMENSIONS

FIG. NG-4427-1 FILLET AND SOCKET WELD DETAILS AND DIMENSIONS

(4) as an alternative to (a)(5) above, postweld heat treatment may be deferred until after removal of the attachment.

NG-4450 REPAIR OF WELD METAL DEFECTS

NG-4451 General Requirements

Defects in weld metal detected by the examinations required by NG-5000 shall be eliminated and repaired when necessary.

NG-4452 Elimination of Surface Defects

Weld metal surface defects may be removed by grinding or machining and need not be repaired by welding, provided that the requirements of (a) through (c) below are met.

(a) The remaining thickness of the section is not reduced below that required by NG-3000.

(b) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(c) The area is examined by a magnetic particle or liquid penetrant method in accordance with NG-5110 after blending and meets the acceptance standards of NG-5300 to ensure that the defect has been removed or the indication reduced to an acceptable limit. Defects detected by the visual or volumetric method and located on an interior surface need only be reexamined by the method which initially detected the defect when the interior surface is inaccessible for surface examination.

NG-4453 Requirements for Making Repairs of Welds

Excavations in weld metal, when repaired by welding, shall meet the requirements of the following subparagraphs.

NG-4453.1 Defect Removal.

Defects may be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined by a liquid penetrant or magnetic particle method in accordance with NG-5110 and meet the acceptance standards of NG-5340 or NG-5350. This examination is not required where defect elimination removes the full thickness of the weld and where the backside of the weld joint is not accessible for removal of examination materials.

NG-4453.2 Requirements for Welding Material, Procedures, and Welders.

The weld repair shall be made using welding material, welders, and welding procedures qualified in accordance with NG-4125 and NG-4300.

NG-4453.3 Blending of Repaired Areas.

After repair the surface shall be blended uniformly into the surrounding surface.

NG-4453.4 Examination of Repair Welds.

The examination of a weld repair shall be repeated as required for the original weld, except that it need only be reexamined by the liquid penetrant or magnetic particle method when the unacceptable indication was originally detected by the liquid penetrant or magnetic particle method and when the repair cavity does not exceed the following:

(a) $\frac{1}{3}t$ for $t \leq \frac{1}{2}$ in. (13 mm).

(b) $\frac{1}{4}$ in. (6 mm) for $\frac{1}{2}$ in. (13 mm) $< t \leq 2\frac{1}{2}$ in. (64 mm).

(c) the lesser of $\frac{3}{8}$ in. (10 mm) or 10% t for $t > 2\frac{1}{2}$ in. (64 mm).

where t equals the thickness of the weld.

NG-4500 BRAZING

Brazing is not permitted for core support structures.

NG-4600 HEAT TREATMENT

NG-4610 WELDING PREHEAT REQUIREMENTS

NG-4611 When Preheat Is Necessary

The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, elevated temperature, physical properties, and material thickness. Some practices used for preheating are given in Appendix D as a general guide for the materials listed by P-Numbers of Section IX. It is cautioned that the preheating suggested in Appendix D does not necessarily ensure satisfactory completion of the welded joint and that the requirements for individual materials within the P-Number listing may be more or less restrictive. The Welding Procedure Specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.

NG-4612 Preheating Methods

Preheat for welding or thermal cutting, when employed, may be applied by any method which does

Page 84

not harm the base material or any weld metal already applied or which does not introduce deleterious material into the welding area which is harmful to the weld.

NG-4613 Interpass Temperature

Consideration shall be given to the limitations of interpass temperatures for quenched and tempered material to avoid detrimental effects on the mechanical properties.

NG-4620 POSTWELD HEAT TREATMENT

NG-4621 Heating and Cooling Methods

Postweld heat treatment (PWHT) may be accomplished by any suitable methods of heating and cooling, provided the required heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control are maintained.

NG-4622 PWHT Time and Temperature Requirements

NG-4622.1 General Requirements.²

Except as otherwise permitted in NG-4622.7, all welds, including repair welds, shall be postweld heat treated. During postweld heat treatment, the metal temperature shall be maintained within the temperature range and for the minimum holding time specified in Table NG-4622.1-1, except as otherwise permitted in NG-4622.4(c). P-Number groups in Table NG-4622.1-1 are in accordance with Section IX, QW-420. Except as provided in NG-4624.3, PWHT shall be performed in temperature-surveyed and -calibrated furnaces, or PWHT shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. In addition, the requirements of the following subparagraphs shall apply.

NG-4622.2 Time-Temperature Recordings.

Time-temperature recordings of all postweld heat treatments shall be made available for review by the Authorized Inspector. Identification on the time-temperature recording shall be to the weld, part, or core support structure. A summary of the time-temperature recording may be provided for permanent records in accordance with NCA-4134.17.

² Any postweld heat treatment time which is anticipated to be applied to the material or item it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time

in the total at temperature specified to be applied to the test specimens.

NG-4622.3 Definition of Nominal Thickness Governing PWHT.

The nominal thickness in Table NG-4622.7(b)-1 is the thickness of the weld, the base material, or the thinner of the base materials being joined, whichever is least. It is not intended that nominal thickness include material provided for forming allowance, thinning, or mill overrun when the excess material does not exceed $\frac{1}{8}$ in. (3.2 mm) For fillet welds the nominal thickness is the throat thickness, and for partial penetration and material repair welds the nominal thickness is the depth of the weld groove or preparation.

NG-4622.4 Holding Times at Temperature

(a) The holding time at temperature as specified in Table NG-4622.1-1 shall be based on the nominal thickness of the weld. The holding time need not be continuous. It may be an accumulation of the times of multiple postweld heat treat cycles.

(b) Holding time at temperature in excess of the minimum requirements of Table NG-4622.1-1 may be used, provided that specimens so heat treated are tested in accordance with NG-2200, NG-2400, and NG-4300.

(c) Alternatively, when it is impractical to postweld heat treat at the temperature range specified in Table NG-4622.1-1, it is permissible to perform the postweld heat treatment of certain materials at lower temperatures for longer periods of time in accordance with Table NG-4622.4(c)-1 and (1), (2), and (3) below.

(1) Except for P-No. 1 materials, when welds in the materials listed in Table NG-4622.4(c)-1 are to be postweld heat treated at these lower minimum temperatures, impact test specimens for the welding procedure qualification required by NG-4300 shall be made using the same minimum temperatures and increased minimum holding time. Welding procedures, qualified at the temperature range and minimum holding time specified in Table NG-4622.1-1 and at the lower temperature and increased minimum holding time permitted by this subparagraph, are also qualified for any temperature in between. When such an in-between temperature is used, the minimum holding time shall be extrapolated from Table NG-4622.1-1 and the alternative requirements of Table NG-4622.4(c)-1.

(2) Except for P-No. 1 materials, when welds in the materials listed in Table NG-4622.4(c)-1 are to be postweld heat treated at these lower minimum temperatures, the welding material certification required by NG-2400 shall be made using the same minimum temperature and increased minimum holding time. Welding material certified at the temperature range and minimum holding time specified in Table NG-4622.1-1 and at the lower minimum temperatures and increased minimum holding time permitted by Table NG-4622.4(c)-1

Page 85

Page 86

TABLE NG-4622.1-1
MANDATORY REQUIREMENTS FOR POSTWELD HEAT
TREATMENT (PWHT) OF WELDS¹

P-No. (Sect. IX, QW-420)	Holding Temperature Range [Note (2)]	Minimum Holding Time at Temperature for Weld Thickness (Nominal)			
		$\frac{1}{2}$ in. or Less	Over $\frac{1}{2}$ in. to 2 in.	Over 2 in. to 5 in.	Over 5 in.
1, 3	1100–1250°F	30 min	1 hr/in.	2 hr plus 15 min each additional inch over 2 in.	2 hr plus 15 min each additional inch over 2 in.
4	1100–1250°F	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
5A, 5B, 5C, 6 except P-No. 6 Gr. 4	1250–1400°F	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
6 Gr. 4	1100–1150°F				
7	1300–1400°F	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
9A Gr. 1	1100–1250°F	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
9B Gr. 1	1100–1175°F				
10F Gr. 1	1100–1250°F	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
10I Gr. 1	1300–1400°F				
11A Gr. 4	1000–1050°F	30 min	1 hr/in.	1 hr/in.	1 hr/in.
P-Nos. 8, 34, 42, 43, 45, and hard surfac- ing on P-No. 1 base metal whose reported carbon content is not more than 0.30%	PWHT neither required nor prohibited				

NOTES:

(1) Exemptions to the mandatory requirements of this Table are defined in NG-4622.7.

(2) All temperatures are metal temperatures.

TABLE NG-4622.1-1 MANDATORY REQUIREMENTS FOR POSTWELD HEAT TREATMENT (PWHT) OF WELDS¹

is also certified for any temperatures in between.

**TABLE NG-4622.4(c)-1
ALTERNATIVE HOLDING TEMPERATURES
AND TIMES**

Material P-Numbers	Alternative Minimum Holding Temperatures	Alternative Minimum Holding Times [Note (1)]
1, 3, 9A Gr.1, 9B Gr.1	1050°F	2 hr/in. thickness
1, 3, 9A Gr.1, 9B Gr.1	1000°F	4 hr/in. thickness

NOTE:

(1) All other requirements of NG-4622 shall apply.

TABLE NG-4622.4(c)-1 ALTERNATIVE HOLDING TEMPERATURE AND TIMES

(3) Base material certified in accordance with NG-2200 may be postweld heat treated at the lower minimum temperatures and increased minimum holding times without recertification. Postweld heat treatment at these lower minimum temperatures and increased minimum holding times may also be the tempering operation, provided a higher tempering temperature is not required by the material specification.

NG-4622.5 PWHT Requirements When Different P-Number Materials Are Joined.

When materials of two different P-Number groups are joined by welding, the applicable postweld heat treatment shall be that specified in Table NG-4622.1-1 for the material requiring the higher PWHT temperature range.

NG-4622.7 Exemptions to Mandatory Requirements.

Postweld heat treatment in accordance with this Subarticle is not required for:

(a) nonferrous materials;

(b) welds exempted in Table NG-4622.7(b)-1;

(c) welds subjected to temperatures above the PWHT temperature range specified in Table NG-4622.1-1, provided the Welding Procedure Specification is qualified in accordance with Section IX and the base material and the deposited weld material have been heat treated at the higher temperature;

(d) postweld heat treatment is not required for core support structures constructed of P-No. 7 Type 405 material or of

Type 410 material with carbon content not exceeding 0.08%, welded with electrodes that produce an austenitic chromium-nickel weld deposit or a nonair-hardening nickel-chromium-iron weld deposit, provided the plate thickness at the welded joint does not exceed $\frac{3}{8}$ in. (10 mm).

NG-4623 PWHT Heating and Cooling Rate Requirements

Above 800°F (427°C) the rate of heating and cooling in any hourly interval shall not exceed 400°F (222°C) divided by the maximum thickness in inches of the material being heat treated, but shall not exceed 400°F (222°C) and need not be less than 100°F (56°C) in any hourly interval. During the heating and cooling period there shall not be a greater variation in temperature than 250°F (139°C) within any 15 ft (4.6 m) interval of weld length. The exceptions of (a) and (b) below are permitted.

(a) P-No. 6 material may be cooled in air from the postweld heat treatment holding temperature specified in Table NG-4622.1-1.

(b) For P-No. 7 material the cooling rate at temperatures above 1200°F (649°C) shall not exceed 100°F/hr (56°C/hr), after which the rate of cooling shall be sufficiently rapid to prevent embrittlement.

NG-4624 Methods of Postweld Heat Treatment

The postweld heat treatment shall be performed in accordance with the requirements of one of the following subparagraphs.

NG-4624.1 Furnace Heating - One Heat.

Heating the core support structure or item in a closed furnace in one heat is the preferred procedure and should be used whenever practical. The furnace atmosphere shall be controlled so as to avoid excessive oxidation, and direct impingement of flame on the core support structure or item is prohibited.

NG-4624.2 Furnace Heating - More Than One Heat.

The core support structure or item may be heated in more than one heat in a furnace, provided the furnace atmosphere control requirements of NG-4624.1 apply and overlap of the heated sections of the core support structure or item is at least 5 ft (1.5 m). When this procedure is used, the portion of the core support structure or item outside the furnace shall be shielded so that the temperature gradient is not harmful. The cross section where the core support structure or item projects from the furnace shall not intersect a structural discontinuity.

NG-4624.3 Local Heating.

Welds may be locally postweld heat treated when it is not practical to heat treat the entire core support structure or item. Local postweld heat treatment shall consist of heating a circumferential band around the core support structure or item at temperature within the ranges specified in this Subarticle. The minimum width of the controlled

Page 87

band at each side of the weld, on the face of the greatest weld width, shall be the thickness of the weld or 2 in. (51 mm), whichever is less. The temperature of the core support structure or item from the edge of the controlled band outward shall be gradually diminished so as to avoid harmful thermal gradients. This procedure may also be used for postweld heat treatment after repairs. Pages 88-88

**TABLE NG-4622.7(b)-1
EXEMPTIONS TO MANDATORY PWHT¹**

P-No. (Sect. IX, QW-420)	Type of Weld [Note (2)]	Nominal Thickness (NG-4622.3)	Max. Reported Carbon, % [Note (3)]	Min. Preheat Req'd., °F
1	All welds where the materials being joined are 1½ in. and less	1¼ in. or less Over 1¼ in. to 1½ in. ¾ in. or less Over ¾ in. to 1½ in.	0.30 or less 0.30 or less Over 0.30 ...	... 200 ... 200
	All welds in material over 1½ in.	¾ in. or less	...	200
1 Gr. 1 or Gr. 2	Cladding or repair of cladding [Note (4)] with A-No. 8 or F-No. 43 filler metal in base material of: 1½ in. or less Over 1½ in. to 3 in. Over 3 in.	...	0.30	100
		...	0.30	200 [Note (5)]
		...	0.30	250 [Note (6)]
3 except Gr. 3	All welds	½ in. or less	0.25 or less	200
4	All welds in pipes or tubes with nominal O.D. 4 in. or less	½ in. or less	0.15 or less	250
5A, 5B, 5C	All welds in pipes or tubes with maximum specified chromium 3.00% or less and nominal O.D. 4 in. or less	½ in. or less	0.15 or less	300
7	Type 405 and 410S welded with A-No. 8, A-No. 9, or F-No. 43 filler metal	⅜ in. or less	0.08 or less	...
9A Gr. 1	All welds provided the procedure qualification is made using equal or greater thickness base material than the production weld	⅝ in. or less	...	200
	Attachment welds joining nonpressure-retaining material to pressure-retaining material over ⅝ in.	½ in. or less	...	200
	Circumferential butt welds or socket welds in pipe and tubes with nominal O.D. 4 in. or less and attachment welds	½ in. or less	0.15 or less	250
9B Gr. 1	All welds provided the procedure qualification is made using equal or greater thickness base material than the production weld	⅝ in. or less	...	200
	Attachment welds joining nonpressure-retaining material to pressure-retaining material over ⅝ in.	½ in. or less	...	200
10I Gr. 1	All welds in material ½ in. and less	½ in. or less	...	...
11A Gr. 4	All welds in material ½ in. and less	½ in. or less	...	250

[Table NG-4622.7(b)-1 continues on next page]

TABLE NG-4622.7(b)-1 EXEMPTION TO MANDATORY PWHT¹

TABLE NG-4622.7(b)-1 (CONT'D)

NOTES:

- (1) The exemptions noted in this Table do not apply to electron beam welds in ferritic materials over $\frac{1}{8}$ in. in thickness.
- (2) Where the thickness of material is identified in the Type of Weld column, it is the thickness of the base material at the welded joint.
- (3) Carbon level of the pressure-retaining materials being joined.
- (4) Maximum process heat input = 150,000 J/in. The maximum resulting hardness in the procedure qualification test plate shall not exceed 35 Rc.
- (5) Intermediate postweld soak at not less than 200°F for 2 hr minimum.
- (6) Intermediate postweld soak at not less than 300°F for 2 hr minimum.

TABLE NG-4622.7(b)-1 (CONT'D)

NG-4624.4 Heating Structures Internally.

The core support structure or item may be heated internally by any appropriate means and with adequate indicating and recording temperature devices to aid in the control and maintenance of a uniform distribution of temperature in the core support structure or item. Previous to this operation, the core support structure or item should be fully enclosed with insulating material.

NG-4630 HEAT TREATMENT OF WELDS OTHER THAN THE FINAL POSTWELD HEAT TREATMENT

The holding temperature, the time at temperature, the heating rate, and the cooling rate need not conform to the requirements of this Article for heat treatments other than the final postweld heat treatment.

NG-4650 HEAT TREATMENT AFTER BENDING OR FORMING

NG-4651 Ferritic Materials

Ferritic materials may be used in the as-formed or as-bent condition, heat treated in accordance with NG-4620, fully annealed, normalized and tempered, or quenched and tempered, provided the requirements of NG-2210, NG-4212, and NG-4213 are met.

NG-4652 Austenitic and Nonferrous Materials

Heat treatment of austenitic and nonferrous materials is neither required nor prohibited after bending or forming operations.

NG-4660 HEAT TREATMENT OF ELECTROSLAG WELDS

Electroslag welds in ferritic material over $1\frac{1}{2}$ in. (38 mm) in thickness at the joints shall be given a grain refining heat treatment.

NG-4700 MECHANICAL JOINTS

NG-4710 THREADED STRUCTURAL FASTENERS

NG-4711 Thread Engagement

All threaded structural fasteners shall be engaged in accordance with the design drawings or Design Specifications.

NG-4712 Thread Lubricants

Any lubricant or compound used in threaded joints shall be suitable for the Service Conditions and shall not react unfavorably with either the service fluid or any component material in the system.

NG-4713 Removal of Thread Lubricants

All threading lubricants or compounds shall be removed from surfaces which are to be seal welded.

NG-4720 TEMPORARY FASTENERS AND THEIR REMOVAL

All fasteners used to connect temporary attachments to the core support structure shall be removed prior to operation.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NG-5000

ARTICLE NG-5000 EXAMINATION

Page 89

Page 90

NG-5100 GENERAL REQUIREMENTS FOR EXAMINATION

NG-5110 PROCEDURES, QUALIFICATIONS, AND EVALUATION

NG-5111 General Requirements

Nondestructive examinations shall be conducted in accordance with the examination methods of Section V, except as they may be modified by the requirements of this Article. Radiographic examination shall be by film radiography or real time radioscopes in accordance with Section V, Article 2, except that fluorescent screens are not permitted for film radiography, the geometric unsharpness shall not exceed the limits of T-285, and the penetrameters of Table NG-5111-1 shall be used in lieu of those shown in Table T-276. The requirements for the retention of radioscopic images are the same as for film radiography. Ultrasonic examination shall be in accordance with Section V, Article 5; magnetic particle examination shall be in accordance with Section V, Article 7; liquid penetrant examination shall be in accordance with Section V, Article 6; and visual examination shall be in accordance with Section V, Article 9. The examinations required by this Article or by reference to this Article shall be performed by personnel who have been qualified as required by this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards of this Article.

NG-5112 Nondestructive Examination Procedures

All nondestructive examinations required by this Article shall be performed in accordance with detailed written procedures which have been proven by actual demonstration to the satisfaction of the Inspector. The procedures shall comply with the appropriate Article of Section V for the particular examination method. The digitization of radiographic film and radioscopic images shall meet the requirements of Section V, Article 2, Mandatory Appendix III, "Digital Image Acquisition, Display, and Storage for Radiography and Radioscopes." Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Inspector on request. At least one copy of the procedure shall be readily available to all applicable nondestructive examination personnel for reference and use.

NG-5113 Post-Examination Cleaning

Following any nondestructive examination in which examination materials are applied to the piece, the piece shall be thoroughly cleaned in accordance with applicable material or procedure specifications.

NG-5120 TIME OF EXAMINATION OF WELDS

Acceptance examinations of welds required by NG-5200 shall be performed at the time stipulated in the following subparagraphs during fabrication and installation.

(a) For welds in core support structure components, radiographic or ultrasonic examination, when required, shall be

performed after an intermediate or final postweld heat treatment if heat treatment is required by NG-4622.

(b) Magnetic particle, liquid penetrant, or visual examinations shall be performed on the final surface after any required postweld heat treatment, except that welds in P-No. 1 material may be examined either before or after postweld heat treatment. Weld surfaces that are covered with weld metal cladding shall be examined before the weld metal cladding is applied. Weld surfaces which are not accessible after a postweld heat treatment shall be examined prior to the operations which caused this inaccessibility.

TABLE NG-5111-1
THICKNESS, PENETRATOR DESIGNATIONS, ESSENTIAL HOLES, AND WIRE DIAMETERS

Penetrator(s) — Hole or Wire Type [Note (1)]								
Single Wall Material Thickness Range, in.	Source Side				Film Side			
	Designation	Hole Size	Essential Hole	Required Wire Diameter — IQI	Designation	Hole Size	Essential Hole	Required Wire Diameter — IQI
Up to .25 incl	5	0.040	4T	0.006	5	0.040	4T	0.006
Over 1/4–3/8	7	0.040	4T	0.006	7	0.040	4T	0.006
Over 3/8–1/2	10	0.040	4T	0.010	10	0.040	4T	0.010
Over 1/2–5/8	12	0.050	4T	0.013	12	0.050	4T	0.013
Over 5/8–3/4	15	0.060	4T	0.016	12	0.050	4T	0.013
Over 3/4–1	20	0.040	2T	0.016	17	0.035	2T	0.013
Over 1–1 1/4	25	0.050	2T	0.020	17	0.035	2T	0.013
Over 1 1/4–1 1/2	30	0.060	2T	0.025	20	0.040	2T	0.016
Over 1 1/2–2	35	0.070	2T	0.032	25	0.050	2T	0.020
Over 2–2 1/2	40	0.080	2T	0.040	30	0.060	2T	0.025
Over 2 1/2–3	45	0.090	2T	0.040	35	0.070	2T	0.032
Over 3–4	50	0.100	2T	0.050	40	0.080	2T	0.040
Over 4–6	60	0.120	2T	0.063	45	0.090	2T	0.040
Over 6–8	80	0.160	2T	0.100	50	0.100	2T	0.050
Over 8–10	100	0.200	2T	0.126	60	0.120	2T	0.063
Over 10–12	120	0.240	2T	0.160	80	0.160	2T	0.100
Over 12–16	160	0.320	2T	0.250	100	0.200	2T	0.126
Over 16–20	200	0.400	2T	0.320	120	0.240	2T	0.160

NOTE:

(1) Hole (plaque) type penetrators may be used on flat plates and on objects with geometries such that the penetrator hole image is not distorted.

TABLE NG-5111-1 THICKNESS, PENETRATOR DESIGNATIONS, ESSENTIAL HOLES, AND WIRE DIAMETERS

(c) All dissimilar metal weld joints, such as in austenitic or high nickel to ferritic material or using austenitic or high nickel alloy filler metal to join ferritic material, shall be examined on the final surface after final postweld heat treatment.

NG-5130 EXAMINATION OF WELD EDGE PREPARATION SURFACES

All full penetration weld edge preparation surfaces in material 1 in. or more in thickness shall be examined by the magnetic particle or liquid penetrant method. Indications shall be evaluated in accordance with the acceptance standards of (a), (b), and (c) below.

(a) Only indications with major dimensions greater than 1/16 in. shall be considered relevant.

(b) Laminar-type discontinuities are acceptable without repair if they do not exceed 1/2 in. (13 mm) in length. The extent of all laminar-type indications exceeding 1/2 in. (13 mm) in length shall be determined by ultrasonic examination. Indications exceeding 1/2 in. (13 mm) in length shall be repaired by welding to a depth of 3/8 in. (10 mm) or the depth of the indication, whichever is less, unless the ultrasonic examination reveals that additional depth of repair is required to meet the ultrasonic

examination requirement for the product form.

(c) The following relevant indications are unacceptable:

(1) any linear indication greater than $\frac{1}{8}$ in. (3.2 mm) long for materials 1 in. (25 mm) thick to under 2 in. (51 mm) thick and $\frac{3}{16}$ in. (4.8 mm) long for materials 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);

(3) four or more indications greater than $\frac{1}{16}$ in. (1.6 mm) long in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more indications greater than $\frac{1}{16}$ in. (1.6 mm) long in any 6 sq in. (3871 mm²) of area whose major dimension is no more than 6 in. (152 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

(d) Weld repairs made to weld edge preparations for Types I, II, and III welds shall be examined by the

Page 93

magnetic particle or liquid penetrant method before the surfaces become inaccessible. The examination may be performed before or after postweld heat treatment.

NG-5200 REQUIRED EXAMINATION OF WELDS

NG-5210 PERMISSIBLE EXAMINATION METHODS

Welds used in core support structures shall be examined in accordance with the requirements of this Subarticle for the type of examination specified by the Certificate Holder to meet the requirement of Table NG-3352-1. The Certificate Holder may upgrade the examination in Table NG-3352-1 to a level higher than originally specified.

NG-5220 REQUIREMENTS FOR RADIOGRAPHY OR ULTRASONIC AND LIQUID PENETRANT OR MAGNETIC PARTICLE EXAMINATION

When required by the Certificate Holder (Table NG-3352-1), welds shall be radiographically examined and the external and accessible internal weld surfaces and adjacent base metal for at least $\frac{1}{2}$ in. (13 mm) on each side of the weld examined by either the magnetic particle or liquid penetrant method. Ultrasonic examination may be substituted for radiography except for those materials and welds which have coarse grains or configurations which do not yield meaningful results by ultrasonic methods.

NG-5230 REQUIREMENTS FOR LIQUID PENETRANT OR MAGNETIC PARTICLE EXAMINATION

NG-5231 Requirements for Progressive Liquid Penetrant or Magnetic Particle Examination

When required by the Certificate Holder (Table NG-3352-1), welds shall be either liquid penetrant or magnetic particle examined progressively at the lesser of either one-third of the thickness of the weld joint or each $\frac{1}{2}$ in. (13 mm), and on the external and accessible internal weld surfaces and the adjacent base material for $\frac{1}{2}$ in. (13 mm) on each side of the weld. For welds $\frac{3}{8}$ in. (10 mm) thick or less, examination of the root, each subsequent layer, and the external and accessible internal weld surfaces and adjacent base material for at least $\frac{1}{2}$ in. (13 mm) on each side of the weld is permitted in lieu of the above.

NG-5232 Requirements for Root and Final Liquid Penetrant or Magnetic Particle Examination

When required by the Certificate Holder (Table NG-3352-1), welds shall be either liquid penetrant or magnetic particle examined after the root and final passes on the external and accessible internal weld surfaces and the adjacent base material for at least $\frac{1}{2}$ in. (13 mm) on each side of the weld.

NG-5233 Requirements for Surface Liquid Penetrant or Magnetic Particle Examination

When required by the Certificate Holder (Table NG-3352-1), welds shall be either liquid penetrant or magnetic particle

examined on the external and accessible internal weld surfaces and the adjacent base material for at least $\frac{1}{2}$ in. (13 mm) on each side of the weld.

NG-5260 REQUIREMENTS FOR SURFACE VISUAL EXAMINATION

NG-5261 Visual Examination in Addition to Other NDT Examination

All welds shall be visually examined to the acceptance criteria of NG-5361. This visual examination shall be in addition to all other required examinations.

NG-5262 Visual Examination for Weld Surface Integrity

When required by the Certificate Holder (Table NG-3352-1), welds shall be visually examined on the final surface to the acceptance criteria of NG-5362.

NG-5270 HARD SURFACING

Hard surfacing shall be examined by the liquid penetrant method in accordance with NG-2546, and the acceptance standards applicable to materials 2 in. (51 mm) thick and greater shall apply.

Page 94

NG-5300 ACCEPTANCE STANDARDS

NG-5320 RADIOGRAPHIC ACCEPTANCE STANDARDS

NG-5321 Evaluation of Indications

Indications shown on the radiographs of welds and characterized as imperfections are unacceptable under the following conditions:

- (a) any indication characterized as a crack or zone of incomplete fusion or penetration;
- (b) any other elongated indication which has a length greater than:
 - (1) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive
 - (2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (57 mm), inclusive
 - (3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm)

where t is the thickness of the thinner portion of the weld;

(c) internal root weld conditions are acceptable when the density change as indicated in the radiograph is not abrupt; elongated indications on the radiograph at either edge of such conditions shall be unacceptable as provided in (b) above;

(d) any group of aligned indications having an aggregate length greater than t in a length of $12t$, unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication;

(e) any group of aligned indications whose aggregate length exceeds the permissible length of a single indication and with the minimum distance between these successive indications less than $3L$, L being the length of the largest indication;

(f) rounded indications in excess of that shown as acceptable in Appendix VI. Four or more rounded indications shall constitute aligned rounded indications for welds covered by Appendix VI.

NG-5330 ULTRASONIC ACCEPTANCE STANDARDS

All imperfections which produce a response equal to or greater than 50% of the reference level are unacceptable, except as noted in (a) below.

- (a)

(a) Imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths exceeding:

(1) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive

(2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (57 mm), inclusive

(3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm) where t is the thickness of the weld being examined; if a weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses.

(b) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

NG-5340 MAGNETIC PARTICLE ACCEPTANCE STANDARDS

NG-5341 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication which is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. After an indication has been verified to be nonrelevant, it is not necessary to reinvestigate repetitive nonrelevant indications of the same type. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NG-5342 Acceptance Standards

(a) Only imperfections producing indications whose major dimensions are greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks and linear indications;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);

(3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm), with the

Page 95

area taken in the most unfavorable location relative to the indications being evaluated.

NG-5350 LIQUID PENETRANT ACCEPTANCE STANDARDS

NG-5351 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities such as may occur from machining marks or surface conditions may produce similar indications which are nonrelevant.

(b) Any indication which is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NG-5352 Acceptance Standards

(a) Only imperfections producing indications whose major dimensions are greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

- (1) any cracks or linear indications;
- (2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);
- (3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;
- (4) ten or more rounded indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) with the area taken in the most unfavorable location relative to the indications being evaluated.

NG-5360 VISUAL EXAMINATION ACCEPTANCE STANDARDS

NG-5361 General Acceptance Standards

When visual examination is performed in accordance with NG-5261, the acceptance standards of (a) and (b) below shall be met.

- (a) Weld reinforcement, underfill, undercut, and overlap shall not exceed the allowable limits of this Subsection.
- (b) The examined surface shall be free of abrupt irregularities.

NG-5362 Acceptance Standards for Visual Examination for Weld Surface Integrity

(a) When visual examination is performed in accordance with NG-5262, the weld surface shall meet the acceptance criteria given in NG-5361.

(b) The following imperfections are unacceptable:

- (1) any imperfection characterized as a crack, or lack of penetration;
- (2) rounded imperfections whose major dimension exceeds $\frac{1}{8}$ in. (3.2 mm);
- (3) four or more rounded imperfections greater than $\frac{1}{32}$ in. (0.8 mm) in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;
- (4) ten or more rounded imperfections greater than $\frac{1}{32}$ in. (0.8 mm) in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) with the area taken in the most unfavorable location relative to the imperfections being evaluated.

NG-5500 QUALIFICATIONS AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

NG-5510 GENERAL REQUIREMENTS

Organizations performing Code-required nondestructive examinations shall use personnel competent and knowledgeable to the degree specified by NG-5520. When these services are subcontracted by the Certificate Holder or Quality System Certificate Holder, he shall verify the qualification of personnel to the requirements of NG-5520. All nondestructive examinations required by this Subsection shall be performed by, and the results evaluated by, qualified nondestructive examination personnel.

NG-5520 PERSONNEL QUALIFICATION, CERTIFICATION, AND VERIFICATION

NG-5521 Qualification Procedure

(a) Personnel performing nondestructive examinations shall be qualified in accordance with the recommended guidelines of SNT-TC-1A.¹² The Employer's³ written practice required by paragraph 5 of SNT-TC-1A shall identify Employer requirements relative to the recommended guidelines. The recommended guidelines of SNT-TC-1A shall be considered minimum requirements except as modified in (1) through (5) below.

(1) Qualification of Level III nondestructive examination personnel shall be by examination.

(a) The basic and method examinations, paragraphs 8.8(1) and 8.8(2) of SNT-TC-1A, may be prepared and administered by the Employer, ASNT, or an outside agency.

(b) The specific examination, paragraph 8.8(3) of SNT-TC-1A, shall be prepared and administered by the Employer or an outside agency. The Employer or outside agency administering the specific examination shall identify the minimum grade requirement in a written program when the basic and method examinations have been administered by ASNT which issues grades on a pass/fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(2) The written practice identified in paragraph 5 of SNT-TC-1A and the procedures used for examination of personnel shall be referenced in the Employer's Quality Program.

1 SNT-TC-1A is a recommended Practice for Nondestructive Testing Personnel Qualification and Certification published by the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, Ohio 43228-0518. SNT-TC-1A-1992 is the applicable edition

2 Personnel qualified by examination and certified to previous editions of SNT-TC-1A are considered to be qualified to the 1992 edition when the recertification is based on continuing satisfactory performance. All reexaminations and new examinations shall be in accordance with the 1992 edition.

3 Employer as used in this Article shall include: N Certificate Holders; Quality System Certificate Holders; Material Organizations who are qualified in accordance with NCA-3862(a)(1); and organizations who provide subcontracted nondestructive examination services to organizations described above.

(3) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform a nondestructive examination of limited scope, may be less than that recommended in Table 6.3.1 of SNT-TC-1A. The training and experience times shall be described in written practice and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate.

The minimum classroom training times identified in Table 6.3.1 of SNT-TC-1A may be reduced from 8 and 16 hours to 4 and 8 hours, respectively, for visual examination personnel.

(4) For visual examination, the Jaeger Number 1 letters shall be used in lieu of the Jaeger Number 2 letters specified in paragraph 8.2(1) of SNT-TC-1A. The use of equivalent type and size letters is permitted.

(5) A Level I individual shall be qualified to perform specific setups, calibrations, and tests, and to record and evaluate data by comparison with specific acceptance criteria defined in written instructions. The Level I individual shall implement these written NDE instructions under the guidance of a Level II or III individual. A Level I individual may independently accept the results of nondestructive examinations when the specific acceptance criteria are defined in the written instructions.

(b) For nondestructive examination methods not covered by SNT-TC-1A documents, personnel shall be qualified to comparable levels of competency by subjection to comparable examinations on the particular method involved.

(c) The emphasis shall be on the individual's ability to perform the nondestructive examination in accordance with the applicable procedure for the intended application.

(d) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use personnel qualified to perform one or more operations. As an example, one person may be used who is qualified to conduct radiographic examination and another may be used who is qualified to interpret and evaluate the radiographic film.

NG-5522 Certification of Personnel

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of the Levels I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations [NG-5521(a)(2)], the Employer may use a letter from ASNT as evidence on which to base the certification.

(c) When an outside agency is the examining agent for Level III qualification of the Employer's personnel, the examination results shall be included with the Employer's record.

Page 97

NG-5523 Verification of Nondestructive Examination Personnel Certification

The Certificate Holder has the responsibility to verify the qualification and certification of nondestructive examination personnel employed by Material Organizations qualified by them in accordance with NCA-3820 and subcontractors who provide nondestructive examination services to them.

NG-5530 RECORDS

Personnel qualification records identified in paragraph 9.4 of SNT-TC-1A shall be retained by the Employer.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NG-8000

ARTICLE NG-8000 NAMEPLATES, STAMPING, AND REPORTS

Page 99

NG-8100 REQUIREMENTS

The applicable requirements given in NCA-8000 shall apply to core support structures.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NG SI UNITS

SI UNITS

Page 101

The 1995 Edition of the Boiler and Pressure Vessel Code is based on U.S. Customary (ft-lb) units of measurement which are to be regarded as the standard. This supplement is provided as a convenience to the Code user and contains SI conversion factors for units contained in the Code.

Page 102

Page 103

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

Quantity	Unit	Symbol	Other Units or Limitations
Space and Time			
plane angle	radian	rad	degree (decimalized)
length	meter	m	
area	square meter	m ²	
volume	cubic meter	m ³	liter (L) for liquid only (use without prefix other than in milliliter, mL)
time	second	s	minute (min), hour (h), day (d), week, and year
Periodic and Related Phenomena			
frequency	hertz	Hz	revolutions per second (r/s)
rotational frequency	revolutions per second	s ⁻¹	revolutions per minute (r/m)
Mechanics			
mass	kilogram	kg	
density	kilogram per cubic meter	kg/m ³	
moment of inertia	kilogram · meter ²	kg · m ²	
force	newton	N	
moment of force (torque)	newton-meter	N · m	
pressure and stress	pascal	Pa	(pascal = newton per square meter)
energy, work	joule	J	kilowatt-hour (kW · h)
power	watt	W	
impact strength	joule	J	
section modulus	meter ³	m ³	
moment of section (second moment of area)	meter ⁴	m ⁴	
fracture toughness	Pa · √m		
Heat			
temperature — thermodynamic [Note (2)]	kelvin	K	degree Celsius (°C)
temperature — other than thermodynamic	degree Celsius	°C	kelvin (K)
linear expansion coefficient	meter per meter-kelvin	K ⁻¹	°C ⁻¹
quantity of heat	joule	J	
heat flow rate	watt	W	
thermal conductivity	watt per meter-kelvin	W/(m · K)	W/(m · °C)
thermal diffusivity	square meter per second	m ² /s	
specific heat capacity	joule per kilogram-kelvin	J/(kg · K)	J/(kg · °C)
Electricity and Magnetism			
electric current	ampere	A	
electric potential	volt	V	
current density	ampere per meter ²	A/m ²	
magnetic field strength	ampere per meter	A/m	

NOTES:

- (1) Conversion factors between SI units and U.S. customary are given in SI-1, "ASME Orientation and Guide for Use of SI (Metric) Units," and ASTM E 380.
- (2) Preferred use for temperature and temperature interval is degrees Celsius (°C), except for thermodynamic and cryogenic work where kelvins may be more suitable. For temperature interval, 1 K = 1°C exactly.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

COMMONLY USED CONVERSION FACTORS
(For Others See ASTM E 380) [See Note (1)]

Quantity	To Convert From	To	Multiply by [Note (2)]	
plane angle	degree	rad	1.745 329	E-02
length	in	m	2.54*	E-02
	ft	m	3.048*	E-01
	yd	m	9.144*	E-01
area	in ²	m ²	6.451 6*	E-04
	ft ²	m ²	9.290 304*	E-02
	yd ²	m ²	8.361 274	E-01
volume	in ³	m ³	1.638 706	E-05
	ft ³	m ³	2.831 685	E-02
	US gallon	m ³	3.785 412	E-03
	Imperial gallon	m ³	4.546 09	E-03
	liter	m ³	1.0*	E-03
mass	lbm	kg	4.535 924	E-01
	ton (metric) (mass)	kg	1.000 00*	E+03
	ton (short 2000 lbm)	kg	9.071 847	E+02
force	kgf	N	9.806 65*	E+00
	lbf	N	4.448 222	E+00
bending, torque	kgf · m	N · m	9.806 65*	E+00
	lbf · in	N · m	1.129 848	E-01
	lbf · ft	N · m	1.355 818	E+00
pressure, stress	kgf/m ²	Pa	9.806 65*	E+00
	lbf/ft ²	Pa	4.788 026	E+01
	lbf/in ² (psi)	Pa	6.894 757	E+03
	kips/in ²	Pa	6.894 757	E+06
	bar	Pa	1.0*	E+05
energy, work	Btu (IT) [Note (3)]	J	1.055 056	E+03
	ft · lbf	J	1.355 818	E+00
power	hp (550 ft · lbf/s)	W	7.456 999	E+02
fracture toughness	ksi $\sqrt{\text{in}}$	Pa · $\sqrt{\text{m}}$	1.098 843	E+06
temperature	°C	K	$t_K = t_C + 273.15$	
	°F	K	$t_K = (t_F + 459.67)/1.8$	
	°F	°C	$t_C = (t_F - 32)/1.8$	
temperature interval	°C	K	1.0*	E+00
	°F	K or °C	5.555 555	E-01

NOTES:

- (1) Care should be taken when converting formulas or equations that contain constant terms or factors. The value of these terms must be understood and may also require conversion.
- (2)(a) Relationships that are exact in terms of the base units are followed by a single asterisk.
- (b) The factors are written as a number greater than 1 and less than 10 with 6 or less decimal places. The number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example: 3.523 907 E-02 is $3.523\ 907 \times 10^{-2}$ or 0.035 239 07.
- (3) International Table

COMMONLY USED CONVERSION FACTORS

July 1, 1998
American Society Of Mechanical Engineers
SEC III D1 NH A98
1998 ADDENDA SUMMARY OF CHANGES

Page XXV

No revisions contained in this Edition.

NOTE:

Volume 42 of the Interpretations to Section III, Divisions 1 and 2, of the ASME Boiler and Pressure Vessel Code follows the last page of the Edition to Subsection NCA.

July 1, 1998
American Society Of Mechanical Engineers
SEC III D1 NH INTRO
Introduction

**1998 ASME
BOILER &
PRESSURE VESSEL CODE
AN INTERNATIONAL CODE**

III

**Division 1 -
Subsection NH**

**Class 1
Components
in Elevated
Temperature
Service**

**RULES FOR
CONSTRUCTION
OF NUCLEAR
POWER PLANT
COMPONENTS**

[ASME logo] The American Society of
Mechanical Engineers

**IMPORTANT INFORMATION ON THE 1998 BOILER AND PRESSURE VESSEL CODE
ADDENDA DISTRIBUTION SCHEDULE**

There is a change in the way the Addenda to the 1998 Edition of the ASME Boiler and Pressure Vessel Code are distributed. The 1998 Edition, published July 1, 1998, incorporates the 1998 Addenda revisions, additions, or deletions. There will be no separate 1998 Addenda issued in a replacement page format. Two additional Addenda to the 1998 Edition, in the form of

replacement pages, will be issued on July 1, 1999 and July 1, 2000.

The Summary of Changes published with the 1998 Edition lists and describes the revisions that are part of the 1998 Addenda. These changes are identified with a margin note, **98**, denoting the affected area.

The Addenda for 1999 and 2000 will also have a Summary of Changes and identifiers printed on the replacement pages. The revisions, additions, or deletions will be incorporated directly into the affected pages. It is advisable to retain the title sheets and all replaced pages for reference.

The effective dates for Code Editions and Addenda are described in the Foreword.

ASME BOILER AND PRESSURE VESSEL CODE
AN INTERNATIONAL CODE

RULES FOR
CONSTRUCTION OF
NUCLEAR POWER
PLANT COMPONENTS

III

Division 1 -

Subsection NH

Class 1

Components
in Elevated
Temperature
Service

1998 Edition

July 1, 1998

ASME BOILER AND
PRESSURE VESSEL
COMMITTEE
SUBCOMMITTEE ON
NUCLEAR POWER

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
NEW YORK, NEW YORK

Date of Issue - July 1, 1998

(Includes all Addenda dated December 1997 and earlier)

This code or standard was developed under procedures accredited as meeting the criteria for American National Standards. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment which provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not "approve," "rate," or "endorse" any item, construction, proprietary device, or activity.

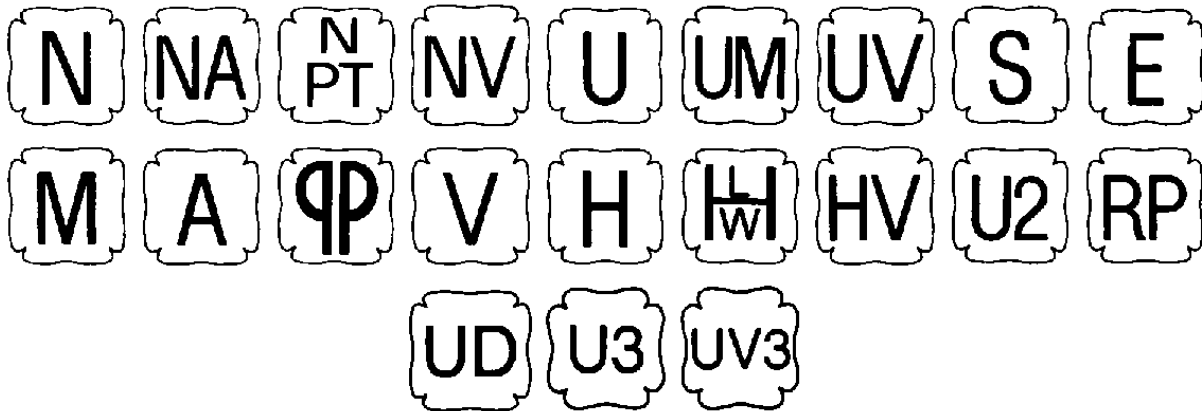
ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of any applicable Letters Patent, nor assume any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations issued in accordance with governing ASME procedures and policies which preclude the issuance of interpretations by individual volunteers.

The footnotes in this document are part of this American National Standard.

[ASME logo] ASME collective membership mark



LOGOS

The above ASME symbols are registered in the U.S. Patent Office.

"ASME" is the trademark of the American Society of Mechanical Engineers.

No part of this document may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Library of Congress Catalog Card Number: 56-3934

Printed in the United States of America

Adopted by the Council of the American Society of Mechanical Engineers, 1914.

Revised 1940, 1941, 1943, 1946, 1949, 1952, 1953, 1956, 1959, 1962, 1965, 1968, 1971, 1974, 1977, 1980, 1983, 1986, 1989, 1992, 1995, 1998

The American Society of Mechanical Engineers

Three Park Avenue, New York, NY 10016-5990

1998 ASME

BOILER AND PRESSURE VESSEL CODE

SECTIONS

I Rules for Construction of Power Boilers

II Materials

Part A - Ferrous Material Specifications

Part B - Nonferrous Material Specifications

Part C - Specifications for Welding Rods, Electrodes, and Filler Metals

Part D - Properties

III Subsection NCA - General Requirements for Division 1 and Division 2

III Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

III Division 2 - Code for Concrete Reactor Vessels and Containments

III Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

IV Rules for Construction of Heating Boilers

V Nondestructive Examination

VI Recommended Rules for the Care and Operation of Heating Boilers

VII Recommended Guidelines for the Care of Power Boilers

VIII Rules for Construction of Pressure Vessels

Division 1

Division 2 - Alternative Rules

Division 3 - Alternative Rules for Construction of High Pressure Vessels

IX Welding and Brazing Qualifications

X Fiber-Reinforced Plastic Pressure Vessels

XI Rules for Inservice Inspection of Nuclear Power Plant Components

ADDENDA

Colored-sheet Addenda, which include additions and revisions to individual Sections of the Code, are published annually and will be sent automatically to purchasers of the applicable Sections up to the publication of the 2001 Code. The 1998 Code is available only in the loose-leaf format; accordingly, the Addenda will be issued in the loose-leaf, replacement-page format.

INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code. The Interpretations for each individual Section will be published separately and will be included as part of the update service to that Section. They will be issued semiannually (July and December) up to the publication of the 2001 Code. Interpretations of Section III, Divisions 1 and 2, will be included with the update service to Subsection NCA.

CODE CASES

The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 1998 Code Cases book: (1) Boilers and Pressure Vessels and (2) Nuclear Components. Supplements will be sent automatically to the purchasers of the Code Cases books up to the publication of the 2001 Code.

Page v

FOREWORD

The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety governing the design, fabrication, and inspection during construction of boilers and pressure vessels, and to interpret these rules when questions arise regarding their intent. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property and to provide a margin for deterioration in service so as to give a reasonably long, safe period of usefulness. Advancements in design and material and the evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction,¹ and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

¹ Construction, as used in this Foreword, in all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are responsible for the application of these programs to their design.

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practice as determined by the engineer.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Boiler and Pressure Vessel Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Mandatory Appendix covering preparation of technical inquiries). Proposed revisions to the Code resulting from inquiries will be presented to the Main Committee for appropriate action. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by ASME.

to invite comments from all interested persons. After the allotted time for public review and final approval by ASME, revisions are published annually in Addenda to the Code.

Code Cases may be used in the construction of components to be stamped with the ASME Code symbol beginning with the date of their approval by ASME.

Code Editions may be used on or after the date of issue shown in the Edition. After Code revisions are approved by ASME, they may be used beginning with the date of issue shown on the Addenda. Revisions to material specifications are originated by the American Society for Testing and Materials (ASTM) and other recognized national or international organizations, and are usually adopted by ASME. However, those revisions may or may not have any effect on the suitability of material, produced to earlier editions of specifications, for use in ASME construction. ASME material specifications approved for use in each construction Code are listed in the Appendices of Section II, Parts A and B. These Appendices list, for each specification, the latest edition adopted by ASME, and earlier and later editions considered by ASME to be identical for ASME construction.

Owners of nuclear power plants are cautioned that Code Editions, Addenda, and Cases to be used in construction shall be acceptable to the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

Each state and municipality in the United States and each province in Canada that adopts or accepts one or more Sections of the Boiler and Pressure Vessel Code is invited to appoint a representative to act on the Conference Committee to the Boiler and Pressure Vessel Committee. Since the members of the Conference Committee are in active contact with the administration and enforcement of the rules, the requirements for inspection in this Code correspond with those in effect in their respective jurisdictions. The required qualifications for an Authorized Inspector under these rules may be obtained from the administrative authority of any state, municipality, or province which has adopted these rules.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, method of fabrication, inspection, and safety devices. Permission may be granted to regulatory bodies and organizations publishing safety standards to use a complete Section of the Code by reference. If usage of a Section, such as Section IX, involves exceptions, omissions, or changes in provisions, the intent of the Code might not be attained.

Where a state or other regulatory body, in the printing of any Section of the Boiler and Pressure Vessel Code, makes additions or omissions, it is recommended that such changes be clearly indicated.

The National Board of Boiler and Pressure Vessel Inspectors is composed of chief inspectors of states and municipalities in the United States and of provinces in Canada that have adopted the Boiler and Pressure Vessel Code. This Board, since its organization in 1919, has functioned to uniformly administer and enforce the rules of the Boiler and Pressure Vessel Code. The cooperation of that organization with the Boiler and Pressure Vessel Committee has been extremely helpful.

The Code Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The Scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Code for vessels or components not considered to be within its Scope or may establish additions or deletions in that Scope. Accordingly, inquiries regarding such laws or regulations are to be directed to the issuing enforcement or regulatory body.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the ASME Boiler and Pressure Vessel Committee. ASME is to be notified should questions arise concerning improper use of an ASME Code symbol.

The specifications for materials given in Section II are identical with or similar to those of specifications published by ASTM, AWS, and other recognized national or international organizations. When reference is made in an ASME material specification to a non-ASME specification for which a companion ASME specification exists, the reference shall be

interpreted as applying to the ASME material specification. Not all materials included in the material specifications in Section II have been adopted for use in this Section. Usage is limited to those materials and grades listed in at least one of the tables of Section II, Part D, Subpart 1, identified as applicable to this Section. All materials allowed by this Section and used for construction within the scope of these rules shall be furnished in accordance with material specifications

Page ix

contained in Section II or referenced in Appendices A of Section II, Parts A and B except where otherwise provided in Code Cases or in this Section of the Code. Materials covered by these specifications are acceptable for use in items covered by the Code Sections only to the degree indicated in the applicable Section. Materials for Code use should preferably be ordered, produced, and documented on this basis. Material produced to an acceptable specification with requirements different from the requirements of the corresponding specification listed in Appendix A of Part A or Part B may also be used in accordance with the above, provided the material manufacturer or vessel manufacturer certifies with evidence acceptable to the Authorized Inspector that the corresponding ASME specification requirements of specifications listed in Appendix A of Part A or Part B have been met. Material produced to an acceptable material specification is not limited as to country of origin.

When required by context in this Section, the singular shall be interpreted as the plural, and vice-versa; and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

Publication of the SI (Metric) Edition of the ASME Boiler and Pressure Vessel Code was discontinued with the 1986 Edition. Effective October 1, 1986, the SI Edition was withdrawn as an ASME Boiler and Pressure Vessel Code document.

Page xi

STATEMENT OF POLICY ON THE USE OF CODE SYMBOLS AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use Code Symbols for marking items or constructions which have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the symbols, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications which might so indicate. An organization holding a Code Symbol and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code."

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified items will carry the symbol. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

The ASME logo, which is the cloverleaf with the letters ASME within, shall not be used by any organization other than ASME.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Code Symbol Stamp described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the various Code Symbols shall not be used on any item which is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME which tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

Page xiii

PERSONNEL ASME Boiler and Pressure Vessel Committee Subcommittees, Subgroups, and Working Groups

As of December 31, 1997

MAIN COMMITTEE

D. A. Canonico, *Chair*
G. G. Karcher, *Vice Chair*
J. S. Brzuszkiewicz, *Secretary*
R. W. Barnes
F. P. Barton
D. L. Berger
M. D. Bernstein
M. N. Bressler
W. J. Carter
T. M. Cullen
J. R. Farr
R. E. Feigel
J. G. Feldstein
M. Gold
O. F. Hedden
A. J. Justin
D. F. Landers
W. M. Lundy
J. R. MacKay
T. J. Mawson
T. G. McCarty
G. C. Millman
R. A. Moen
C. C. Neely
C. J. Pieper
R. F. Reedy
B. W. Roberts
F. J. Schaaf, Jr.
A. Selz
K. K. Tam
D. E. Tanner

EXECUTIVE COMMITTEE (MAIN COMMITTEE)

G. G. Karcher, *Chair*
D. A. Canonico, *Vice Chair*

D. A. Canonico, *Vice Chair*
J. S. Brzuszkiewicz, *Secretary*
F. P. Barton
J. R. Farr
J. G. Feldstein
M. Gold
O. F. Hedden
A. J. Justin
J. R. MacKay
T. G. McCarty
T. P. Pastor
T. E. Quaka
R. F. Reedy
A. J. Spencer

HONORARY MEMBERS (MAIN COMMITTEE)

R. D. Bonner
R. J. Bosnak
H. M. Canavan
L. J. Chockie
J. S. Clarke
W. E. Cooper
W. D. Doty
R. C. Griffin
E. J. Hemzy
E. C. Kistner, Jr.
J. E. Lattan
J. LeCoff
F. N. Moschini
C. E. Rawlins
W. E. Somers
L. P. Zick, Jr.

HONORS AND AWARDS COMMITTEE

J. R. MacKay, *Chair*
A. J. Spencer, *Vice Chair*
F. R. Lyons, *Secretary*
F. P. Barton
W. J. Carter
J. G. Feldstein
M. Gold
F. E. Gregor
E. C. Kistner, Jr.
T. P. Pastor
R. F. Reedy

MARINE CONFERENCE GROUP

J. Tiratto, *Chair*
C. F. Banks

L. W. Douthwaite
J. L. Jones
G. F. Wright

CONFERENCE COMMITTEE

D. E. Tanner - Tennessee (*Chair*)
R. D. Reetz - North Dakota (*Vice Chair*)
A. J. Justin - National Board of Boiler and Pressure Vessel Inspectors (*Secretary*)
R. J. Aben, Jr. - Michigan
J. S. Aclaro - Los Angeles, California
E. A. Anderson - Chicago, Illinois
J. Anderson - South Dakota
R. Barkdoll - Washington
F. P. Barton - Virginia
C. Castle - Nova Scotia, Canada
R. R. Cate - Louisiana
L. Chase - Northwest Territories, Canada
R. A. Coomes - Kentucky
J. Corcoran - Connecticut
M. H. Diehl, Jr. - Maryland
D. A. Douin - Illinois
D. Eastman - Newfoundland and Labrador, Canada
G. L. Ebeyer - New Orleans, Louisiana
F. Ellis - New Hampshire
E. Everett - Georgia
P. C. Hackford - Utah
D. Hanrath - North Carolina
J. B. Harlan - Delaware
K. Hynes - Prince Edward Island, Canada
D. T. Jagger - Ohio
D. J. Jenkins - Kansas
M. Kotb - Quebec, Canada
J. P. Larson - Minnesota
K. T. Lau - Alberta, Canada
J. Lemire - California
G. A. Lundberg - Florida
W. C. Lundine - Oregon
M. A. Malek - Maine
I. W. Mault - Manitoba, Canada
H. T. McEwen - Mississippi
A. W. Meiring - Indiana
R. Mile - Ontario, Canada
T. J. Monroe - Oklahoma
Y. Nagpaul - Hawaii
J. D. Payton - Pennsylvania
D. K. Peetz - Missouri
D. C. Price - Yukon Territory, Canada

R. S. Pucek - Wisconsin
T. E. Rennie - Arizona
L. Roussinos - British Columbia, Canada
M. Shuff - West Virginia
R. Snyder - New Jersey
N. Surtees - Saskatchewan, Canada
M. J. Verhagen - Wisconsin
R. B. West - Iowa
M. J. Wheel - Vermont
K. A. White - Nevada
R. K. White - New York
T. F. Wickham - Rhode Island
C. S. Withers - Colorado

SUBCOMMITTEE ON POWER BOILERS (SC I)

J. R. MacKay, *Chair*
M. D. Bernstein, *Vice Chair*
P. D. Stumpf, *Secretary*
D. L. Berger
E. Everett
D. N. French
F. R. Gerety
J. Hainsworth
T. E. Hansen
J. S. Hunter
W. L. Lowry
T. C. McGough
P. A. Molvie
D. K. Parrish
J. T. Pillow
R. G. Presnak
B. W. Roberts
R. D. Schueler, Jr.
R. V. Wielgoszinski
R. L. Williams

Page xiv

Subgroup on Design (SC I)

M. D. Bernstein, *Chair*
R. D. Schueler, Jr., *Vice Chair*
P. A. Molvie, *Secretary*
M. A. Farrugia
J. D. Fishburn
C. F. Jeerings
K. C. Morrison
A. Nassif
N. Surtees

R. V. Wielgoszinski

Subgroup on Fabrication and Examination (SC I)

D. L. Berger, *Chair*

R. E. McLaughlin, *Secretary*

R. W. Boyce

D. N. French

J. Hainsworth

T. E. Hansen

M. H. Iken

J. M. Lyons

J. T. Pillow

M. E. Reese

R. D. Schueler, Jr.

R. F. Slack, Sr.

R. V. Wielgoszinski

Subgroup on General Requirements (SC I)

T. C. McGough, *Chair*

M. D. Bernstein, *Vice Chair*

W. L. Lowry, *Secretary*

D. L. Berger

E. Everett

F. R. Gerety

J. Hainsworth

C. F. Jeerings

J. M. Lyons

R. E. McLaughlin

D. K. Parrish

J. T. Pillow

W. E. Somers

R. L. Williams

Subgroup on Materials (SC I)

B. W. Roberts, *Chair*

C. E. Spaeder, Jr., *Chair*

J. S. Hunter, *Secretary*

T. M. Cullen

D. N. French

J. F. Henry

J. P. Libbrecht

F. Masuyama

J. M. Tanzosh

Subgroup on Piping (SC I)

T. E. Hansen, *Chair*

D. L. Berger

M. D. Bernstein

P. D. Edwards

W. L. Lowry
T. C. McGough
R. G. Presnak
E. Whittle
P. L. Ziegler

SUBCOMMITTEE ON MATERIALS (SC II)

M. Gold, *Chair*
T. M. Cullen, *Vice Chair*
F. R. Lyons, *Secretary*
A. P. Ahrendt
M. N. Bressler
A. Cohen
R. Dirscherl
W. D. Doty
W. D. Edsall
D. Gandy
M. H. Gilkey
J. J. Heger
J. F. Henry
G. C. Hsu
F. Masuyama
E. Michalopoulos
R. A. Moen
R. K. Nanstad
E. G. Nisbett
J. T. Parsons
D. W. Rahoi
B. W. Roberts
E. Shapiro
C. E. Spaeder, Jr.
R. W. Swindeman
J. M. Tanzosh
B. E. Thurgood
A. W. Zeuthen

Subgroup on External Pressure (SC II)

R. W. Mikitka, *Chair*
D. J. Green
D. S. Griffin
E. Michalopoulos
B. R. Morelock
D. Nadel
C. E. Spaeder, Jr.
C. H. Sturgeon

Subgroup on Ferrous Specifications (SC II)

E. G. Nisbett, *Chair*

B. M. Dingman
W. D. Edsall
T. Graham
W. N. Holliday
E. A. Jonas
D. C. Krouse
J. F. Longenecker
W. C. Mack
A. S. Melilli
J. T. Parsons
E. J. Rozic, Jr.
E. Upitis
A. W. Zeuthen
R. H. Zong

Subgroup on International Material Specifications (SC II)

J. T. Parsons, *Chair*
D. C. Agarwal
J. Cameron
R. Dirscherl
W. D. Doty
D. M. Fryer
M. Gold
M. H. Iken
W. M. Lundy
H. Masahisa
T. F. Miskell
F. Osweiller
A. P. Povilonis
R. D. Schueler, Jr.
R. R. Seeley
E. A. Steen
E. Upitis
E. O. Woolridge

Subgroup on Nonferrous Alloys (SC II)

D. W. Rahoi, *Chair*
D. C. Agarwal, *Secretary*
W. R. Apblett
L. G. Coffee
A. Cohen
R. Dirscherl
M. H. Gilkey
G. C. Hsu
M. Katcher
E. Shapiro
L. E. Shoemaker
R. C. Sutherlin

Subgroup on Strength, Ferrous Alloys (SC II)

B. W. Roberts, *Chair*
J. M. Tanzosh, *Secretary*
A. P. Ahrendt
W. R. Apblett
T. M. Cullen
M. Gold
J. J. Heger
C. L. Hoffmann
A. Iseda
F. Masuyama
R. A. Moen
D. W. Raho
C. E. Spaeder, Jr.
R. W. Swindeman
B. E. Thurgood

Subgroup on Strength of Weldments (SC II & SC IX)

C. E. Spaeder, Jr., *Chair*
W. D. Doty
D. W. Raho
B. W. Roberts
C. Robino
W. J. Sperko
J. M. Tanzosh
B. E. Thurgood

Subgroup on Toughness (SC II)

J. M. Barsom
D. A. Hansen
A. Selz
R. S. Vecchio
S. Yukawa
R. Zawierucha

Page xv

SUBCOMMITTEE ON NUCLEAR POWER (SC III)

C. J. Pieper, *Chair*
R. M. Jessee, *Vice Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
Y. Asada
R. W. Barnes
J. N. Baysden
W. H. Borter
E. B. Branch
M. N. Bressler
F. C. Cherny

G. D. Cooper
R. P. Deubler
W. D. Doty
F. R. Drahos
K. Ennis
B. A. Erler
D. Hanrath
C. L. Hoffmann
K.-H. Hsu
D. F. Landers
W. C. LaRochelle
T. J. Mawson
W. N. McLean
R. A. Moen
D. B. Nickerson
R. F. Perrin
R. F. Reedy
M. W. Smith
J. D. Stevenson
R. E. Tome
K. R. Wichman

Subgroup on Containment Systems for Spent Fuel and High-Level Waste Transport Packagings (SC III)

J. D. Stevenson, *Chair*
H. H. Chung
R. R. Doggart
E. L. Farrow
K. Goldmann
R. H. Jones
W. H. Lake
R. W. Lambert
H. W. Lee
P. McConnell
R. E. Nickell
D. J. Nolan
D. T. Raske
T. Saegusa
R. H. Smith
K. B. Sorenson
P. Turula
N. Urabe
C. R. Witt
S. Yukawa

Subgroup on Design (SC III)

R. W. Barnes, *Chair*
E. B. Branch, *Vice Chair*

R. S. Hill III, *Secretary*

Y. Asada

M. N. Bressler

C. W. Bruny

J. R. Cole

G. D. Cooper

R. P. Deubler

N. W. Edwards

R. E. Gimple

D. Hanrath

R. W. Haupt

T. Iida

B. Jarman

D. F. Landers

W. N. McLean

D. B. Nickerson

E. C. Rodabaugh

J. R. Santangelo

G. C. Slagis

J. D. Stevenson

J. H. Wawrzeniak

K. R. Wichman

R. Wray

Working Group on Administration (SG-D) (SC III)

E. B. Branch, *Chair*

R. W. Barnes, *Vice Chair*

R. S. Hill III, *Secretary*

C. W. Bruny

G. D. Cooper

R. P. Deubler

J. T. Land

D. F. Landers

W. N. McLean

D. B. Nickerson

J. R. Santangelo

R. Wray

Working Group on Core Support Structures (SG-D) (SC III)

J. T. Land, *Chair*

R. H. Hansen

K. B. Larsen

J. F. Mullooly

B. L. Silverblatt

Working Group on Dynamic and Extreme Load Conditions (SG-D) (SC III)

R. Wray, *Chair*

A. E. Meligi, *Secretary*

P. L. Anderson

P. L. Anderson
M. K. Au-Yang
R. D. Blevins
G. J. Bohm
D. L. Caldwell
P.-Y. Chen
A. Hadjian
M. Hartzman
W. S. LaPay
H. Lockert
P. R. Olson
R. F. Perry
J. Wallach

Working Group on Piping (SG-D) (SC III)

D. F. Landers, *Chair*
R. S. Hill III, *Vice Chair*
P. Hirschberg, *Secretary*
T. M. Adams
G. A. Antaki
J. R. Cole
A. B. Glickstein
R. W. Haupt
J. C. Hennart
R. D. Hookway
R. B. Jenkins
K. A. Manoly
J. C. Minichiello
S. E. Moore
A. N. Nguyen
D. B. Nickerson
O. O. Oyamada
R. D. Patel
E. C. Rodabaugh
J. R. Santangelo
M. S. Sills
G. C. Slagis
E. A. Wais

Working Group on Pumps (SG-D) (SC III)

D. B. Nickerson, *Chair*
H. L. Brammer
P. Burchett
R. E. Cornman, Jr.
A. A. Fraser
M. Higuchi
G. R. Jones
J. W. Leavitt

J. E. Livingston
R. A. Schussler
H. Tafarrodi
G. K. Vaghasia

Working Group on Supports (SG-D) (SC III)

R. P. Deubler, *Chair*
R. M. Dulin, Jr., *Secretary*
U. S. Bandyopadhyay
F. J. Birch
M. N. Bressler
J. R. Cole
J. C. Finneran, Jr.
R. W. Haupt
J. C. Hennart
A. S. Laurenson
A. Lee
R. J. Masterson
A. E. Meligi
A. N. Nguyen
J. R. Stinson

Working Group on Valves (SG-D) (SC III)

W. N. McLean, *Chair*
E. A. Bake
R. R. Brodin
W. G. Knecht
R. Koester
J. J. McGavin
S. N. Shields
H. R. Sonderegger
J. C. Tsacoyeanes
R. G. Visalli
J. R. Zahorsky

Working Group on Vessels (SG-D) (SC III)

C. W. Bruny, *Chair*
T. K. Burr, Sr.
G. D. Cooper
G. A. Deaver
N. W. Edwards
D. Hanrath
W. J. Heilker
B. Jarman
T. M. Khan
O. Maekawa
K. A. Manoly
A. Merend

G. K. Miller
W. Z. Novak
E. Pelling
H. S. Thornton

Page xvi

Special Working Group on Environmental Effects (SG-D) (SC III)

R. S. Hill III, *Chair*
Y. Asada
W. J. Heilker
C. L. Hoffmann
R. A. Moen
W. Z. Novak
S. Yukawa

Special Working Group on Seismic Piping Rules (SG-D) (SC III)

E. B. Branch, *Chair*
T. M. Adams
G. A. Antaki
R. D. Hookway
J. C. Minichiello
M. S. Sills
E. A. Wais

Subgroup on General Requirements (SC III & SC 3C)

W. C. LaRochelle, *Chair*
K. Ennis, *Secretary*
A. Appleton
J. R. Barbee
J. N. Baysden
L. M. Beason
B. H. Berg
R. E. Kelley
G. S. Korin
A. S. Laurenson
C. Lizotte
M. J. Meyer
M. R. Minick
L. C. Oakes
R. F. Perrin
U. Potapovs
B. B. Scott
D. E. Tanner
D. V. Walshe

Subgroup on Materials, Fabrication, and Examination (SC III)

C. L. Hoffmann, *Chair*
G. P. Milley, *Secretary*
C. W. Allison

D. Doyle
F. R. Drahos
G. M. Foster
G. B. Georgiev
J. E. Harris
R. W. Jackson
R. M. Jessee
C. C. Kim
R. A. Moen
C. J. Pieper
R. R. Seeley
N. M. Simpson
R. C. Soin
W. J. Sperko
K. B. Stuckey
S. Yukawa

Subgroup on Pressure Relief (SC III)

F. C. Cherny, *Chair*
S. F. Harrison, Jr.
E. M. Petrosky
M. W. Smith
A. L. Szeglin
B. S. York
J. R. Zahorsky

Special Working Group on Editing and Review (SC III)

R. F. Reedy, *Chair*
W. H. Borter
M. N. Bressler
R. P. Deubler
B. A. Erler
W. C. LaRochelle
M. W. Smith
J. D. Stevenson
E. O. Woolridge

JOINT ACI-ASME COMMITTEE ON CONCRETE COMPONENTS FOR NUCLEAR SERVICE (SC 3C)

B. A. Erler, *Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
R. M. Attar
A. C. Eberhardt
J. Gutierrez
D. J. Haavik
M. F. Hessheimer
T. E. Johnson
G. R. Murphy

S. F. Putman
B. B. Scott
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Design (SC 3C)

D. G. Adams
A. C. Eberhardt
T. E. Johnson
S. F. Putman
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Materials, Construction, and Examination (SC 3C)

D. J. Haavik, *Chair*
J. F. Artuso
R. M. Attar
B. A. Erler
J. Gutierrez

SUBCOMMITTEE ON HEATING BOILERS (SC IV)

F. P. Barton, *Chair*
P. A. Molvie, *Vice Chair*
B. P. Feder, *Secretary*
R. B. Duggan
W. L. Haag, Jr.
W. M. Hiddleston
J. D. Hoh
K. M. McTague
R. I. Mullican
E. A. Nordstrom
J. L. Seigle
D. E. Tanner
S. V. Voorhees
R. H. Weigel
R. V. Wielgoszinski
J. I. Woodworth
T. L. Bedeaux, *Alternate*

Subgroup on Care and Operation of Heating Boilers (SC IV)

J. I. Woodworth, *Chair*
B. P. Feder, *Secretary*
K. J. Hoey
J. D. Hoh
F. M. Lucas
K. M. McTague
P. A. Molvie

R. I. Mullican
R. H. Weigel
T. F. Wickham
T. L. Bedeaux, Alternate

Subgroup on Cast Iron Boilers (SC IV)

K. M. McTague, *Chair*
R. B. Duggan
R. H. Weigel
T. F. Wickham
J. I. Woodworth
T. L. Bedeaux, Alternate

Subgroup on Water Heaters (SC IV)

W. L. Haag, Jr., *Chair*
T. D. Gantt
W. M. Hiddleston
F. M. Lucas
K. M. McTague
R. I. Mullican
D. Smith
D. E. Tanner
M. A. Taylor

Subgroup on Welded Boilers (SC IV)

P. A. Molvie, *Chair*
T. L. Bedeaux
D. H. Mapes
E. A. Nordstrom
J. L. Seigle
R. F. Slack, Sr.
R. P. Sullivan
D. E. Tanner
R. V. Wielgoszinski

SUBCOMMITTEE ON NONDESTRUCTIVE EXAMINATION (SC V)

T. G. McCarty, *Chair*
J. E. Batey, *Vice Chair*
F. S. Fitzgerald, *Secretary*
A. S. Birks
B. H. Clark, Jr.
W. T. Clayton
R. A. Coomes
N. Y. Faransso
H. C. Graber
O. F. Hedden
G. W. Hembree
F. B. Kovacs
J. F. Manning

Subgroup on General Requirements/Personnel Qualifications and Inquiries (SC V)

R D. McGuire, *Chair*

J. E. Batey

W. T. Clayton

N. Y. Faransso

H. C. Graber

G. W. Hembree

J. R. MacKay

J. P. Swezy

Subgroup on Surface Examination Methods (SC V)

H. C. Graber, *Chair*

S. J. Akrin

T. Alexander

A. S. Birks

B. H. Clark

R. A. Coomes

G. W. Hembree

Subgroup on Volumetric Methods (SC V)

J. E. Batey, *Chair*

S. J. Akrin

W. T. Clayton

N. Y. Faransso

H. C. Graber

G. W. Hembree

B. Kellerhall

E. K. Kietzman

F. B. Kovacs

R. W. Kruzic

J. F. Manning

W. C. McGaughey

J. R. Mitchell

Working Group on Acoustic Emissions (SG-VM) (SC V)

B. H. Clark, Jr.

P. M. Horrigan

J. F. Manning

J. R. Mitchell

Working Group on Radiography (SG-VM) (SC V)

G. W. Hembree, *Chair*

S. J. Akrin

T. Alexander

J. E. Batey

N. Y. Faransso

H. C. Graber
F. B. Kovacs

Working Group on Ultrasonics (SG-VM) (SC V)

W. T. Clayton, *Chair*
O. F. Hedden
B. Kellerhall
E. K. Kietzman
J. F. Manning
W. C. McGaughey
R. Paillaman
F. J. Sattler
M. L. Shakinovsky

SUBCOMMITTEE ON PRESSURE VESSELS (SC VIII)

T. P. Pastor, *Chair*
K. Mokhtarian, *Vice Chair*
A. J. Roby, *Secretary*
A. P. Ahrendt
V. Bogosian
S. M. Caldwell
W. J. Carter
S. C. Cyr
R. Dirscherl
R. M. Elliott
J. R. Farr
R. E. Feigel
J. G. Feldstein
G. L. Hollinger
M. J. Houle
W. S. Jacobs
G. G. Karcher
G. B. Komora
K. T. Lau
R. W. Mikitka
U. R. Miller
C. C. Neely
K. J. Schneider
A. Selz
J. R. Sims, Jr.
A. J. Spencer
E. A. Steen
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Design (SC VIII)

U. R. Miller, *Chair*
R. E. Knoblock, *Secretary*

M. R. Bauman
M. R. Breach
S. M. Caldwell
N. W. Edwards
J. R. Farr
J. A. Hayward
G. L. Hollinger
W. S. Jacobs
G. G. Karcher
G. B. Komora
R. W. Mikitka
K. Mokhtarian
T. P. Pastor
M. D. Rana
A. Selz
S. C. Shah
J. W. Stokes
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Fabrication and Inspection (SC VIII)

E. A. Steen, *Chair*
K. Mokhtarian, *Vice Chair*
W. J. Bees
R. W. Boyce
S. C. Cyr
R. E. Feigel
H. E. Gordon
M. J. Houle
W. S. Jacobs
R. A. Johnson
A. S. Lester III
F. C. Ouyang
M. J. Rice
W. P. Webb

Subgroup on General Requirements (SC VIII)

R. M. Elliott, *Chair*
A. P. Ahrendt
V. Bogosian
W. J. Carter
W. P. Crow
J. P. Glaspie
C. R. Good
D. B. Kadakia
J. C. Keenan
W. E. Laveck, Jr.

A. S. Mann
C. C. Neely
A. S. Olivares
K. J. Schneider
A. J. Spencer

Subgroup on Materials (SC VIII)

R. Dirscherl, *Chair*
D. C. Agarwal
A. P. Ahrendt
J. Cameron
W. D. Doty
W. D. Edsall
M. Katcher
W. M. Lundy
E. E. Morgenegg
E. G. Nisbett
J. T. Parsons
D. W. Rahoi
K. K. Tam
B. K. Thakur

Special Working Group on Heat Transfer Equipment (SC VIII)

G. B. Komora, *Chair*
R. P. Zoldak, *Secretary*
C. F. Andreone
D. E. Bolt
S. M. Caldwell
T. K. Haldas
M. J. Holtz
W. G. Jandrasits
R. Mahadeen
U. R. Miller
F. Osweiller
J. E. Soehrens
A. I. Soler
W. A. Treff
S. Yokell

Page xviii

Special Working Group on High-Pressure Vessels (SC VIII)

J. R. Sims, Jr., *Chair*
P. A. Reddington, *Secretary*
L. P. Antalffy
J. E. Baxter
R. C. Biel
T. B. Boyd
D. J. Burns
P. N. Chaku

E. L. Danfelt
R. E. Feigel
D. M. Fryer
J. L. Heck, Jr.
A. H. Honza
V. T. Hwang
M. M. James
P. Jansson
J. A. Kapp
D. P. Kendall
A. K. Khare
S. C. Mordre
G. J. Mraz
E. H. Perez
L. M. Picqueur
E. D. Roll
W. L. Stewart
J. F. Sullivan
F. W. Tatar

Special Working Group on Toughness (SC VIII)

W. S. Jacobs, *Chair*
J. Cameron
W. D. Doty
D. A. Hansen
G. G. Karcher
G. B. Komora
K. Mokhtarian
J. L. Mooney
C. C. Neely
M. D. Rana
J. W. Stokes

SUBCOMMITTEE ON WELDING (SC IX)

J. G. Feldstein, *Chair*
W. J. Sperko, *Vice Chair*
J. Labrador, *Secretary*
R. Barkdoll
D. A. Bowers
M. L. Carpenter
W. D. Doty
P. D. Flenner
M. J. Houle
R. A. Johnson
W. M. Lundy
R. D. McGuire
J. J. Meyer

A. H. Miller
B. R. Newmark
P. P. Norris
S. D. Reynolds, Jr.
W. K. Scattergood
G. W. Spohn III
M. J. Stanko
J. M. Tanzosh
R. R. Young

Subgroup on Brazing (SC IX)

M. J. Houle, *Chair*
A. S. Artayet
M. L. Carpenter
C. F. Jeerings
A. H. Miller
C. Robino

Subgroup on General Requirements (SC IX)

B. R. Newmark, *Chair*
R. Barkdoll
P. R. Evans
P. C. Filean
R. M. Jessee
D. W. Mann
A. S. Olivares
C. E. Wainwright
R. A. Weiss
K. R. Willens

Subgroup on Materials (SC IX)

M. L. Carpenter, *Chair*
L. P. Connor
P. D. Flenner
R. M. Jessee
A. H. Miller
H. A. Sadler
C. E. Sainz
C. E. Spaeder, Jr.
W. J. Sperko
M. J. Stanko
R. R. Young

Subgroup on Performance Qualification (SC IX)

J. J. Meyer, *Chair*
V. A. Bell
D. A. Bowers
L. P. Connor
R. A. Coomes

P. D. Flenner
G. Herrmann
M. J. Houle
W. M. Lundy
R. D. McGuire
S. R. Nordman
P. P. Norris
W. K. Scattergood
G. W. Spohn III

Subgroup on Procedure Qualification (SC IX)

J. J. Meyer, *Chair*
R. K. Brown, Jr.
R. A. Johnson
A. H. Miller
P. P. Norris
A. S. Olivares
F. C. Ouyang
S. D. Reynolds, Jr.
M. J. Rice
W. K. Scattergood
W. J. Sperko
T. C. Wiesner

SUBCOMMITTEE ON FIBER-REINFORCED PLASTIC PRESSURE VESSELS (SC X)

P. J. Conlisk, *Chair*
D. Eisberg, *Vice Chair*
A. J. Roby, *Secretary*
K. M. Agrawal
F. L. Brown
J. L. Bustillos
T. W. Cowley
T. J. Fowler
S. V. Hoa
L. E. Hunt
J. C. Murphy
A. L. Newberry
D. J. Painter
J. A. Rolston
B. F. Shelley
P. R. Wilt

SUBCOMMITTEE ON NUCLEAR INSERVICE INSPECTION (SC XI)

O. F. Hedden, *Chair*
T. J. Mawson, *Vice Chair*
G. L. Fechter, *Secretary*
C. W. Allison
W. H. Bamford, Jr.

R. L. Beverly
J. M. Bloom
R. W. Boyce
C. D. Cowfer
D. D. Davis
R. L. Dyle
T. N. Epps III
R. E. Gimple
F. E. Gregor
L. B. Gross
K. Iida
C. A. Ireland
R. D. Kerr
D. F. Landers
T. F. Lentz
J. T. Lindberg
G. C. Millman
C. R. Osman
P. C. Riccardella
L. Sage
F. J. Schaaf, Jr.
J. E. Staffiera
R. P. Sullivan
R. W. Swayne
R. J. Tamminga
J. C. Tobin
R. A. Yonekawa

Honorary Members (SC XI)

S. H. Bush
L. J. Chockie
J. P. Houstrup
L. R. Katz
R. R. MacCary

Page xix

Subgroup on Evaluation Standards (SC XI)

W. H. Bamford, Jr., *Chair*
M. Kupinski, *Secretary*
J. M. Bloom
R. C. Cipolla
R. M. Gamble
T. J. Griesbach
P. J. Hijeck
K. Iida
Y. Imamura
J. G. Merkle
S. Ranganath

P. C. Riccardella
D. A. Scarth
W. L. Server
C. A. Tomes
W. A. Van Der Sluys
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa

Working Group on Flaw Evaluation (SG-ES) (SC XI)

R. C. Cipolla, *Chair*
W. H. Bamford, Jr.
M. Basol
J. M. Bloom
E. Friedman
T. J. Griesbach
F. D. Hayes
D. N. Hopkins
K. Iida
Y. Imamura
M. Kupinski
H. S. Mehta
J. G. Merkle
J. S. Panesar
R. K. Qashu
S. Ranganath
D. A. Scarth
T. S. Schurman
W. L. Server
F. A. Simonen
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Working Group on Operating Plant Criteria (SG-ES) (SC XI)

T. J. Griesbach, *Chair*
W. H. Bamford, Jr.
H. Behnke
B. A. Bishop
W. F. Brady
E. Friedman
S. R. Gosselin
E. M. Hackett

P. J. Hijeck
S. D. Leshnoff
P. Manbeck
J. S. Panesar
W. E. Pennell
J. H. Phillips
S. Ranganath
S. T. Rosinski
W. L. Server
E. A. Siegel
F. A. Simonen
T. D. Spry
K. K. Yoon
S. Yukawa

Working Group on Pipe Flaw Evaluation (SG-ES) (SC XI)

D. A. Scarth, *Chair*
G. M. Wilkowski, *Secretary*
W. H. Bamford, Jr.
J. M. Bloom
R. C. Cipolla
N. G. Cofie
S. K. Daftuar
G. H. De Boo
E. Friedman
D. N. Hopkins
K. Iida
H. S. Mehta
J. G. Merkle
J. S. Panesar
D. Quinones
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Subgroup on Liquid-Metal-Cooled Systems (SC XI)

C. G. McCargar, *Chair*
W. L. Chase
S. Hattori
R. Hundal
W. Kwant
J. C. Tobin

Working Group on Liquid-Metal Reactor Covers (SG-LMCS) (SC XI)

W. L. Chase, *Chair*
S. Hattori
R. Hundal
W. Kwant

Subgroup on Nondestructive Examination (SC XI)

R. L. Beverly, *Chair*
N. R. Bentley, *Secretary*
D. C. Adamonis
F. L. Becker
F. T. Carr
C. B. Cheezem
W. T. Clayton
C. D. Cowfer
F. J. Dodd
T. N. Epps III
D. O. Henry
M. R. Hum
S. N. Liu
R. D. McGuire
M. C. Modes
C. R. Osman
F. J. Schaaf, Jr.
J. C. Spanner, Jr.
C. J. Wirtz

Working Group on Personnel Qualification and Surface Visual and Eddy Current Examination (SG-NDE) (SC XI)

C. J. Wirtz, *Secretary*
B. L. Curtis
N. Economos
H. B. Garland
D. O. Henry
H. E. Houserman
J. J. McArdle III
R. D. McGuire
S. A. Redner
M. F. Sherwin
A. L. Smith
D. Spake
J. C. Spanner, Sr.
J. C. Spanner, Jr.
T. V. Tran

Working Group on Pressure Testing (SG-NDE) (SC XI)

G. P. Alexander
T. M. Anselmi
T. B. Basso
J. Boughman
T. R. Bugelholl
R. J. Cimocho
C. E. Jensen
W. N. Keisler

D. Lamond
F. J. Schaaf, Jr.
D. Terao

Working Group on Procedure Qualification and Volumetric Examination (SG-NDE) (SC XI)

C. D. Cowfer, *Chair*
C. E. Larsen, *Secretary*
D. C. Adamonis
F. L. Becker
N. R. Bentley
B. Bevins
F. T. Carr
C. B. Cheezem
W. T. Clayton
S. R. Doctor
F. J. Dodd
T. N. Epps III
B. Kellerhall
G. A. Lofthus
J. K. McClanahan
M. C. Modes
M. Saporito
T. T. Taylor
S. M. Walker

Subgroup on Repairs, Replacements, and Modifications (SC XI)

R. E. Gimple, *Chair*
W. C. Holston, *Secretary*
R. W. Boyce
M. N. Bressler
S. B. Brown
C. E. Hartz
R. A. Hermann
C. A. Ireland
R. D. Kerr
D. F. Landers
R. S. Lewis
T. J. Mawson
M. S. McDonald
R. R. Stevenson
R. P. Sullivan
R. W. Swayne
R. E. Tome
D. E. Waskey
R. A. Yonekawa

Working Group on Design Reconciliation (SG-RR&M) (SC XI)

W. C. Holston, *Chair*
J. T. Conner, *Secretary*
R. W. Boyce
S. B. Brown
J. E. Charnley
T. E. Hiss
E. V. Imbro
D. N. Irvine, Jr.
D. F. Landers
R. W. Swayne
F. Tehranchi
H. J. Thailer
R. E. Tome

Working Group on Responsibilities and Program Requirements

R. A. Yonekawa, *Chair*
R. R. Stevenson, *Secretary*
S. K. Fisher
G. M. Foster
C. E. Hartz
R. S. Lewis
M. S. McDonald
U. Potapovs
S. M. Swilley
A. J. Walcutt
J. Ghergurovich, *Alternate*

Working Group on Welding and Special Repair Processes (SG-RR&M) (SC XI)

D. E. Waskey, *Chair*
R. E. Cantrell, *Secretary*
D. A. Delsignore
A. L. Finney
P. D. Fisher
A. J. Giannuzzi
R. A. Hermann
R. P. Indap
R. D. Kerr
B. R. Newton
P. P. Norris
J. E. O'Sullivan
J. H. Sodergren
K. R. Willens

Subgroup on Water-Cooled Systems (SC XI)

T. F. Lentz, *Chair*
K. Christian, *Secretary*
C. W. Allison
W. J. Briggs

T. R. Bugelhoff
D. D. Davis
A. F. Deardorff
R. L. Dyle
L. B. Gross
T. C. Hinkle
S. D. Kulat
M. P. Lintz
J. E. Staffiera
C. W. Tahnk
R. J. Tamminga
D. Terao
S. M. Walker
R. A. West

Working Group on Concrete Containment (SG-WCS) (SC XI)

W. J. Briggs, *Chair*
B. Talmadge, *Secretary*
H. G. Ashar
K. K. N. Chao
M. J. Ferlisi
H. T. Hill
R. D. Hough
C. N. Krishnaswamy
D. Naus
S. C. Petitgout
C. G. Ranganath

Working Group on Implementation of Risk-Based Examination (SG-WCS) (SC XI)

T. J. Mawson, *Chair*
A. McNeill III, *Secretary*
J. Agold
S. A. Ali
B. A. Bishop
J. W. Connor
A. F. Deardorff
H. Q. Do
R. Fougrousse
S. R. Gosselin
J. T. Lindberg
I. Mach
R. K. Mattu
P. J. O'Regan
J. H. Phillips
F. A. Simonen
T. V. Vo
R. A. West

Working Group on Inspection of Systems and Components (SG-WCS) (SC XI)

R. L. Dyle, *Chair*
G. C. Park, *Secretary*
G. L. Belew
T. W. Brombach
R. Fougrousse
T. C. Hinkle
M. R. Hum
S. D. Kulat
J. T. Lindberg
M. P. Lintz
T. K. McLellan
C. Pendleton
C. M. Ross
C. W. Tahnk
K. B. Thomas
E. Throckmorton
R. A. West
J. Whitman

Working Group on Metal Containment (SG-WCS) (SC XI)

J. E. Staffiera, *Chair*
W. E. Norris, *Secretary*
W. J. Briggs
K. K. N. Chao
M. J. Ferlisi
R. W. Hammelmann
M. P. Lintz
S. C. Petitgout
C. G. Ranganath
G. W. Robin
R. T. Zak

Special Working Group on Low-Temperature Heavy Water Reactors (SG-WCS) (SC XI)

C. D. Cowfer, *Chair*
J. M. Morrison, *Secretary*
B. Awadalla
K. F. Schmidt
P. R. Vormelker
S. H. Zaidi

Working Group on General Requirements (SC XI)

A. T. Roberts III, *Chair*
R. G. Edl, *Secretary*
D. A. Graham
L. B. Gross
C. A. Ireland
D. A. Jackson
R. K. Mattu

L. Sage
R. J. Scott
J. C. Shropshire
R. J. Tamminga

Special Working Group on Editing and Review (SC XI)

R. W. Swayne, *Chair*
R. L. Beverly
L. B. Gross
M. P. Lintz
J. E. Staffiera
C. J. Wirtz

Special Working Group on Plant Life Extension (SC XI)

F. E. Gregor, *Chair*
L. B. Gross, *Secretary*
D. D. Davis
D. A. Graham
D. L. Harrison
M. P. Lintz
P. Manbeck
H. W. Massie, Jr.
D. W. Peltola
D. A. Piccione
C. M. Regan
V. N. Shah
R. J. Tamminga

SUBCOMMITTEE ON TRANSPORT TANKS (SC XII)

A. Selz, *Chair*
P. D. Stumpf, *Secretary*
A. N. Antoniou
S. C. Cyr
K. Ennis
M. Hennemand
C. H. Hochman
G. G. Karcher
P. P. Laluc
G. McRae
M. R. Minick
T. P. Pastor
M. D. Rana
C. M. Serratella
G. R. Stoeckinger
N. Surtees
J. P. Swezy
A. P. Varghese
S. V. Voorhees

Subgroup on Design and Materials (SC XII)

M. D. Rana, *Chair*
D. A. Canonico
W. D. Doty
G. G. Karcher
P. P. Laluc
T. P. Pastor
T. A. Rogers
C. M. Serratella
A. P. Varghese
E. Whittle

Subgroup on Fabrication and Inspection (SC XII)

S. V. Voorhees, *Chair*
D. A. Canonico
M. L. Coats
M. Hennemand
D. J. Kreft
G. McRae
M. R. Minick
N. Surtees
J. P. Swezy

Subgroup on General Requirements (SC XII)

C. H. Hochman, *Chair*
T. Alexander
A. N. Antoniou
D. Carter
K. Ennis
M. A. Garrett
J. C. Keenan
F. A. Licari
G. R. Stoeckinger
W. L. White

SUBCOMMITTEE ON BOILER AND PRESSURE VESSEL ACCREDITATION (SC-BPVA)

A. J. Spencer, *Chair*
A. J. Justin, *Vice Chair*
K. I. Baron, *Secretary*
M. B. Doherty
D. A. Douin
P. D. Edwards
R. M. Elliott
C. E. Ford
J. J. Greene
R. C. Howard

B. B. MacDonald
M. L. Sisk
B. C. Turczynski
R. V. Wielgoszinski
R. L. Williams
V. A. Bell, Alternate
V. Bogosian, Alternate
M. A. De Vries, Alternate
J. R. Farr, Alternate
R. G. Friend, Alternate
W. C. LaRochelle, Alternate
A. S. Lester III, Alternate
K. M. McTague, Alternate
G. P. Milley, Alternate
R. E. Muise, Alternate
P. G. Scheckermann, Alternate
N. Surtees, Alternate

SUBCOMMITTEE ON NUCLEAR ACCREDITATION (SC-NA)

T. E. Quaka, *Chair*
R. R. Stevenson, *Vice Chair*
S. Griffin, *Secretary*
C. W. Allison
M. N. Bressler
G. Deily
F. R. Drahos
J. E. Harris
M. Kotb
W. C. LaRochelle
U. Potapovs
H. B. Prasse
A. J. Spencer
G. M. Tolson
L. M. Beason, Alternate
R. W. Boyce, Alternate
S. Dasgupta, Alternate
P. D. Edwards, Alternate
J. P. Ellenberger, Alternate
R. E. Feigel, Alternate
D. Hanrath, Alternate
K. A. Huber, Alternate
A. J. Justin, Alternate
N. C. Kist, Alternate
A. A. Lotfi, Alternate
R. P. McIntyre, Alternate
O. E. Trapp, Staff Representative

SUBCOMMITTEE ON DESIGN (SC-D)

W. J. Carter, *Chair*
F. S. Fitzgerald, *Secretary*
R. W. Barnes
C. Becht IV
O. F. Hedden
R. W. Mikitka
K. Mokhtarian
W. J. O'Donnell
R. D. Schueler, Jr.
M. P. Schwartz
A. Selz

Subgroup on Design Analysis (SC-D)

T. P. Pastor, *Secretary*
P. J. Conlisk
A. G. Eggers
J. L. Hechmer
G. L. Hollinger
D. P. Jones
A. Kalnins
W. J. Koves
T. H. Liu
O. Maekawa
A. Merend
T. V. Narayanan
E. L. Thomas, Jr.

Subgroup on Elevated Temperature Design (SC-D)

C. Becht IV, *Chair*
J. M. Corum, *Secretary*
C. R. Brinkman
R. D. Campbell
D. S. Griffin
R. I. Jetter
C. Lawton
W. J. O'Donnell
D. A. Osage
C. C. Schultz, Jr.
L. K. Severud
D. F. Shaw
A. L. Snow
B. E. Thurgood

Subgroup on Fatigue Strength (SC-D)

C. R. Brinkman
P. R. Donavin
J. A. Hayward
J. L. Hechmer

J. L. Hechmer
D. P. Jones
G. Kharshafdjian
C. Lawton
A. Merend
H. H. Ziada

Subgroup on Openings (SC-D)

M. P. Schwartz, *Chair*
R. W. Mikitka, *Secretary*
M. R. Breach
V. T. Hwang
S. C. Lou
R. B. Luney
J. P. Madden
K. C. Morrison
D. R. Palmer
M. D. Rana
E. C. Rodabaugh

Special Working Group on Bolted Flanged Joints (SC-D)

R. W. Mikitka, *Chair*
G. D. Bibel
G. Kharshafdjian
D. L. Kurle
E. Michalopoulos
S. N. Pagay
J. R. Payne
R. W. Schneider
R. D. Schueler, Jr.
A. Selz

SUBCOMMITTEE ON SAFETY VALVE REQUIREMENTS (SC-SVR)

E. C. Kistner, Jr., *Chair*
M. D. Bernstein, *Vice Chair*
U. D'Urso, *Secretary*
J. F. Ball
J. A. Cox
R. D. Danzy
R. J. Doelling
D. A. Douin
R. G. Friend
H. I. Gregg
S. F. Harrison, Jr.
C. F. Laitner
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson

D. J. Scallan
C. M. Schroepfer
A. J. Spencer
J. C. Standfast
E. A. Steen
L. L. Thompson
J. A. West
T. J. Ferrigan, Alternate

Page xxii

Subgroup on Design (SC-SVR)

R. G. Friend, *Chair*
J. Cahoon, Jr.
R. D. Danzy
D. B. DeMichael
R. J. Doelling
H. I. Gregg
S. R. Irvin
C. F. Laitner
P. R. Sievert
A. J. Spencer
E. A. Steen
T. R. Tarbay
J. A. West

Subgroup on General Requirements (SC-SVR)

M. D. Bernstein, *Chair*
J. F. Ball
V. M. Deluca
D. A. Douin
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson
J. C. Standfast
L. L. Thompson

Subgroup on Testing (SC-SVR)

S. F. Harrison, Jr., *Chair*
S. Cammeresi
J. A. Cox
W. F. Hart
D. M. Papa
D. J. Scallan
C. M. Schroepfer
D. E. Snyder

Page xxiii

ORGANIZATION OF SECTION III

1. GENERAL

Section III consists of Division 1, Division 2, and Division 3. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter "N" for Division 1, by the letter "C" for Division 2, and by the letter "W" for Division 3. The following eleven books make up the three Divisions.

Subsection NCA - General Requirements for Division 1 and Division 2

Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

Division 2 - Code for Concrete Reactor Vessels and Containments

Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

The Division 2 book includes Subsection CC - Concrete Containments and Division 2 Appendices.

The Division 3 book includes Subsections WA and WB for General Requirements and Class TP (Type B) Containment, respectively.

2. SUBSECTIONS

Subsections are divided into Articles, Subarticles, paragraphs, and, where necessary, subparagraphs and subsubparagraphs.

3. ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections followed by Arabic numbers, such as NB-1000. Where possible, Articles dealing with the same topics are given the same number in each Subsection in accordance with the following general scheme:

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination
6000	Testing
7000	Overpressure Protection
8000	Nameplates, Stamping, and Reports

The numbering of Articles and the material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the rules have been prepared with some gaps in the numbering.

4. SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

5. SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as NB-2130, and generally have no text. When a number such as NB-1110 is followed by text, it is considered a paragraph.

6. PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

7. SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as NB-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

8. SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

Page xxiv

9. REFERENCES

References used within Section III generally fall into one of the following four categories.

A. References to Other Portions of Section III

When a reference is made to another Article, Subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to NB-3000 includes all material in Article NB-3000; reference to NB-3200 includes all material in Subarticle NB-3200; reference to NB-3230 includes all paragraphs NB-3231 through NB-3236.

B. References to Other Sections

Other Sections referred to in Section III are:

Section II, Materials. When a requirement for a material, or for the examination or testing of a material, is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II. These references begin with the letter "S."

Section V, Nondestructive Examination. Section V references begin with the letter "T" and relate to the nondestructive examination of material or welds.

Section IX, Welding and Brazing Qualifications. Section IX references begin with the letter "Q" and relate to welding and brazing requirements.

Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components. When a reference is made to inservice inspection, the rules of Section XI shall apply.

C. Reference to Specifications and Standards Other Than Published in Code Sections

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials. At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E 71-64 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

2The American National Standards Institute (ANSI) was formerly known as the American Standards Association. Standards approved by the Association were designated by the prefix "ASA" followed by the number of the standard and the year of publication. More recently, the American National Standards Institute was known as the United States of America Standards Institute. Standards were designated by the prefix "USAS" followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the number of the standards have remained unchanged.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by the American Society of Mechanical Engineers and approved by the American National Standards Institute.² When a product is to conform to such a standard, for example ANSI B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NB-3132-1, for example ANSI B16.5 - 1977. Standards published by the American Society of Mechanical Engineers are available from ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-6, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, 127 Park Street, N.E., Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NB-3132-1, for example MSS SP-6-1963.

(4) Specifications for welding and brazing materials are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33135. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix "SF," for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-620 and API-2000. When documents so designated are referred to in Section III, they are standards published by the American Petroleum Institute.

D. References to Appendices

Two types of Appendices are used in Section III and are designated Mandatory and Nonmandatory.

(1) Mandatory Appendices contain requirements which must be followed in construction; such references are designated by a Roman numeral followed by Arabic numerals. References to II-1100 or XI-3212, for example, relate to the Mandatory Appendices.

(2) Nonmandatory Appendices provide information or guidance for the use of Section III; such references are designated by a capital letter followed by Arabic numerals. A reference to D-1100, for example, relates to a Nonmandatory Appendix.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NH-1000

ARTICLE NH-1000 INTRODUCTION

Page 1

NH-1100 SCOPE

NH-1110 ASPECTS OF CONSTRUCTION COVERED BY THESE RULES

(a) Subsection NH contains rules for materials, design, fabrication, examination, testing, and overpressure relief of Class 1 components, parts, and appurtenances which are expected to function even when metal temperatures exceed those covered by the rules and stress limits of Subsection NB and Tables 2A, 2B, and 4 of Section II, Part D, Subpart 1.

(b) The rules of Subsection NH are applicable to Class 1 components independent of the type of contained fluid - water, steam, sodium, helium, or any other process fluid.

(c) The stress limits and design rules of Subsection NB are applicable only to service conditions where creep and relaxation

effects are negligible. Consequently, the rules of Subsection NB only guard against the time-independent failure modes - ductile rupture, gross distortion (buckling and incremental collapse), and fatigue. Therefore, those portions of the component, part, or appurtenance which are at all times experiencing temperatures within the range covered by Tables 2A, 2B, and 4 of Section II, Part D, Subpart 1 may be designed in compliance with the rules of NH-3000 in Subsection NH, or alternatively, in compliance with the rules of NB-3000. In addition, the rules of Subsection NH extend specific rules of NB-3000 to elevated temperature service, provided the designer can demonstrate that the combined effects of temperature, stress level, and duration of loading do not introduce significant creep effects.

(d) At temperatures and loading conditions where creep effects are significant, the design analysis shall also consider the time-dependent material properties and structural behavior by guarding against the four modes of failure shown below:

- (1) ductile rupture from short-term loadings
- (2) creep rupture from long-term loadings
- (3) creep fatigue failure
- (4) gross distortion due to incremental collapse and ratcheting

Brief guidelines are also provided in Subsection NH for the three modes of failure shown below:

- (5) loss of function due to excessive deformation
- (6) buckling due to short-term loadings
- (7) creep buckling due to long-term loadings

(e) Design procedures and materials data not contained in Subsection NH may be required to ensure the integrity or the continued functioning of the structural part during the specified service life. For example, the rules do not provide methods to evaluate deterioration which may occur in service as a result of corrosion, mass transfer phenomena, radiation effects, or other material instabilities. Nor do the rules ensure continued functional performance of deformation-sensitive structures such as valves and pumps.

NH-1120 TEMPERATURE AND SERVICE LIFE LIMITS

The rules of Subsection NH shall not be used for structural parts which will be subjected either to metal temperatures or to times greater than those values associated with the S_{mt} data for the specified material (see Appendix I-14).

NH-1130 ORGANIZATION OF SUBSECTION NH RULES

In general, the numbering of rules in Subsection NH follows the numbering system used in Subsection NB. References to Appendices are to this Subsection unless otherwise identified.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NH-2000

ARTICLE NH-2000 MATERIAL

Page 5

NH-2120 PRESSURE RETAINING MATERIALS

NH-2121 Permitted Material Specifications

(a) All materials shall comply with the rules of NB-2000, except for those paragraphs replaced by correspondingly numbered paragraphs of Subsection NH.

(b) In complying with (a) above, the base and weld material specifications of Tables I-14.1, I-14.10, and I-14.11 and the allowable stress intensities in Tables I-14.3 and I-14.13 shall be considered extensions of Tables 2A, 2B, and 4 of Section II, Part D, Subpart 1.

(c) Pressure retaining material and material welded thereto, except for temporary or nonstructural attachments as per NB-4435 and in (h) below, and except for hard surfacing metals and cladding which is 10% or less of the thickness of the base material, shall conform to the requirements of one of the specifications for material given in Tables 2A, 2B, and 4 of Section II, Part D, Subpart 1, and to all of the special requirements of this Article which apply to the product form in which the material is used.

(d) The requirements of this Article do not apply to items not associated with the pressure retaining function of a component such as shafts, stems, trim, spray nozzles, bearings, bushings, springs, wear plates, nor to seals, packing, gaskets, valve seats, and ceramic insulating material and special alloys used as seal material in electrical penetration assemblies.

(e) Material made to specifications other than those specified in Tables 2A, 2B, and 4 of Section II, Part D, Subpart 1 may be used for safety valve disks and nozzles, when the nozzles are internally contained by the external body structure, and for valve disks in line valves whose inlet connections are NPS 2¹ and less.

¹ Values of nominal pipe size have not been converted to SI.

(f) Material for instrument line fittings, NPS 1 and less, may be of material made to specifications other than those listed in Section II, Part D, provided that the fittings are in conformance with the requirements of NB-3671.4 and the material is determined to be adequate for the service conditions by the piping system designer.

(g) Welding material used in the manufacture of items shall comply with Table I-14.1(b) and the SFA specifications in Section II, Part C, and shall also comply with the applicable requirements of this Article. The requirements of this Article do not apply to material used as backing rings or backing strips in welded joints.

(h) Attachments welded to a pressure boundary (including the weld metal used to make the attachment) expecting elevated temperature service need not comply with the limits on upper values of service temperatures and times, as stated in Tables 2A, 2B, and 4 of Section II, Part D, Subpart 1, provided the rules listed below are met.

(1) The design of the welded attachment complies with the rules in NH-3354.

(2) The attachment material and weld are of similar alloy composition to the pressure boundary material.²

NH-2123 Design Stress Intensity Values

Design stress intensity values for material are listed in Tables 2A, 2B, and 4 of Section II, Part D, Subpart 1, as extended in coverage by the rules of NH-2121(b). With the exception of attachment material covered by NH-2121(h), no material shall be used at metal and design temperatures above those for which values are given.

² Different product forms, such as castings, are acceptable for the attachment.

NH-2160 DETERIORATION OF MATERIAL IN SERVICE

(a) Consideration of deterioration of material caused by service is generally outside the scope of this Subsection.

Page 8

It is the responsibility of the Owner to select material suitable for the conditions stated in the Design Specifications (NCA-3250), with specific attention being given to the effects of service conditions upon the properties of the material.

(b) Special consideration shall be given to the influence of elements such as copper and phosphorus on the effects of irradiation on the properties of material (including welding material) in the core belt line region of the reactor vessel. Any special requirement shall be specified in the Design Specifications (NCA-3252 and NB-3124). When so specified, the check analysis shall be made in accordance with the base metal specification and in accordance with NB-2420 for the welding material.

(c) The combination of fabrication induced cold working and subsequent elevated temperature service may affect

time-dependent material properties.

NH-2433 Delta Ferrite Determination

A determination of delta ferrite shall be performed on A-No. 8 weld material (QW-442, Section IX) backing filler metal (consumable inserts); bare electrode, rod, or wire filler metal; or weld metal, except that delta ferrite determinations are not required for SFA-5.4, Type 16-8-2, nor A-No. 8 weld filler metal to be used for weld metal cladding.

NH-2433.1 Method.

Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of chemical analysis of NB-2432 in conjunction with Fig. NB-2433.1-1.

- (a) Calibration of magnetic instruments shall conform to AWS-A4.2-91.
- (b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with NB-2432.1(c).
- (c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number.

NH-2433.2 Acceptance Standards.

For design temperatures up to and including 800°F (427°C), the minimum acceptable delta ferrite shall be 5-FN (Ferrite Number). For design temperatures exceeding 800°F (427°C), the delta ferrite shall be limited to the range FN-3 to FN-10. The results of the delta ferrite determination shall be included in the Certified Material Test Report of NB-2130 or NB-4120.

NH-2539 Repair of Plates by Welding

The Material Organization may repair by welding material from which defects have been removed, provided the depth of the repair cavity does not exceed one-third of the nominal thickness and the requirements of the following subparagraphs are met. The weld material used to make weld repairs shall meet the requirements of Table I-14.1(b) and NB-2400. Additional requirements may be listed in the Design Specifications, as per NB-2160, to assure that the repair weld is adequate for the service conditions. Prior approval of the Certificate Holder shall be obtained for the repair of plates to be used in the manufacture of vessels.

(NB-2539.1 through NB-2539.7 are unchanged.)

NH-2540 FATIGUE ACCEPTANCE TEST

- (a) For 304 and 316 austenitic stainless steel components intended for service where conditions for levels A, B, and C do not satisfy the limits of T-1324(a) and (b), a uniaxial fatigue acceptance test of each lot of material shall be performed.
- (b) The fatigue test shall be performed in air at 1,100°F (593°C) at an axial strain range of 1.0% with a one-hour hold period at the maximum positive strain point in each cycle. Test-specimen location and orientation shall be in accordance with the general guidance of SA-370, paras. 6.1.1 and 6.1.2 and the applicable product specifications. Testing shall be conducted in accordance with ASTM Standard E 606. The test shall exceed 200 cycles without fracture or a 20% drop in the load range.
- (c) Failure to meet this requirement shall be cause for rejection of the lot for use in Class 1 elevated temperature components.
- (d) The definition of "lot" shall be obtained from the material specification. Where more than one definition is provided by the specification, the definition used to establish the tensile properties shall govern. Either the Material Organization or N-Type Certificate Holder may perform the lot qualification test.
- (e) Retesting is permitted. Two additional specimens shall be tested and both specimens must pass the cyclic life requirement. Further retests are not permitted.

NH-3100 GENERAL REQUIREMENTS FOR DESIGN

NH-3110 SCOPE, ACCEPTABILITY, AND LOADINGS

NH-3111 Scope

(a) Article NH-3000 is a self-contained set of design rules for metal structures serving as component pressure retaining boundaries under temperatures which may at times exceed those for which design stress-intensity values S_m are given in Section II, Part D, Subpart 1.

(b) The design rules of NB-3000 shall apply only where specifically called out by the rules of Subsection NH.

NH-3111.1 Acceptability.

An acceptable design of a Class 1 Component for elevated temperature service is one which:

(a) is capable of meeting the functional requirements as specified in the Design Specifications (NCA-3250); and

(b) satisfies the requirements for a design by analysis, either in NH-3200 or in the Design Rules for components, while under the loadings described in NH-3111.2 and the Design Specifications; and

(c) satisfies the general design rules of NH-3130 and the applicable design rules for components which apply to a vessel (NH-3300), pump (NH-3400), valve (NH-3500), or piping (NH-3600). The Design Specifications shall state which Subarticle applies to the given component.

(d) As an alternative to (b) and (c) above, the rules of NB-3000 may be applied to those portions of the component which never experience temperatures above those for which design stress-intensity values are given in Tables 2A, 2B, and 4 of Section II, Part D, Subpart 1.

NH-3111.2 Loadings.

The loadings that shall be taken into account in designing a component include but are not limited to the following:

(a) internal and external pressure;

(b) weight of the component and its normal contents under service or test loadings, including additional pressure due to static and dynamic head of liquids;

(c) superimposed loads such as from other components, operating equipment, insulation, corrosion-resistant or erosion-resistant linings and piping;

(d) wind loads, snow loads, vibrations, and earthquake loads where specified;

(e) reactions of supporting lugs, rings, saddles, or other types of supports;

(f) temperature effects;

(g) impact forces caused by either external or internal events.

NH-3112 Design Parameters

(a) The design parameters are the pressures, temperatures, and mechanical load forces applicable to the design of nuclear power plant components. The simplest set of design parameters would consist of the temperature, pressure, and load forces that exist at some given time.

(b) To design a zone of a component for service at elevated temperature, two types of design parameter data are needed in the Design Specifications (NCA-3250): first, an expected loading history which consists of how each design parameter varies as a function of time; and second, a list of events which occur under each loading category defined in NH-3113.

(c) The design parameter data stipulated in (1) and (2) below shall be specified in the Design Specifications (NCA-3250) for each component:

(1) the loading event history to be used in the structural analysis;

(2) the design parameters from which the designer will determine the most severe loading for each loading category defined in NH-3113. (If fluid conditions are specified, the designer eventually must convert the data to metal temperatures and surface pressures.)

(d) It is permissible for the designer to establish the zone boundaries inside the component. However, the

Page 16

zone boundaries and applicable design parameters shall be fully described in the Stress Report.

NH-3112.1 Specified Pressure

(a) The specified internal and external pressure histories shall describe pressure values not less than the maximum pressure differences between the inside and outside of the pressure boundary in a given zone of the component, or between any two chambers of a combination unit.

(b) The specified pressure histories shall be used in the computations made to show compliance with the limits of NH-3200.

(c) All pressures referred to in this Article are to be taken as the value above atmospheric pressure unless otherwise stated.

NH-3112.2 Specified Temperature.

The specified temperature history for the loading category shall enable the designer to describe a temperature value not less than the maximum local wall averaged temperature that will exist in the structural metal in a given zone of the component. And for the particular analyses of Service Loadings (NH-3113.2), the designer shall determine the history of the maximum local metal temperature in a given zone and shall use these metal temperature histories in the computations to show compliance with the limits of NH-3200.

(a) All temperatures referred to in this Article are the metal temperatures expressed in degrees Fahrenheit (F) unless otherwise stated.

(b) Where a component is heated by trace heating, induction coils, jacketing, or by internal heat generation, the designer shall consider the effect of such heating in the establishment of the design temperature histories.

(c) Elevated temperature mechanical properties are extremely sensitive to temperature. The Design Specifications shall specify any inaccuracies in temperature measurement and prediction that are to be considered in the design analyses made to show compliance with the limits of NH-3200.

NH-3112.3 Specified Mechanical Load Forces.

The specified load forces for a given loading category (NH-3113) shall define all expected mechanical loadings which must be considered in design analysis computations made to show compliance with the limits of NH-3200.

NH-3113 Loading Categories

Loading categories used in this Subsection consist of Design Loading, Service Loadings (Levels A, B, C, and D), and

Test Loadings.

NH-3113.1 Design Loadings.

The specified design parameters for the Design Loadings category shall equal or exceed those of the most severe combination of coincident pressure, temperature, and load forces specified under events which cause Service Level A Loadings (NH-3113.3) for the same zone of the component. These specified design parameters for Design Loadings shall be called Design Temperature, Design Pressure, and Design Mechanical Loads. These specified design parameters shall be used in computations to show compliance with the requirements on Design Limits in NH-3222.1.

NH-3113.2 Service Loadings.

Each loading to which the component may be subjected shall be categorized in accordance with the following definitions and shall be described in the Design Specifications (NCA-3250) in such detail as will provide a complete basis for construction in accordance with these rules. The Service Loading categories shall be as defined in the next four subparagraphs below.

NH-3113.3 Level A Service Loadings.

Level A Service Loadings are any loadings arising from system startup, operation in the design power range, hot standby, and system shut-down, and excepting only those loadings covered by Levels B, C, and D Service Loadings or Test Loading.

NH-3113.4 Level B Service Loadings.

(From incidents of moderate frequency.) These are deviations from Level A Service Loadings that are anticipated to occur often enough that design should include a capability to withstand the loadings without operational impairment. The events which cause Level B Service Loadings include those transients which result from any single operator error or control malfunction, transients caused by a fault in a system component requiring its isolation from the system, and transients due to loss of load or power. These events include any abnormal incidents not resulting in a forced outage and also forced outages for which the corrective action does not include any repair of mechanical damage. The estimated duration of a Level B Service Loading shall be included in the Design Specifications.

NH-3113.5 Level C Service Loadings.

(From infrequent incidents.) These are deviations from Level A Service Loadings which require shutdown for correction of the loadings or repair of damage in the system. The conditions have a low probability of occurrence, but are included to provide assurance that no gross loss of structural integrity will result as a concomitant effect of any damage developed in the system. The total number of postulated occurrences for such events may

Page 17

not exceed 25. If more than 25 are expected, then some types of events must be evaluated by the more stringent requirements of the Level B Service Limits.

NH-3113.6 Level D Service Loadings.

(From limiting faults.) These are combinations of loadings associated with extremely low probability, postulated events whose consequences are such that the integrity and operability of the nuclear energy system may be impaired to the extent that only considerations of public health and safety are involved.

NH-3113.7 Test Loadings.

These are pressure loadings which occur during hydrostatic tests, pneumatic tests, and leak tests. Other types of tests shall be classified under either Service Level A or B loading categories given in the above subparagraphs. If any elevated temperature tests are specified as Test Loadings for a component, then these loadings shall be considered as part of the Service Level B loadings for the component.

NH-3114 Load Histogram

NH-3114.1 Level A and B Service Events.

The Design Specifications (NCA-3250) shall include an expected loading history or load histogram for all Service Loadings from Level A and B service events (including all Test Loadings). These load histograms shall give all expected mechanical load forces, pressure, and temperatures for the various zones of the component throughout its service life. These histograms are then used in meeting the analysis requirements of NH-3200.

NH-3114.2 Level C Service Events.

The Design Specifications shall include a time history of the design parameters during each type of Level C Service event. However, these events need not be specified as to time of occurrence during the service life of the component. The design parameter data shall be used in meeting the analysis requirements of NH-3200. Level C Service events may be assumed as occurring between operational cycles (NH-3213.15) of Level A Service events unless otherwise specified in the Design Specifications (NCA-3250).

NH-3130 GENERAL DESIGN RULES

NH-3131 Scope

Design rules generally applicable to all components are provided in NH-3130. The Design Subarticle for the specific component provides rules applicable to that particular component. In case of conflict between NH-3130 and the design rules for a particular component, the component design rules shall govern.

NH-3132 Dimensional Standards for Standard Products

Dimensions of standard products shall comply with the standards and specifications listed in Table NB-3132-1 when the standard or specification is referenced in the specific design Subarticle. However, compliance with these standards does not replace or eliminate the requirements for stress analysis when called for by the design Subarticle for a specific component.

NH-3133 Size Restrictions in Nozzle, Branch, Piping, and Other Connections

The size of certain design features is restricted on nozzle, branch, piping, and other connections. Table NH-3133-1 provides assistance in understanding where the limits are imposed.

NH-3134 Leak Tightness

Where a system leak tightness greater than that required or demonstrated by a hydrostatic test is required, the leak tightness requirements for each component shall be set forth in the applicable Design Specifications (NCA-3250).

NH-3135 Attachments

Lugs, brackets, stiffeners, and other attachments may be welded, bolted, or studded to the outside or inside of a component. The effects of attachments in producing thermal stresses, stress concentrations, and restraints on pressure retaining members shall be taken into account in the analysis for compliance with design criteria of NH-3200. For example, the temperature patterns around an attachment may lead to higher thermal stresses simply due to the *cooling-fin effect* of the attachment.

NH-3136 Reinforcement for Openings

See NH-3330 and NH-3643 for the rules applicable to reinforcement of openings in the pressure boundaries of vessels and piping, respectively. For all other components, the rules of NH-3330 shall apply unless otherwise specified in the Design Specifications.

**TABLE NH-3133-1
SIZE RESTRICTIONS ON CONNECTIONS**

Reference Paragraph	Service Conditions	Item Description	Item	Nominal Sizes Allowed
NB-3352.4(d) & NB-3337.3	Non-creep	Partial penetration nozzle welds & other Cat. D welds	Vessel	All
NH-3352(e) & NH-3337.3	Creep	(as above)	Vessel	OD ≤ 1-in.
NB-3431, NH-3337.3 & NB-3352.4(d)	Non-creep	Partial penetration piping connection weld	Pump	OD ≤ 2-in.
NH-3421.4, NH-3337.3 & NH-3352(e)	Creep	(as above)	Pump	OD ≤ 2-in.
NB-3544.8	Non-creep	Socket weld ends	Valve	OD ≤ 2-in.
NH-3544	Creep	(as above)	Valve	OD ≤ 2-in.
NB-3661.3	Non-creep	Partial penetration branch connection weld	Pipe	OD ≤ 2-in.
NH-3660(a) & NH-3352(e), NH-3337.3	Creep	(as above)	Pipe	OD ≤ 1-in.
NB-3643 & NB-3661.2	Non-creep	Socket welds	Pipe	OD ≤ 2-in.
NH-3660(b)	Creep	(as above)	Pipe	OD ≤ 1-in.
NB-3671.3	Non-creep	Seal-welded threaded joints	Pipe	All
NH-3660(b)	Creep	(as above)	Pipe	OD ≤ 1-in.
NB-3671.6 & NB-4511	Non-creep	Brazed joints	Tubesheet, tube & pipe	OD ≤ 1-in.
NB-4511 & NH-3671.6	Creep	(as above)	Tubesheet, tube & pipe	OD ≤ 1-in.
NB-3671.4	Non-creep	Flared, flareless & compression joints	Tube & pipe	OD ≤ 1-in.
NH-3671.1	Creep	(as above)	Tube & pipe	None
NB-4730	Non-creep	Tube joints at electrical & mechanical penetration assemblies	Tube & pipe	OD ≤ 2-in.
NB-4730	Creep	(as above)	Tube & pipe	OD ≤ 2-in.
NB-3643.3 & NB-3661.1, NB-3337.2 & NB-3352.4(d)	Non-creep	Deposited weld metal as reinforcement for openings & branch connections	All	All
NH-3331(b)	Creep	(as above)	All	OD ≤ 4-in.
NB-3352.4(c) & NB-3661.1	Non-creep	Full-penetration corner welds at nozzle, branch & piping connections	All	All
NH-3352(d) & NH-3660(c)	Creep	(as above)	All	OD ≤ 4-in.

TABLE NH-3133-1 SIZE RESTRICTION ON CONNECTIONS

NH-3137 Design Considerations Related to Other Articles of the Code

NH-3137.1 Design Considerations for Static Pressure Testing.

Since every component and appurtenance must eventually undergo a static pressure test, the designer shall ensure that such a test can be performed. If the only available test fluid can leave harmful residues on surfaces, the design shall preferably be such as to leave surfaces accessible for cleaning following the static pressure test. Special access hatches as well as drain lines may be required.

NH-3137.2 Design Considerations for Overpressure Protection of the System

(a) Each component and the system into which it will be installed shall be protected against overpressure events as required by the rules on overpressure protection of Class 1 components and systems exposed to elevated temperature service.

service.

(b) The Service Loadings listed in the Design Specifications include those overpressure events which the designer shall consider in the design of that particular component. However, the component designer shall also review the final design to determine if additional

Page 19

overpressure transients can arise from one of the following:

- (1) failure of nonpressure boundary parts of the component;
- (2) failure of external power sources to the component;
- (3) functioning of the component in conjunction with specified plant and system service conditions (Levels A, B, C, and D).

The designer shall report to the Owner regarding all sources of overpressure transients that can arise from (1), (2), and (3) above.

NH-3138 Elastic Follow-up

(a) When only a small portion of the structure undergoes inelastic strains while the major portion of the structural system behaves in an elastic manner, the calculations of load forces, stresses, and strains shall consider the behavior of the entire structural system. In these cases, certain areas may be subjected to strain concentrations, due to the elastic follow-up of the rest of the connected structure. These abnormally large strain concentrations may result when structural parts of different flexibility are in series and the flexible portions are highly stressed. Examples include:

- (1) local reduction in size of a cross section or local use of a weaker material;
 - (2) in a piping system of uniform size, a configuration for which most of the system lies near the hypothetical straight line connecting the two anchors, (stiffeners, flanges, or other stiff members), and with only a small portion departing from this line. Then the small portion absorbs most of the expansion strain.
- (b) If possible, the above conditions should be avoided in design. Where such conditions cannot be avoided, the analysis required in NH-3250 will determine the acceptability of the design to guard against harmful consequences of elastic follow-up.

NH-3139 Welding

NH-3139.1 Abrupt Changes in Mechanical Properties at Weld and Compression Contact Junctions.

In satisfying the requirements of NH-3000, particular considerations shall be given to the design, analysis, and construction of welded and compression contact junctions between two materials which have different mechanical properties. Such properties at elevated temperatures include thermal expansion, creep rate, creep ductility, and fatigue life. Examples of such junctions are bimetallic welds, brazed joints, compression or shrink fits, bolted flanges, and other types of mechanical joints. When temperatures cycle between low temperatures and elevated temperatures, the inelastic strains can result in significant localized strain accumulation near an abrupt change in mechanical properties.

NH-3139.2 Weld Design.

All welds shall comply with the rules of NB-3350. Exceptions to this requirement are allowed only if a specific callout is made in either NH-3400, NH-3500, or NH-3600.

NH-3200 DESIGN BY ANALYSIS

NH-3210 DESIGN CRITERIA

NH-3211 Requirements for Acceptability

For a Class 1 component intended for elevated temperature service, the requirements for the acceptability of a design based on analysis shall be as stipulated in (a) through (d) below.

(a) The design shall be such that the calculated or experimentally determined stresses, strains, and deformations will not exceed the limits described in this Subarticle;

(b) The design details shall conform to the rules of NH-3100 and to those given in subsequent Subarticles applicable to the specific component;

(c) If the designer has demonstrated that the elevated temperature service parameters (time, stress level, and temperature) do not introduce significant creep effects¹, then the experimental and analytical methods of Subsection NB shall be applicable. The other restrictions on temperature maxima that appear in Subsection NB [see NB-3228.5(e)] shall not apply provided the designer demonstrates the validity of values and methods for the higher temperatures.

(d) For portions of the component which do not experience elevated temperature service, the rules of NB-3000 may be used to satisfy (a) and (b) above. Alternatively, properties and allowable stress values from Subsection NB may be used in analyses to demonstrate compliance with the rules of NH-3200.

NH-3212 Basis for Determining Stress, Strain, and Deformation Quantities

1 A report documenting the experimental data or calculations based on experimental data or both shall demonstrate that the elevated temperature service does not introduce creep effects. This document shall be incorporated into the Stress Report (NCA-3550) and shall be approved by the Owner by means of a certified revision to the Design Specifications (NCA-3250).

(a) For elastic analysis allowed by Subsection NH, the maximum shear stress theory shall be used to

Page 20

determine stress intensities for multiaxial stress states (NB-3212).

(b) For inelastic analysis required by Subsection NH, appropriate multiaxial stress-strain relationships and associated flow rules shall be used to combine multiaxial stresses and strains.

NH-3213 Terms Relating to Analysis

In Subsection NH, the stress and strain limits for design evaluation are related to the type of structural behavior under loading. The controlled quantities fall into two general categories:²

(a) *Load Controlled Quantities* - These quantities are stress intensities which are computed on the basis of equilibrium with the applied forces and moments during plant operation. Included in this category are general primary membrane, local primary membrane, primary bending stresses, and secondary stresses with a large amount of elastic follow-up.

(b) *Deformation Controlled Quantities* - These quantities are strains, cyclic strain ranges, or deformations which result from load deflection and/or strain compatibility.

Other terms used in Subsection NH relating to structural analysis are defined in the subparagraphs of NH-3213.

NH-3213.1 Elastic Stress Intensity.

Elastic stress intensity³ is the equivalent intensity of combined stress. In short, the stress intensity is defined as twice the maximum shear stress. In other words, the stress intensity is the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tensile stresses are considered positive and compressive stresses are considered negative.

2 Note that the expansion stress (P) defined in NB-3222.3 is deleted for Subsection NH. Stresses resulting from the constraint of free end displacement and the effects of anchor motion shall be assigned to either primary or secondary stress categories [see NH-3213(a), NH-3213(b), and NH-3217].

3 This definition of stress intensity is not related to the definition of stress intensity applied in the field of Fracture Mechanics.

NH-3213.2 Gross Structural Discontinuity.

Gross structural discontinuity is a geometric or material discontinuity which affects the stress or strain distribution through the entire wall thickness of the pressure retaining member. Gross discontinuity type stresses are those portions

of the actual stress distributions that produce net bending and membrane force resultants when integrated through the wall thickness. Examples of gross structural discontinuities are head-to-shell and flange-to-shell junctions, nozzles, and junctions between shells of different diameters or thicknesses.

NH-3213.3 Local Structural Discontinuity.

Local structural discontinuity is a geometric or material discontinuity which affects the stress or strain distribution through a fractional part of the wall thickness. The stress distribution associated with a local discontinuity causes only very localized types of deformation or strain and has no significant effect on the shell type discontinuity deformation. Examples are small fillet radii, small attachments, and partial penetration welds.

NH-3213.4 Normal Stress.

Normal stress is the component of stress normal to the plane of reference. This is also referred to as direct stress. Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to be made up in turn of two components, one of which is uniformly distributed and equal to the average value of stress across the thickness under consideration, and the other of which varies from this average value with the location across the thickness.

NH-3213.5 Shear Stress.

Shear stress is the component of stress tangent to the plane of reference.

NH-3213.6 Membrane Stress.

Membrane stress is the component of normal stress which is uniformly distributed and equal to the average of stress across the thickness of the section under consideration.

NH-3213.7 Bending Stress.

Bending stress is the variable component of normal stress described in NH-3213.4. The variation may or may not be linear across the thickness.

NH-3213.8 Primary Stress.

Primary stress is any normal stress or a shear stress developed by an imposed loading which is necessary to satisfy the laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary membrane stress is divided into general and local categories. A general primary membrane stress is one which is so distributed in the structure that no redistribution of load occurs as a result of yielding. Examples of primary stresses are:

- (a) general membrane stress in a circular cylindrical or a spherical shell due to internal pressure or to distributed live loads;
- (b) bending stress in the central portion of a flat head due to pressure;
- (c) stresses in piping due to net cross section load forces (normal or shear) arising from thermal expansion of structural material.

NH-3213.9 Secondary Stress.

Secondary stress is a normal stress or a shear stress developed by the constraint of adjacent material or by self-constraint of the structure, and thus it is normally associated with a deformation controlled quantity at elevated temperatures. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions which cause the stress to occur and failure from one application of the stress is not to be expected. Examples of secondary stresses are:

- (a) bending stress at a gross structural discontinuity;

(b) bending stress in piping where loads cannot cause excessive creep deformation (e.g., buckling or dimpling) in a local region;

(c) bending stress due to a linear radial thermal strain (αT) profile through the thickness of a section;

(d) bending stress due to an equivalent linear thermal strain profile for the actual (nonlinear) strain profile [The equivalence is based on having the linear profile exert the same net bending moment as that from the actual profile (NH-3213.13).];

(e) stress produced by an axial temperature distribution in a cylindrical shell;

(f) stress produced by the temperature difference between a nozzle and the shell to which it is attached.

NH-3213.10 Local Primary Membrane Stress.

Cases arise in which a membrane stress produced by pressure or other mechanical loading and associated with a primary or a discontinuity effect produces excessive distortion in the transfer of load to other portions of the structure. Conservatism requires that such a stress be classified as a local primary membrane stress even though it has some characteristics of a secondary stress. A stressed region may be considered local if the distance over which the membrane stress intensity exceeds $1.1S_o$ does not extend in the meridional direction more than $1.0 \sqrt{Rt}$, where R is the minimum midsurface radius of curvature and t is the minimum thickness in the region considered. Regions of local primary stress intensity involving axisymmetric membrane stress distributions which exceed $1.1S_o$ shall not be closer in the meridional direction than $2.5 \sqrt{Rt}$, where R is defined as $(R_1 + R_2)/2$ and t is defined as $(t_1 + t_2)/2$ (where t_1 and t_2 are the minimum thicknesses at each of the regions considered, and R_1 and R_2 are the minimum midsurface radii of curvature at these regions where the membrane stress intensity exceeds $1.1S_o$). Discrete regions of local primary membrane stress intensity, such as those resulting from concentrated loads acting on brackets, where the membrane stress intensity exceeds $1.1S_o$, shall be spaced so that there is no overlapping of the areas in which the membrane stress intensity exceeds $1.1S_o$. An example of a local primary membrane stress is the membrane stress in a shell produced by external load and moment at a permanent support or at a nozzle connection.

NH-3213.11 Peak Stress.

Peak stress is that increment of stress which is additive to the primary plus secondary stresses by reason of local discontinuities or local thermal stress [see NH-3213.13(b)] including the effects (if any) of stress concentrations. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture, and, at elevated temperatures, as a possible source of localized rupture or creep-fatigue failure. A stress which is not highly localized falls into this category if it is of a type which cannot cause noticeable distortion. Examples of peak stresses are:

(a) the thermal stress in the austenitic steel cladding of a carbon steel component;

(b) certain thermal stresses which may cause fatigue but not distortion;

(c) the stress at a local structural discontinuity;

(d) surface stresses produced by thermal shock.

NH-3213.13 Thermal Stress.

Thermal stress is a self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally should under a change in temperature. For the purpose of establishing allowable stresses, two types of thermal stress are recognized, depending on the volume or area in which distortion takes place, as described in the following subsubparagraphs.

(a) General thermal stress is associated with distortion of the structure in which it occurs. When thermal stresses are to be considered as primary or secondary loadings, they are in this category. For example, see T-1331(d).

(b)

no significant distortion. Such stresses shall be considered only from the fatigue standpoint and are therefore classified as peak stresses. Examples of local thermal stresses are:

(1) the stress in a small hot spot in a vessel wall;

(2) the difference between the actual stress and the equivalent linear stress resulting from a radial temperature distribution in a cylindrical shell;

(3) the thermal stress in a cladding material which has a coefficient of expansion different from that of the base metal.

Page 22

NH-3213.15 Operational Cycle.

Operational cycle is defined as the initiation and establishment of new parameter values followed by a return to the values which prevailed at the beginning of the cycle. The description of the types of plant and system operating conditions which may occur in a nuclear energy system, are beyond the scope of Section III.

NH-3213.16 Strain Cycle.

Strain cycle is a condition in which the strain goes from an initial value, through an algebraic maximum value and an algebraic minimum value and then returns to the initial value. In cases where creep or ratcheting are present in the cycle, there will not be a return to the initial strain value. Instead the designer will have to examine the hysteresis loop for inelastic analysis and the stress history for elastic analysis to determine the end point of the cycle. See T-1413 for the method of combining cycles for fatigue analysis. A single operational cycle may result in one or more strain cycles. Dynamic effects shall also be considered as strain cycles.

NH-3213.17 Fatigue Strength Reduction Factor.

Fatigue strength reduction factor is a stress intensification or a strain intensification factor which accounts for the effect of a local structural discontinuity (stress or strain concentration) on the fatigue strength. Factors currently exist only for cycles which do not involve significant creep effects.

NH-3213.18 Free End Displacement.

Free end displacement consists of the relative motions that would occur between a fixed attachment and connected piping if the two members were separated and permitted to move.

NH-3213.20 Deformation.

Deformation of a component part is an alteration of its shape or size.

NH-3213.21 Inelasticity.

Inelasticity is a general characteristic of material behavior in which the material does not return to its original shape and size after removal of all applied loads. Plasticity and creep are special cases of inelasticity.

NH-3213.22 Creep.

Creep is the special case of inelasticity that relates to the stress-induced time-dependent deformation under load. Small time-dependent deformations may occur after the removal of all applied loads.

NH-3213.23 Plasticity.

Plasticity is the special case of inelasticity in which the material undergoes time-independent nonrecoverable deformation.

NH-3213.24 Plastic Analysis.

Plastic analysis is that method which computes the structural behavior under given loads considering the plasticity characteristics of the materials, including strain hardening and the stress redistribution occurring in the structure.

NH-3213.25 Plastic Analysis - Collapse Load.

A plastic analysis may be used to determine the collapse load for a given combination of loads on a given structure. The following criteria for determination of the collapse load shall be used. A load-deflection or load-strain curve is plotted with load as the ordinate and deflection or strain as the abscissa. The angle that the linear part of the load deflection or load strain curve makes with the ordinate is called θ . A second straight line, hereafter called the collapse limit line, is drawn through the origin so that it makes an angle $\phi = \tan^{-1} (2 \tan \theta)$ with the ordinate. The collapse load is the load at the intersection of the load-deflection or load-strain curve and the collapse limit line. If this method is used, particular care should be given to assuring that the strains or deflections that are used are indicative of the load carrying capacity of the structure.

NH-3213.26 Plastic Instability Load.

The plastic instability load for members under predominantly tensile or compressive loading is defined as that load at which unbounded plastic deformation can occur without an increase in load. At the plastic tensile instability load, the true stress in the material increases faster than strain hardening can accommodate.

NH-3213.27 Limit Analysis.

Limit analysis is a special case of plastic analysis in which the material is assumed to be ideally plastic (nonstrain-hardening). In limit analysis the equilibrium and flow characteristics at the limit state are used to calculate the collapse load. The two bounding methods which are used in limit analysis are the lower bound approach, which is associated with a statically admissible stress field, and the upper bound approach, which is associated with a kinematically admissible velocity field. For beams and frames, the term *mechanism* is commonly used in lieu of *kinematically admissible velocity field*.

NH-3213.28 Limit Analysis - Collapse Load.

The methods of limit analysis are used to compute the maximum carrying load for a structure assumed to be made of ideally plastic material. If creep effects exist, then the influence of time-dependent deformations on the collapse load shall be considered.

NH-3213.29 Calculated Collapse Load - Lower Bound.

If, for a given load, any system of stresses can be found which everywhere satisfies equilibrium, and nowhere exceeds the material yield strength, the

Page 23

load is at or below the collapse load. This is the lower bound theorem of limit analysis which permits calculations of a lower bound to the collapse load. If creep effects exist, then the influence of time-dependent deformations on the collapse load shall be considered.

NH-3213.30 Plastic Hinge.

A plastic hinge is an idealized concept used in Limit Analysis. In a beam or a frame, a plastic hinge is formed at the point where the moment, shear, and axial force lie on the yield interaction surface. In plates and shells, a plastic hinge is formed where the generalized stresses lie on the yield surface.

NH-3213.31 Strain Limiting Load.

When a limit is placed upon a strain, the load associated with the strain limit is called the strain limiting load.

NH-3213.32 Test Collapse Load.

Test collapse load is the collapse load determined by tests according to the criteria given in Article II-1430 of Section

III.

NH-3213.33 Ratcheting.

Ratcheting is a progressive cyclic inelastic deformation. Total inelastic strain per cycle may vary from cycle to cycle in the most general situation. Stable ratcheting occurs when the net inelastic strain from a given load cycle is constant for subsequent cycles.

(a) Progressive incremental inelastic deformation can occur in a component that is subjected to cyclic variations of mechanical secondary stress, thermal secondary stress, or both in the presence of a primary stress.

(b) Where creep effects are significant, creep ratcheting can occur, even in the absence of plastic yielding. At least two mechanisms are involved in creep ratcheting. First, creep can alter the residual stresses and thus affect the time-independent behavior. Secondly, the time-dependent deformation can be enhanced because of the nonlinear interaction of primary and secondary stresses. This latter effect is referred to as *enhanced creep*.

NH-3213.34 Shakedown.

Shakedown is the absence of significant progressive, cyclic, inelastic deformation, or ratcheting (NH-3213.23). A structure shakes down if, after a few cycles of load application, the deformation stabilizes.

NH-3213.35 Design Information on the Nameplate.

Design Information on the Nameplate are the Design Temperature and the Design Pressure for the zone of the structure nearest the pressure relief device (or the top of the component if there are no pressure relief devices). The values for these parameters shall appear on the nameplate.

NH-3213.36 Use-Fraction.

Use-fraction is the material damage due to primary stresses expressed as a time ratio.

NH-3213.37 Fatigue Damage.

Fatigue damage is that part of the total material damage caused by cyclic deformation which is independent of time effects (e.g., stress holdtime, strain holdtime, frequency). The damage is expressed in terms of a cycle ratio.

NH-3213.38 Creep Damage.

Creep damage is that part of the total material damage caused by time exposure to steady and transient stresses at elevated temperatures, expressed as a time ratio. (Relaxation damage is a form of creep damage.)

NH-3213.39 Creep-Fatigue Interaction.

Creep-fatigue interaction is the effect of combined creep and fatigue on the total creep-fatigue damage accumulated at failure.

NH-3214 Stress Analysis

A detailed stress analysis of all major structural components shall be prepared in sufficient detail to show that each rule or limit of NH-3220 and NH-3230 is satisfied when the component is subjected to the loadings described in NH-3111. This detailed analysis shall become a part of the Stress Report (NCA-3550).

NH-3214.1 Elastic Analysis.

The analysis guidelines and methods in Article NB-3000 apply (NH-3211). As an aid to the evaluation of these elastic stresses, formulas and methods for the solution of certain recurring problems have been placed in Appendix A of Section III.

NH-3214.2 Inelastic Analysis.

When thermal and mechanical loadings are sufficiently severe to produce yielding and/or when thermal creep processes are active, inelastic design analysis may be required. The rules and limits of Appendix T were established with the expectation that inelastic analyses would sometimes be required, and that such analyses would be sufficiently comprehensive to predict significant behavioral features. Generally, this requires analysis of combined time-independent elastic-plastic material behavior and time-dependent creep behavior capable of predicting stresses, strains, and deformations as functions of time for specific thermal-mechanical load histories.

The constitutive equations, which describe the inelastic behavior, should reflect the following features when they have a significant influence on structural response: the effects of plastic strain hardening including cyclic loading effects and the hardening or softening which can occur with high temperature exposure; primary

Page 24

creep and the effects of creep strain hardening as well as softening (due to reverse loadings); and the effects of prior creep on subsequent plasticity, and vice versa.

The basis for choosing the selected methods and relations used should be included in the Design Report.

Since the rules and limits incorporate design factors and margins to account for material property variations and uncertainties, it is generally appropriate to use average stress-strain and creep data in inelastic design analyses. The buckling and instability limits of Appendix T are an exception; in T-1510(g) it is stated that the minimum expected stress-strain curve should be used.

NH-3214.3 Mechanical Properties.

The values of some mechanical properties needed for analysis are listed in Appendix I-14 and in Appendix T. Properties covered include:

- (a) isochronous stress-strain curves
- (b) yield strength
- (c) stress-to-rupture
- (d) modulus of elasticity
- (e) instantaneous and mean coefficients of thermal expansion

Other mechanical property relations used in the analysis shall be described and justified in the Stress Report.

NH-3215 Derivation of Stress Intensities

One requirement for the acceptability of a design (NH-3210) is that the calculated stress intensities shall not exceed specified allowable limits. These limits differ depending on the stress category (primary, secondary, etc.) from which the stress intensity is derived. This paragraph describes the procedure for the calculation of the stress intensities which are subject to the specified limits. The steps in the procedure are stipulated in the following subparagraphs.

(a) At the point on the component which is being investigated, choose an orthogonal set of coordinates such as tangential, longitudinal, and radial, and designate them by the subscripts, t , l , and r . The stress components in these directions are then designated σ_t , σ_l , and σ_r for direct stresses and τ_{lt} , τ_{lr} , and τ_{rt} for shearing stresses.

(b) Calculate the stress components for each type of loading to which the part will be subjected and assign each set of stress values to one or a group of the following categories:

- | | |
|-------|---|
| F | = peak stress components as defined in NH-3213.11. Tables NH-3217-1 and NH-3217-2 provide assistance in the determination of the category to which a stress should be assigned. |
| P_b | = primary bending stress components at a surface as defined in NH-3213.8 |

P_m, P_I

= average primary stress components as defined in NH-3213.8 and NH-3213.10

 Q

= secondary stress components as defined in NH-3212.9

It should be noted that each of the symbols for the above stress categories represents six scalar quantities corresponding to the six stress components, $\sigma_t, \sigma_l, \sigma_r, \tau_{lt}, \tau_{lr},$ and τ_{rt} . In the particular case of the six membrane stress components, each component shall be averaged across the thickness of the structural section.²

(c) For each category, calculate the algebraic sum of the σ_i values which result from the different types of loadings and similarly for the other five stress components. Certain combinations of the categories must also be considered.

(d) Translate the stress components for the $t, l,$ and r directions into principal stresses, $\sigma_1, \sigma_2,$ and σ_3 . (In many pressure component calculations, the $t, l,$ and r directions may be so chosen that the shearing stress components are zero and $\sigma_1, \sigma_2,$ and σ_3 are identical to $\sigma_t, \sigma_l,$ and σ_r .)

(e) Calculate the stress differences $S_{12}, S_{23},$ and S_{31} from the relations:

$$S_{12} = \sigma_1 - \sigma_2$$

$$S_{23} = \sigma_2 - \sigma_3$$

$$S_{31} = \sigma_3 - \sigma_1$$

The stress intensity, S , is the largest absolute value of $S_{12}, S_{23},$ and S_{31} .

NH-3216 Derivation of Stress Differences and Strain Differences

The ability of the component to withstand the specified cyclic operation without creep-fatigue failure shall be determined as in NH-3250. The evaluation shall demonstrate, by evaluating the stresses and strains at selected points of the components, that the combined creep-fatigue damage is everywhere within design limits. Only the stress and strain differences due to the operational cycles as specified in the Design Specifications need be considered.

NH-3217 Classification of Stresses

Tables NH-3217-1 and NH-3217-2 provide assistance in the determination of the category to which a stress

Page 25

_____ should be assigned. For portions of the component not exposed to elevated temperature service, the classification or _____ category may be selected as in NB-3000. Pages 26-26

TABLE NH-3217-1
CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES

Vessel Component	Location	Origin of Stress	Type of Stress	Classification
Cylindrical or spherical shell	Shell plate remote from discontinuities	Internal pressure	General membrane Gradient through plate thickness	P_m Q
		Axial thermal gradient	Membrane Bending	Q [Note (1)] Q
	Junction with head or flange	Internal pressure	Membrane Bending	P_L Q [Note (2)]
Any shell or head	Any section across entire vessel	External load or moment, or internal pressure	General membrane averaged across full section. Stress component perpendicular to cross section	P_m
		External load or moment	Bending across full section. Stress component perpendicular to cross section	P_m
	Near nozzle or other opening	External load or moment, or internal pressure	Local membrane Bending Peak (fillet or corner)	P_L Q F
	Any location	Temp. diff. between shell and head	Membrane Bending	Q [Note (1)] Q
Dished head or conical head	Crown	Internal pressure	Membrane Bending	P_m P_b
	Knuckle or junction to shell	Internal pressure	Membrane Bending	P_L [Note (3)] Q
Flat head	Center region	Internal pressure	Membrane Bending	P_m P_b
	Junction to shell	Internal pressure	Membrane Bending	P_L Q [Note (2)]
Perforated head or shell	Typical ligament in a uniform pattern	Pressure	Membrane (Av. thru cross section) Bending (Av. thru width of lig., but gradient thru plate) Peak	P_m P_b F
	Isolated or atypical ligament	Pressure	Membrane Bending Peak	Q F F

(Table continued on next page)

TABLE NH-3217-1 CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES

**TABLE NH-3217-1 (CONT'D)
CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES**

Vessel Component	Location	Origin of Stress	Type of Stress	Classification
Nozzle (NH-3227.5)	Within the limits of reinforcement defined by NH-3334	Pressure and external loads and moments including those attributable to restrained free end displacements of attached piping	General membrane Bending (other than gross structural discontinuity stresses) averaged through nozzle thickness	P_m P_m
	Outside the limits of reinforcement defined by NH-3334	Pressure and external axial, shear, and torsional loads other than those attributable to restrained free end displacements of attached piping	General membrane stresses	P_m
		Pressure and external loads and moments other than those attributable to restrained free end displacements of attached piping	Membrane Bending	P_L P_b
		Pressure and all external loads and moments	Membrane Bending Peak	P_L Q F
	Nozzle wall	Gross structural discontinuities at nozzle to shell junction	Local membrane Bending Peak	P_L Q F
	Any	Differential expansion	Membrane Bending Peak	Q [Note (1)] Q F
Cladding	Any	Differential expansion	Membrane Bending	F F
Any	Any	Radial temp. Distribution [Note (5)]	Equivalent Linear stress [Note (4)]	Q
			Nonlinear portion of stress distribution	F
Any	Any	Any	Stress concentration (notch effect)	F

NOTES:

- (1) These classifications may be modified for purposes of certain criteria in Appendix T.
- (2) If the bending moment at the edge is required to maintain the bending stress in the middle to acceptable limits, the edge bending is classified as P_b . Otherwise, it is classified as Q .
- (3) Consideration must also be given to the possibility of wrinkling and excessive deformation in vessels with large diameter-to-thickness ratio.
- (4) Consider possibility of thermal stress ratched (see NH-3250).
- (5) Equivalent linear stress is defined as the linear stress distribution which has the same net bending moment as the actual stress distribution.

TABLE NH-3217-1 (CONT'D) CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES

TABLE NH-3217-2
CLASSIFICATION OF STRESS INTENSITY IN PIPING, TYPICAL CASES

Piping Component	Locations	Origin of Stresses	Classification [Note (1)]	Discontinuities Considered	
				Gross	Local
Pipe or tube, elbows, and reducers. Intersections and branch connections except in the crotch regions	Any, except crotch regions of intersections	Internal pressure	P_m	No	No
			P_L and Q	Yes	No
			F	Yes	Yes
		Sustained mechanical loads including weight	P_b	No	No
			P_L and Q	Yes	No
		Expansion	F	Yes	Yes
			P_m , P_b , and Q [Notes (1), (2)]	Yes	No
Intersections, including tees and branch connections	In the crotch region	Axial thermal gradient	F	Yes	Yes
			Q [Note (1)]	Yes	No
			F	Yes	Yes
		Internal pressure, sustained mechanical loads, and expansion	P_L and Q [Note (3)]	Yes	No
			F	Yes	Yes
		Axial thermal gradient	Q [Note (1)]	Yes	No
			F	Yes	Yes
Bolts and flanges	Any	Internal pressure, gasket compression, bolt load	P_m	No	No
			Q	Yes	No
			F	Yes	Yes
		Thermal gradient	Q [Note (1)]	Yes	No
			F	Yes	Yes
		Expansion	P_m , P_b , and Q [Notes (1) and (2)]	Yes	No
			F	Yes	Yes
Any	Any	Nonlinear radial thermal gradient	F	Yes	Yes
		Linear radial thermal gradient	Q [Note (1)]	Yes	No

NOTES:

(1) These classifications may be modified for purposes of certain criteria in Appendix T.

(2) See NH-3138 and NH-3213.8.

(3) Analysis is not required when reinforced in accordance with NH-3643.

TABLE NH-3217-2 CLASSIFICATION OF STRESS INTENSITY IN PIPING, TYPICAL CASES

NH-3220 DESIGN RULES AND LIMITS FOR LOAD CONTROLLED STRESSES IN STRUCTURES OTHER THAN BOLTS

NH-3221 General Requirements

(a) The rules for design against failure from load controlled stresses are illustrated in Fig. NH-3221-1 and are explained in NH-3220. The allowable stress intensity values used in NH-3220 are listed in Tables 2A and 2B of Section II, Part D, Subpart 1 and Tables I-14.0. Note that the strain, deformation, and fatigue limits of NH-3250 require analyses beyond those required by the rules of NH-3220.

(b) The stress intensity limits used in Fig. 3221-1 and throughout this Subsection are defined for base metal and at weldments as follows:

(1) *Base Metal*

S_m

= the lowest stress intensity value at a given temperature among the time-independent strength quantities which are

defined in Section II, Part D as criteria for determining S_m ; in Subsection NH, the S_m values are extended to elevated temperatures by using the same criteria.

= the allowable limit of general primary membrane stress intensity to be used as a reference for stress calculations for the actual service life and under the Level A and B Service Loadings; the allowable values are shown in Figs. I-14.3 and in Tables I-14.3. The S_{mt} values are the lower of two stress intensity values, S_m (time-independent) and S_t (time-dependent).

S_{mt}

Page 28

Page 29

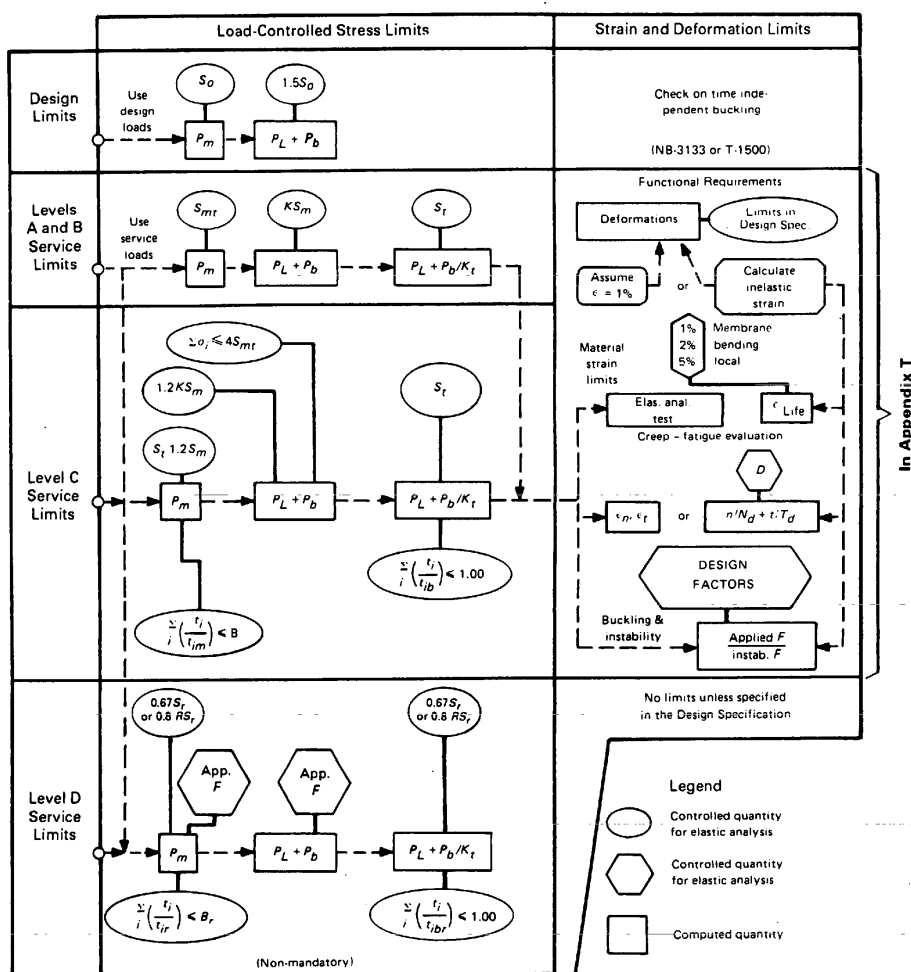


FIG. NH-3221-1 FLOW DIAGRAM FOR ELEVATED TEMPERATURE ANALYSIS

FIG. NH-3221-1 FLOW DIAGRAM FOR ELEVATED TEMPERATURE ANALYSIS

S_o = the maximum allowable value of general primary membrane stress intensity to be used as a reference for stress calculations under Design Loadings. The allowable values are given in Table I-14.2. [The values correspond to the S values given in Section II, Part D, Subpart 1, Table 1A, except for a few cases at lower temperatures where values of S_{mt} (defined below and given in Tables I-14.3) at 300,000 hours exceed the S values. In those limited cases, S_o is equal to S_{mt} at 300,000 h rather than S .]

S_t = a temperature and time-dependent stress intensity limit; the data considered in establishing these values are obtained from long-term, constant load, uniaxial tests. For each specific time, t , the S_t values shall be the lesser of: (1) 100% of the average stress required to obtain a total (elastic, plastic, primary, and secondary creep) strain of 1%; (2) 80% of the minimum stress to cause initiation of tertiary creep; and (3) 67% of the minimum stress to cause rupture.

S_y = the yield strength of a material at a given temperature

(2) Weldments

S_{mt} = the allowable limit of general primary membrane stress intensity, and shall be taken as the lower of the S_{mt} values from Tables I-14.3, or:

$$0.8 S_r \times R$$

S_t = temperature and time-dependent stress intensity limit at a weldment, and shall be taken as the lower of the tabulated S_t values from Tables I-14.4, or:

$$0.8 S_r \times R$$

where

R = the appropriate ratio of the weld metal creep rupture strength to the base metal creep rupture strength from Tables I-14.10. The lowest S_t value of the adjacent base metals shall be utilized for the weldment.

S_r = the expected minimum stress-to-rupture strength given in Tables I-14.6

NH-3222 Design and Service Limits

NH-3222.1 Design Limits.

The stress calculations required for the analysis of Design Loadings (NH-3113.1) shall be based on a linearly elastic material model. The calculated stress intensity values shall satisfy the limits of (a) and (b) below.

(a) The general primary membrane stress intensity, derived from P_m , shall not exceed S_o^4

$$(1) P_m \leq S_o$$

(b) The combined primary membrane plus bending stress intensity, derived from P_L and P_b , shall not exceed $1.5 S_o$:

$$(2) (P_L + P_b) \leq (1.5) S_o$$

Note that the local primary membrane stress, P_L , includes the general primary membrane stress, P_m . As in Subsection NB, the left-hand side of Eq. (2) does not represent a simple algebraic combination since P_L and P_b may each represent as many as six quantities [NH-3215(b)].

(c) External pressure and other compression inducing loadings shall be investigated for adequate buckling strength, using the limits of NB-3133 or other limits and time-independent factors permitted under NH-3252.

NH-3222.2 Level A Service Limits.

The stress intensity limits for Level A Service Limits (NH-3113.3) also apply to the stresses under both Level A and B Service Loadings. The limits for both are given in NH-3223.

NH-3223 Level A and B Service Limits

The stress calculations required for the analysis of Level A and B Service Loadings (NH-3113.4) are based on a linearly elastic material model. The calculated stress-intensity values shall satisfy the conditions of (a) through (f) below.

(a) The general primary membrane stress intensity, derived from P_m for Level A and B Service Loadings, shall not exceed S_{mt} :

$$(3) P_m \leq S_{mt}$$

⁴ To satisfy Eq. (1) for straight cylindrical shapes, the minimum wall thickness may be calculated by the equations in PG-27 of Section I, Power Boilers, using S_o in place of S .

where S_{mt} is determined for the time, t , corresponding to the total duration of the particular loading during

Page 30

the entire service life, and for temperature, T , corresponding to the maximum wall averaged temperature that occurs during the particular loading event.

(b) When time, t , [in (a) above] is less than the total specified service life of the component, the cumulative effect of all the loadings shall be evaluated by the use-fraction sum in NH-3224(b). In addition, it is permissible and often advantageous to subdivide a loading history into several load levels and into several temperatures at any given load level.

(c) The combined primary membrane plus bending stress intensities, derived from P_L and P_b for Level A and B Service Loadings, shall satisfy the following limits with:

$$(4) P_L + P_b \leq K S_m$$

$$(5) P_L + P_b / K_t \leq S_t$$

The factor K_t accounts for the reduction in extreme fiber bending stress due to the effect of creep. The factor is given by:

$$(6) K_t = (K + 1) / 2$$

The factor, K , is the section factor for the cross section being considered. It is the ratio of the load set producing a fully plastic section to a load set producing initial yielding of the extreme fiber of the cross section. In evaluating the initial yield and fully plastic section capabilities, the ratios of each individual load in the respective load set to each other load in that load set shall be the same as the respective ratios of the individual loads in the specified service load set. Values of K for various sections are given in Table A-9521(b)-1 of Appendix A of Section III.

(d) In evaluating across-the-wall bending of shell type structures, $K = 1.5$ (for rectangular sections) shall be used. Thus, for across-the-wall shell bending, $K_t = 1.25$ in Eq. (6). Note that the classification of stresses of primary membrane or primary bending for use with these section factors shall be consistent with the specific rules for the component type (see NH-3300 to NH-3600).

(e) In Eq. (5), the S_t value is determined for the time, t , corresponding to the total duration of the combined stress intensity derived from P_L and P_b / K_t and the maximum wall averaged temperature, T , during the entire service life of the component.

(f) When t is less than the total service life of the component, the cumulative effect of all $[P_L + (P_B/K_T)]$ loadings shall be evaluated by the use-fraction sum of NH-3224(d). It is permissible and often advantageous to separate a loading history into several load levels and into several temperatures at any given load level.

(g) Under all conditions where a bending loading occurs across a section, the propensity for buckling of that part of the section in compression shall be investigated under the requirements of NH-3250.

NH-3224 Level C Service Limits

The stress calculations required for Level C Service Loadings analysis are based on a linearly elastic material model. The calculated stress intensity values shall satisfy the conditions of (a) through (d) below.

(a) The general primary membrane stress intensity, derived from P_m for Level C Service Loadings, shall not exceed the smaller of $1.2 S_m$ and $1.0 S_t$:

$$P_m \leq \begin{cases} 1.2 S_m \\ 1.0 S_t \end{cases} \quad (7)$$

(7)

(b) In addition, the use-fraction sum associated with the general primary membrane stresses for all increments of primary loadings during Levels A, B, and C Loadings shall satisfy the following requirements:

$$\sum_i \left(\frac{t_i}{t_{im}} \right) \leq B \quad (8)$$

(8)

where

B

= use-fraction factor and is equal to 1.0 [or less if so specified in the Design Specifications (NCA-3250)]

t_i

= the total duration of a specific loading, P_{mT} , at elevated temperature, T , during the entire service life of the component.

Note that

$$\sum_i (t_i)$$

is that part of the component service life at elevated temperatures (i.e., temperatures above values governed by the rules of Subsection NB as explained in NH-3211).

t_{im}

= maximum allowed time under the load stress intensity, S_p , as determined from a graph of S_t -vs-time (see Figs. I-14.4.)

The use of Figs. I-14.4 for determining t_{im} for two loading conditions at two different temperatures is shown schematically in Fig. NH-3224-1. In Fig. NH-3224-1, P_{mi} ($i = 1, 2, 3$, etc.) represents the calculated membrane stress intensity for the loading condition and temperature in question; and T_i represents the maximum local wall averaged temperature during t_i . Note that it may be desirable to consider that a given stress intensity,

Page 31

P_{mi} acts during several time periods, t_p , in order to take credit for the fact that the temperature varies with time.

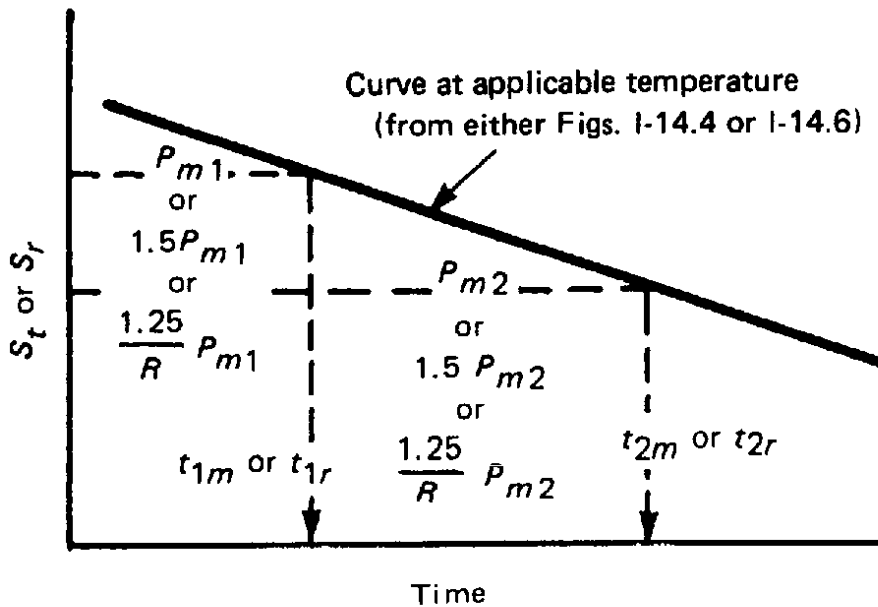


FIG. NH-3224-1 USE-FRACTIONS FOR MEMBRANE STRESS

FIG. NH-3224-1 USE-FRACTIONS FOR MEMBRANE STRESS

(c) The combined primary membrane plus bending stress intensities, derived from P_L and P_b for Level C Service Loadings, shall satisfy the following limits, with $1.0 < K \leq 1.5$:

$$(9) P_L + P_b \leq 1.2 K S_m$$

$$(10) P_L + P_b / K_t \leq S_t$$

where K_t is defined as in NH-3223(c).

(d) In addition, the sum of the use-fractions associated with the primary membrane plus bending stresses for all increments of primary loadings during Levels A, B, and C Service Loadings shall not exceed the value, 1.00:

$$\sum_i \left(\frac{t_i}{t_{ib}} \right) \leq 1.00 \quad (11)$$

(11)

where

t_i

= the total duration of the loading at temperature, T_i ; and

t_{ib}

= the time value determined by entering Figs. I-14.4 at a value of stress equal to $P_L + P_b / K_p$ as shown in Fig. NH-3224-2.

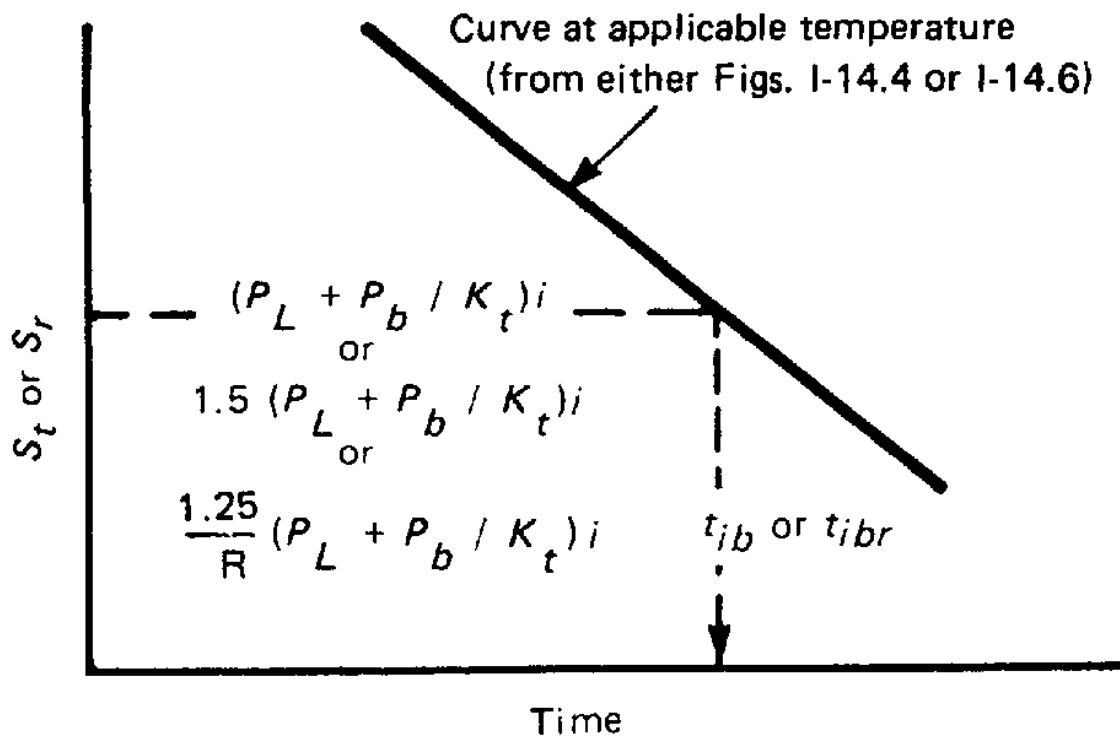


FIG. NH-3224-2 USE-FRACTIONS FOR MEMBRANE PLUS BENDING STRESS

FIG. NH-3224-2 USE-FRACTIONS FOR MEMBRANE PLUS BENDING STRESS

NH-3225 Level D Service Limits

The rules of this paragraph may be used in the evaluation of components subjected to loads specified as Level D Service Loadings.

(a) The rules in NH-3225 (and in Appendix F of Section III) shall be applied in all instances unless alternative or supplementary criteria, as required by public health and safety considerations for specific components or systems, are defined in, and made applicable by, the Owner's Design Specifications [NCA-3250]. The type of analysis (elastic or inelastic) used by the system designer shall be indicated in the Design Specifications (see F-1322.1).

(b) The general primary membrane stress intensity, derived from P_m for the Level D Service Loadings, shall not exceed the smaller of $0.67 S_p$, $0.8 RS_p$, and one of the Level D Service Limits in Appendix F of Section III:

$$P_m \leq \begin{cases} \text{Limit in Appendix F for } P_m \\ 0.67 S_r \\ 0.8 RS_r \end{cases} \quad (12)$$

(12)

where

R

= the appropriate ratio of the weld metal creep fatigue strength to the base metal strength from Tables I-14.10

S_r

= the expected minimum stress-to-rupture in time t taken from Figs. I-14.6

(c) In addition, the use-fraction sum associated with the general primary membrane stresses that arise from all Service Loadings, shall satisfy the requirement:

Page 32

$$\sum_i \left(\frac{t_i}{t_{ir}} \right) \leq B_r$$

where

B_r

= use-fraction factor and is equal to 1.0 (or less if so specified in the Design Specifications [NCA-3250])

t_i

= the total duration of a specific loading, P_{mi} , at elevated temperature, T_i , during the entire service life of the component. Note that

$$\sum_i (t_i)$$

is that part of the component service life at elevated temperatures (i.e., temperatures above values governed by the rules of Subsection NB, as explained in NH-3211).

t_{ir}

= maximum allowed time under the load stress intensity $1.5 P_{mi}$ for base metal or, for weldments, the higher of $1.5 P_{mi}$ ($1.25/R$) P_{mi} . The allowable time under load is determined from the graph of minimum stress-to-rupture vs time (see Figs. I-14.6).

The use of Figs. I-14.6 for determining t_{ir} for two loading conditions at two different temperatures is shown schematically in Fig. NH-3224-1. In Fig. NH-3224-1, $1.5 P_{mi}$ ($i = 1, 2, 3$, etc.) represents 1.5 times the calculated membrane stress intensity for the loading condition and temperature in question, and T_i represents the maximum local wall averaged temperature during t_i . Note that it may be desirable to consider that a given stress intensity acts during several time periods, t_p , in order to take credit for the variation of temperature with time.

(d) The combined primary membrane plus bending stress intensities, derived from P_L and P_b , shall satisfy the following limits, with $1.0 \leq K \leq 1.5$, and Level D Service Limits in Appendix F for $P_L + P_b$:

$$P_L + P_b/K_t \leq \begin{cases} 0.67 S_r \\ 0.8 RS_r \end{cases} \quad (13)$$

(13)

where K_t is defined in NH-3223(c).

(e) In addition, the sum of the use-fraction associated with the primary membrane plus bending stresses that arise from all Service Loadings, shall not exceed the value of 1.00:

$$\sum_i \left(\frac{t_i}{t_{ibr}} \right) \leq 1.00$$

where

t_i

= the total duration of loading at temperature, T_i

t_{ibr}

= the time value determined by entering Figs. I-14.6 at a value of stress equal to $1.5 (P_L + P_b/K_t)$ for base metal or higher of $1.5 (P_L + P_b/K_t)$ and $1.25 (P_L + P_b/K_t)/R$ for weldments as shown in Fig. NH-3224-2

(f) For the purpose of Section III, Appendix F calculations, the yield strength and tensile strength values shall be defined as follows:

(1) Yield strength values shall be the product of the value shown in Table I-14.5 and the strength reduction factor shown in Tables NH-3225-2, NH-3225-3A, and NH-3225-3B.

(2) Tensile strength values shall be the product of the value shown in Table NH-3225-1 and the strength reduction factor shown in Tables NH-3225-2, NH-3225-3A, and NH-3225-3B, where the strength reduction factor is selected as a function of the accumulated time-temperature history to which the component has been exposed prior to the event under analysis. Where a component has been exposed to a varying temperature history, the reduction factor employed shall be determined by assuming that the component has operated at the maximum temperature throughout its prior operational life (exclusive of Level D Service Condition.)

NH-3226 Pressure Testing Limitations

During any static pressure testing, the following limits shall not be exceeded in any structural part:

- (a) The general primary membrane stress intensity shall not exceed 90% of the tabulated yield strength at temperature;
- (b) The primary membrane plus bending stress intensity shall not exceed 135% of the tabulated yield stress at temperature;
- (c) The external pressure shall not exceed 135% of the maximum pressure allowed by the design rules of NH-3250.

NH-3227

The following deviations from the basic stress limits are provided to cover special operating conditions or configurations. Some of these deviations are more restrictive, and some are less restrictive, than the basic stress limits. In cases of conflict between these requirements and the basic stress limits, the rules of NH-3227 take precedence for the particular situations to which they apply.

NH-3227.1 Bearing Loads

(a) The average bearing stress for resistance to crushing under the maximum load, experienced as a result

Page 33

of load categories other than Level D Service Loading, shall be considered.

TABLE NH-3225-1
TENSILE STRENGTH VALUES (S_u), ksi

For Metal Temperature Not Exceeding, °F	304 SS		316 SS	Ni-Fe-Cr Alloy 800H	2¼Cr-1Mo
At min. UTS	70.0	75.0	75.0	65.0	60.0
700	59.3	63.5	71.8	61.9	58.2
750	58.9	63.1	78.4	61.9	58.2
800	58.5	62.7	70.9	61.9	58.2
850	57.7	61.9	69.7	61.9	58.2
900	57.0	61.0	68.5	61.8	58.2
950	55.4	59.4	66.5	61.2	58.2
1,000	53.9	57.7	64.4	60.2	54.7
1,050	51.6	55.3	61.9	59.0	48.8
1,100	48.5	52.0	58.6	56.8	36.6
1,150	45.4	48.6	55.3	54.0	35.3
1,200	42.4	45.4	51.2	50.4	26.1
1,250	39.3	42.1	47.0	47.1	...
1,300	35.4	37.9	42.9	43.5	...
1,350	30.8	33.0	38.8	39.0	...
1,400	27.0	28.9	33.8	33.7	...
1,450	23.1	24.7	29.7	...	...
1,500	19.3	20.7	24.8	...	...

GENERAL NOTES:

- The tabulated values of tensile strength and yield strength are those which the Committee believes are suitable for use in design calculations required by this Section. At temperatures above room temperature, the values of tensile strength tend toward an average or expected value which may be as much as 10% above the tensile strength trend curve adjusted to the minimum specified room temperature tensile strength. At temperatures above room temperature, the yield strength values correspond to the yield strength trend curve adjusted to the minimum specified room temperature yield strength. Neither the tensile strength nor the yield strength values correspond exactly to either *average* or *minimum* as these terms are applied to a statistical treatment of a homogeneous set of data.
- Neither the ASME Material Specifications nor the rules of this Section required elevated temperature testing for tensile or yield strengths of production material for use in Code components. It is not intended that results of such tests, if performed, be compared with these tabulated tensile and yield strength values for ASME Code acceptance/rejection purposes for materials. If some elevated temperature test results on production material appear lower than the tabulated values by a large amount (more than the typical variability of material and suggesting the possibility of some error), further investigation by retest or other means should be considered.

TABLE NH-3225-1 TENSILE STRENGTH VALUES (S_u), ksi

The average bearing stress for Service Levels A, B, and C shall be limited to the lesser of:

- (1) the tabulated yield strength at the Service Temperature; or
 - (2) the stress at 0.2% offset strain as obtained from the isochronous stress-strain curve for the temperature of service and for the time duration equal to the total service life the component is expected to spend at temperatures greater than those listed in Tables 2A and 2B of Section II, Part D, Subpart 1.
- (b) For clad surfaces, the properties of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.

Page 34

**TABLE NH-3225-2
TENSILE AND YIELD STRENGTH REDUCTION
FACTOR DUE TO LONG TIME PRIOR
ELEVATED TEMPERATURE SERVICE**

Material	Service Temp., °F	YS Reduction Factor	TS Reduction Factor
304SS	≥ 900	1.00	0.80
316SS	≥ 900	1.00	0.80
800E	≥ 1,350	0.90	0.90
2 $\frac{1}{4}$ Cr-1Mo	≥ 800	[Note (1)]	[Note (1)]

GENERAL NOTE: No reduction factor required for service below the indicated temperature.

NOTE:

(1) See Tables NH-3225-3A and NH-3225-3B.

TABLE NH-3225-2 TENSILE AND YIELD STRENGTH REDUCTION FACTOR DUE TO LONG TIME PRIOR ELEVATED TEMPERATURE SERVICE

TABLE NH-3225-3A
YIELD STRENGTH REDUCTION FACTORS FOR 2¹/₄Cr-1Mo

Temp., °F	1.E0	1.E1	3.E1	1.E2	3.E2	1.E3	3.E3	1.E4	3.E4	1.E5	3.E5
700	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
750	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
800	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
850	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.92
900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.93	0.86
950	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.91	0.85	0.80
1,000	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.91	0.85	0.79	0.74
1,050	1.00	1.00	1.00	1.00	1.00	0.96	0.90	0.84	0.78	0.72	0.67
1,100	1.00	1.00	1.00	1.00	1.00	0.91	0.85	0.79	0.73	0.68	0.63
1,150	1.00	1.00	1.00	1.00	0.94	0.86	...	...	...	...	...
1,200	1.00	1.00	1.00	0.96	0.89	0.82	...	...	...	...	...

TABLE NH-3225-3A YIELD STRENGTH REDUCTION FACTORS FOR 2¹/₄Cr-1Mo

TABLE NH-3225-3B
TENSILE STRENGTH REDUCTION FACTORS FOR 2¹/₄Cr-1Mo

Temp., °F	1.E0	1.E1	3.E1	1.E2	3.E2	1.E3	3.E3	1.E4	3.E4	1.E5	3.E5
700	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
750	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
800	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.94
850	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.92	0.88
900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.92	0.86	0.82
950	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.91	0.86	0.82	0.77
1,000	1.00	1.00	1.00	1.00	1.00	0.97	0.92	0.86	0.82	0.76	0.72
1,050	1.00	1.00	1.00	1.00	1.00	0.92	0.88	0.82	0.77	0.71	0.67
1,100	1.00	1.00	1.00	1.00	0.94	0.88	0.83	0.77	0.72	0.67	0.62
1,150	1.00	1.00	1.00	0.95	0.89	0.83	...	...	...	...	...
1,200	1.00	1.00	1.00	0.90	0.84	0.78	...	...	...	...	...

TABLE NH-3225-3B TENSILE STRENGTH REDUCTION FACTORS FOR 2¹/₄Cr-1Mo

(c) When bearing loads are applied near free edges, such as at a protruding edge, the possibility of a shear failure shall be considered. The average shear stress shall be limited to $0.6 S_{mt}$ in the case of load controlled stresses. For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

NH-3227.2 Pure Shear

(a) The average primary shear stress across a section loaded in pure shear (for example, keys, shear rings, screw threads), experienced as a result of any loading categories other than Level D Service Loadings, shall be limited to $0.6 S_{mt}$

(b) The maximum primary shear stress, experienced as a result of any loading categories other than Level D Service Loadings, exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.8 S_{mt}$

NH-3227.3 Progressive Distortion of Nonintegral Connections.

Screwed on caps, screwed in plugs, shear

Page 35

ring closures, and breech lock closures are examples of nonintegral connections which are subject to failure by bell mouthing or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operational cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Such nonintegral connections shall not be used where service temperatures are expected to exceed those associated with allowable stress intensity values for the specific materials as shown in Tables 2A and 2B of Section II, Part D, Subpart 1.

NH-3227.4 Triaxial Stresses.

The algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) shall not exceed four times the tabulated value of S_{mt}

NH-3227.5 Nozzle Piping Transition.

The P_m classification of stresses resulting from pressure, external loads, and moments is applicable for that length of nozzle which lies within the limits of reinforcement given by NB-3334, whether or not nozzle reinforcement is provided. Beyond the limits of reinforcement, a P_m classification shall be applied to the general primary membrane stress intensity averaged across the section (not thickness) resulting from combined pressure and external mechanical loads; a P_L or $P_L + P_b$ classification shall be respectively applied to local primary membrane or local primary membrane plus bending stress intensities that result from design pressure and external mechanical loads; and a $P_L + P_b + Q$ classification shall be applied to primary plus secondary stress intensities resulting from all loads including external load or moment attributable to restrained free end displacement of the attached pipe.

NH-3227.7 Requirements for Specially Designed Welded Seals

(a) Welded seals, such as omega and canopy seals (NB-4360), shall be designed to meet the pressure-induced general primary membrane stress intensity limits specified in Subsection NH for their materials of fabrication. Note that the general primary membrane stress intensity varies around the toroidal cross section.

(b) All other membrane and bending stress intensities developed in the welded seals may be considered as secondary stress intensities or peak stress intensities, as appropriate.

NH-3227.8 Cladding.

The rules of (a) through (d) below apply to the analysis of clad components constructed of material under this Subsection.

(a) *Load Controlled Stresses.* No structural strength shall be attributed to the cladding in satisfying the load controlled stress limits in NH-3200.

(b) *Design Dimensions.* The dimensions stipulated in (1) and (2) below shall be used in the design of the component.

(1) For components subjected to internal pressure, the inside diameter shall be taken at the nominal inner face of the cladding;

(2)

metal.

(c) *Deformation Controlled Quantities.* No structural strength shall be attributed to the cladding in satisfying requirements on buckling instability. However, the cladding shall be considered in all other calculations related to satisfying limits on deformation controlled quantities.

(d) *Bearing Stresses.* In satisfying (a), the presence of cladding shall be included.

NH-3230 STRESS LIMITS FOR LOAD CONTROLLED STRESSES ON BOLTS

NH-3231 General Requirements

(a) Elevated temperature components which contain bolts not exposed to elevated temperature service may be designed using the materials, design methods, and design limits of Subsection NB (NB-3230 and Appendix E of Section III).

(b) Bolts which are to experience elevated temperature service shall comply with the requirements of NH-3230.

NH-3232 Design Limits for Bolts at Elevated Temperatures

(a) The number and cross-sectional area of bolts required to resist the design pressure may be determined in accordance with the procedures of Appendix E of Section III, using the larger of the bolt loads given by the equations of Appendix E of Section III as a design mechanical load. The reference allowable bolt design stress intensity values shall be the S_o values given in Table I-14.12 for bolting materials.

(b) When the seal is effected by a seal weld and no gasket is used, the gasket factor, m , and the minimum design seating stress, y , may be taken as zero.

Page 36

(c) When gaskets are used for preservice testing only, the design shall be acceptable if the requirements of (a) above are satisfied using $m = y = 0$, and the requirements of NH-3233 are satisfied using the appropriate m and y factors for the test gasket.

NH-3233 Level A and B Service Limits for Bolts at Elevated Temperatures

NH-3233.1 Average Stress.

The maximum value of stress due to pressure loading, averaged across the bolt cross section and neglecting stress concentrations, shall not exceed the S_{mt} stress values of Table I-14.13C. The rules of NH-3232 shall apply except for the S_{mt} values replacing S_o values.

NH-3233.2 Maximum Stress in the Cross Section.

The maximum values for service stresses (averaged across the bolt cross section and neglecting stress concentrations), such as those produced by a combination of preload, pressure, and thermal expansion, shall not exceed two times the S_{mt} values of Figs. I-14.13 unless the design lifetime is divided into two or more loading periods and the possibility of creep rupture due to membrane stresses is guarded against by satisfying the use-fraction rule described in NH-3224(b), with the use-fraction factor, B , set equal to 0.5.⁵ Stress intensity, rather than maximum stress, shall be limited to this value when bolts are tightened by devices which result in residual torsion stresses. Residual torsion stresses are minimized by devices such as heaters and stretchers.

NH-3233.3 Maximum Stress in the Bolt Periphery.

The maximum value of service stress at the periphery of the bolt cross section (resulting from tension-plus-bending and neglecting stress concentrations) shall not exceed the lesser of three times the S_{mt} values in Figs. I-14.13 or $K_t S_t$ unless the design lifetime is divided into two or more loading periods and the possibility of creep rupture due to bending stresses is guarded against by satisfying the use-fraction rule described in NH-3224(d), but with the use-fraction set at 0.67 instead of 1.0.⁵ Stress intensity, rather than maximum stress, shall be limited to this value when bolts are tightened by devices which result in residual torsion stresses. Residual torsion stresses are minimized by devices such as heaters

and stretchers.

NH-3233.4 Nonductile Fracture.

The rules of NH-3241 shall apply to bolts.

5 S_t values to be used are twice those given in Table I-14.13C.

NH-3234 Level C Service Limits

The limits of NH-3233 shall apply to primary loads in bolts.

NH-3235 Level D Service Limits

The rules of NH-3225 shall apply to primary loads in bolts.

NH-3240 SPECIAL REQUIREMENTS FOR ELEVATED TEMPERATURE COMPONENTS

NH-3241 Nonductile Fracture

(a) A portion of the Stress Report (NCA-3550) shall justify the ability of the component to withstand the expected service conditions without undergoing nonductile fracture. Even though components are not expected to fail by nonductile fracture while at elevated temperatures, the stress relaxation occurring under elevated temperature conditions will often lead to high residual stresses during the portion of the operational cycle with lowest temperatures. For loading times, stresses, and temperatures where creep effects are not significant (NH-3211), an acceptable procedure for nonductile failure prevention is given in Appendix G of Section III for ferritic materials. When Appendix G of Section III is not applicable, the fracture analysis shall consider the anticipated stress level and flaw size, and compare these conditions with the fracture toughness of the material in the flaw region and at the appropriate temperature.

(b) The above justification requirements do not apply to Type 304 SS, Type 316 SS, or Alloy 800H, unless the fabrication effects substantially alter the fracture characteristics of these materials in such a manner that nonductile fracture becomes a plausible failure mode. The Design Specifications shall state when and how environmental effects shall be considered for nonductile fracture behavior in these materials.

NH-3250 LIMITS ON DEFORMATION CONTROLLED QUANTITIES

NH-3251 General Requirements

The strains and deformation resulting from the specified operating conditions shall be evaluated. This evaluation shall include the effects of ratcheting, the interaction of creep and fatigue, and the possibility of buckling and structural instability. The N Certificate Holder shall

Page 37

document, as a portion of the Design Report (NCA-3550), what effects and conditions were considered the final analysis procedures, the evaluation criteria, and the conclusions of the evaluation.

NH-3252 Criteria

It is the responsibility of the Owner to define the acceptability criteria to be applied as buckling, strain, deformation, and fatigue limits in the Design Specifications (NCA-3250). The acceptability criteria and material properties contained in Appendix T may be used. However, alternative criteria may be applied by the Manufacturer subject to approval by the Owner. The Owner's approval shall be indicated by incorporating the alternative criteria into the Design Specifications.

NH-3300 VESSEL DESIGNS

NH-3310 GENERAL REQUIREMENTS

NH-3311 Acceptability

(a) The requirements for acceptability of Class 1 vessel design are stated in NH-3111.1.

(b) In cases of conflict between this Subarticle and the rules of Subarticles NH-3100 and NH-3200, the requirements of NH-3300 shall govern.

NH-3330 OPENINGS AND REINFORCEMENT

NH-3331 General Requirements for Openings

(a) For vessels or parts thereof which meet the requirements of NH-3330, the analysis limits of NH-3220 related to load controlled stresses need not be demonstrated in the vicinity of the openings. However, the deformation controlled limits (NH-3250) shall be satisfied in the vicinity of any opening exposed to conditions where creep effects are significant [NH-3211(c)].

(b) Openings (for nozzle, branch, and piping connections) using deposited weld metal as reinforcement, as shown in Fig. NB-4244(c)-1, shall be limited to nominal diameters of 4 in. or less.

(c) If it is shown by analysis that all of the requirements of NH-3200 have been met for the structural material near an opening, then the rules of NH-3332 through NH-3339 are waived.

NH-3332 Reinforcement Requirements for Openings in Shells and Formed Heads

The rules of NB-3332 shall apply except that:

(a) The $1.1 S_m$ limit, which defines a locally stressed area, shall be replaced by $1.1 S_{mt}$. The S_{mt} value shall correspond to the time equal to the service life of the vessel.

(b) t_r is the thickness which meets the requirements for primary membrane and primary membrane plus bending under Level A and B Service Loadings.

NH-3333 Reinforcement Required for Openings in Flat Heads

The requirements of NB-3333 shall apply, with the t_r defined as in NH-3332.

NH-3334 Limits of Reinforcement

The requirements of NB-3334 shall apply.

NH-3335 Metal Available for Reinforcement

The requirements of NB-3335 shall apply except that subparagraph (a) is replaced by:

(a) metal forming a part of the vessel wall which is in excess of t_r (as defined in NH-3332) and is exclusive of corrosion allowance;

NH-3336 Strength of Reinforcing Material

(a) Material used for nozzle wall reinforcement shall be made of the same alloy type as that of the vessel wall, and the strength properties shall be assumed equivalent to those of the vessel wall material.

(b) When the deposited weld metal is used as reinforcement, the coefficients of thermal expansion of the base metal, the weld metal, and the nozzle shall not differ by more than 15% of the lowest coefficient involved.

NH-3337 Attachment of Nozzles and Other Connections

NH-3337.1 General Requirements.

Nozzles and other Category D connections (NH-3351) shall be attached to the shell or head of the vessel by one of the methods provided in NH-3352.

NH-3337.2 Full Penetration Welded Nozzles.

Full penetration nozzle welds, as shown in Figs. NB-4244(a)-1, NB-4244(b)-1, NB-4244(c)-1, and NB-4244(e)-1, may be used (except as otherwise provided in NH-3337.3)

Page 38

for the purpose of achieving continuity of metal and facilitating the required radiographic examination. When all or part of the required reinforcement is attributable to the nozzle, the nozzle shall be attached by full penetration welds through either the vessel or the nozzle thickness, or both.

NH-3337.3 Partial Penetration Welded Nozzles

(a) Partial penetration welds, as shown in Figs. NB-4244(d)-1 and NB-4244(d)-2, are allowed only for attachments on which there are essentially no piping reactions. Examples of such attachments include control rod housings, pressurized heater attachments, and openings for instrumentation.

(b) Earthquake loadings normally need not be considered in determining whether piping reactions are substantial. However, such loadings shall be considered if significant creep effects can occur at the nozzle.

(c) For such attachments, all reinforcement shall be integral with the portion of the vessel penetrated. Partial penetration welds shall be of sufficient size to develop the full strength of the attachment.

(d) Nozzles attached by partial penetration welds shall have an interference fit or a maximum diametral clearance between the nozzle and the vessel penetration of:

- (1) 0.010 in. for $d \leq 1$ in.
- (2) 0.020 in. for $1 \text{ in.} < d \leq 4$ in.
- (3) 0.030 in. for $d > 4$ in.

where d is the outside diameter of the nozzle.

(e) The ratio of nominal nozzle diameter to that of the main vessel shall be 0.1 or less.

(f) If significant creep effects occur in the vicinity of the nozzle, the use of partial penetration welds shall be restricted to nozzles with nominal diameters of 1 in. (25 mm) or less.

NH-3338 Pressure Stresses in Openings for Fatigue Evaluation

The rules of NB-3338 apply only to stress, temperature, and time conditions in which creep phenomena are insignificant [NH-3211(c)]. For conditions where creep effects are significant, the rules of NH-3250 apply. Hence, openings not exposed to elevated temperatures are meeting the fatigue requirements of Subsection NB.

NH-3339 Alternative Rules for Nozzle Design

The rules of NB-3339 apply only when the elastic model analysis of NH-3338 is also applicable.

NH-3350 DESIGN OF WELDED CONSTRUCTION

NH-3351 Welded Joint Category

The term *Category*, as used herein, defines the location of a joint in a vessel, but not the type of joint. The categories established by this paragraph are for use in specifying special requirements regarding joint type and degree of examination for certain welded pressure joints. Since these special requirements, which are based on service, material, and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in the categories. The special requirements will apply to joints of a given category only when specifically so stated. The joints included in each category are designated as joints of Categories A, B, C, and D. Figure NH-3351-1 illustrates typical joint locations included in each category.

NH-3351.1 Category A.

Category A comprises longitudinal welded joints within the main shell, communicating chambers,⁶ transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head, or within the side plates⁷ of a flat sided vessel; and circumferential welded joints connecting hemispherical heads to main shells, to main shells, to transitions in diameters, to nozzles, or to communicating chambers.⁶

NH-3351.2 Category B.

Category B comprises circumferential welded joints within the main shell, communicating chambers,⁶ nozzles, or transitions in diameter, including joints between the transition and a cylinder at either the large or small end; circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers.⁶

NH-3351.3 Category C.

Category C comprises welded joints connecting flanges, Van Stone laps, tube-sheets, or flat heads to main shell, to formed heads, to transitions in diameter, to nozzles, or to communicating chambers⁶ any welded joint connecting one side plate⁷ to another side plate of a flat sided vessel.

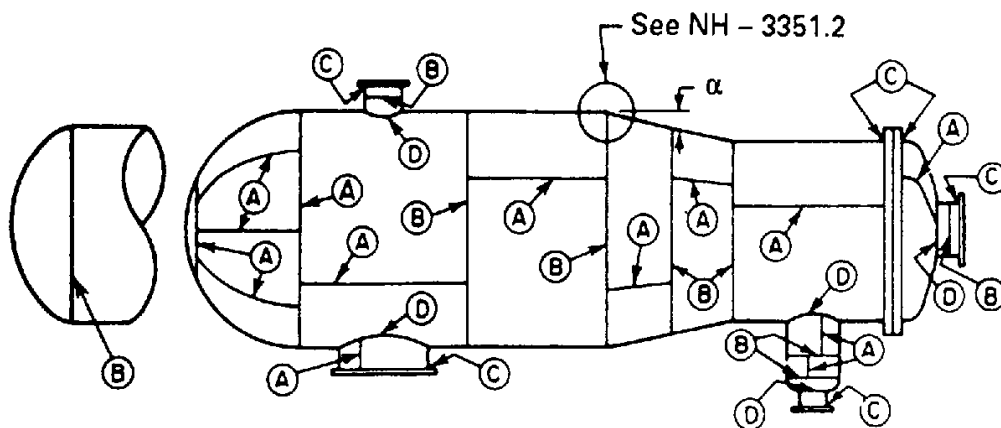
NH-3351.4 Category D.

Category D comprises welded joints connecting communicating chambers⁶ or nozzles to main shells, to spheres, to transitions in diameter, to heads or to flat sided vessels, and those joints connecting nozzles to communicating chambers.

⁶ Communicating chambers are defined as appurtenances to the vessel which intersect the shell or heads of a vessel and form an integral part of the pressure retaining closure, e.g., sumps.

⁷ Side plates of a flat-sided vessel are defined as any of the flat plates forming an integral part of the pressure retaining enclosure.

For nozzles at the small end of a transition in diameter, see Category B.



**FIG. NH-3351-1 WELDED JOINT LOCATIONS
TYPICAL OF CATEGORIES A, B, C, AND D**

NH-3352 Permissible Types of Welded Joints

(a) The permissible types of welded joints and their dimensional requirements are described in the rules for fabrication of Class 1 components for elevated temperature service.

(b) The design of the vessel shall meet the requirements for each category of joint. Butt joints are full penetration joints between plates or other elements that lie approximately in the same plane. Category B angle joints between plates or other elements that have an offset angle, α , not exceeding 30 deg are considered as meeting the requirements for butt joints. Figure NH-3352-1 shows typical butt welds for each category joint.

(c) When Category B joints with opposing lips to form an integral backing strip or joints with backing strips not later removed are used, the suitability for cyclic operation shall be analyzed using a fatigue strength reduction factor of not less than 2 under conditions where creep effects are insignificant [NH-3211(c)]. For conditions where creep effects are significant, see NH-3353(b).

(d) The corners of the end of each nozzle neck extending less than $\sqrt{d_r t_n}$ beyond the inner surface of the part penetrated, shall be rounded to a radius of one-half the thickness, t_r of the nozzle neck, or $\frac{3}{4}$ in. (19 mm), whichever is smaller. The d is the outside diameter of the nozzle.

(e) Where partial penetration welds are used, a fatigue strength reduction factor of not less than 4 shall be used for any related fatigue and analysis under conditions where creep effects are insignificant [NH-3211(c)]. For conditions where creep effects are significant, see NH-3353(b).

(f) Oblique full penetration nozzles are permitted provided (1), (2), and (3) below are satisfied.

(1) The opening shall be completely reinforced, with the reinforcement located in the shell or head of the vessel.

(2) The nozzle shall be subjected to essentially no pipe reactions and no thermal stresses greater than in the vessel itself.

(3) The nozzle wall and the weld shall develop the full strength of the nozzle.

(g) Non-full penetration welds, which are permitted by NH-3354 and NH-3356 at attachment welds, shall have a surface geometry free from weld irregularities and abrupt changes in contour. When the designer determines that contour control is required in order that the criteria of this Subsection be satisfied, the necessary dimensions and tolerances shall be indicated on the fabrication drawings.

(h) Full penetration corner welds [as shown in Figs. NB-4243-1 and NB-4244(b)-1, and defined as Categories C and D vessel welds, or, as similar welds for piping, pumps, and valves] shall be limited to nominal diameters of 4 in. or less.

NH-3353 Design of Welded Construction at Elevated Temperatures

(a) Because of the potential for limited ductility of weld metal at elevated temperatures and the potential for high strain concentrations (both metallurgical and geometric) in the heat affected zones of weldments, the analysis requirements of this paragraph shall be satisfied for the design and location of all pressure

Page 40

retaining and other primary structural welds subjected to metal temperatures where creep effects are significant (NH-3211). The potential for reduced ductility often precludes locating welds in regions of high loading.

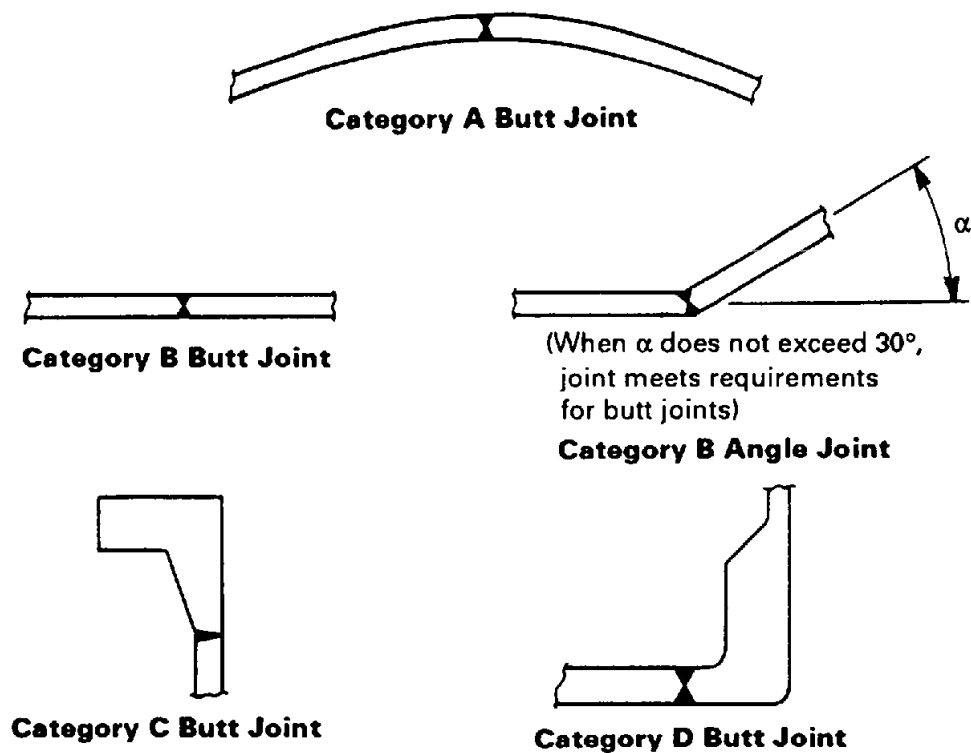


FIG. NH-3352-1 TYPICAL BUTT JOINTS

FIG. NH-3352-1 TYPICAL BUTT JOINTS

(b) For meeting the analysis requirements of NH-3251 at elevated temperature weld regions, the assumed weld surface should model the most severe strain concentrations expected in the actual weld placed in service. This geometry may be prescribed on a drawing or may be recorded by prior observation. Prior observations of weld surface geometry can be visual; remote visual (e.g., using a borescope device or making a surface replica); or ultrasonic, based on a weld mockup test in which the same weld procedures are used on the same nominal pipe diameter and wall thickness, or based on a radiographic technique that is suitable for inspection of internal surfaces.

NH-3354 Structural Attachment Welds

(a) Welds for structural attachments shall meet the requirements of NB-4430, NB-4240, and the rules of NH-3352(g).

(b) Those attachments using the exemption of NH-2121(h) shall also comply with the design rules listed below.

(1) The attachment weld shall be located on a rib outside the limits of reinforcement as defined by NB-3334 (see example in Fig. NH-3354-1). The rib may be fabricated by forging, machining, or weld metal build-up.

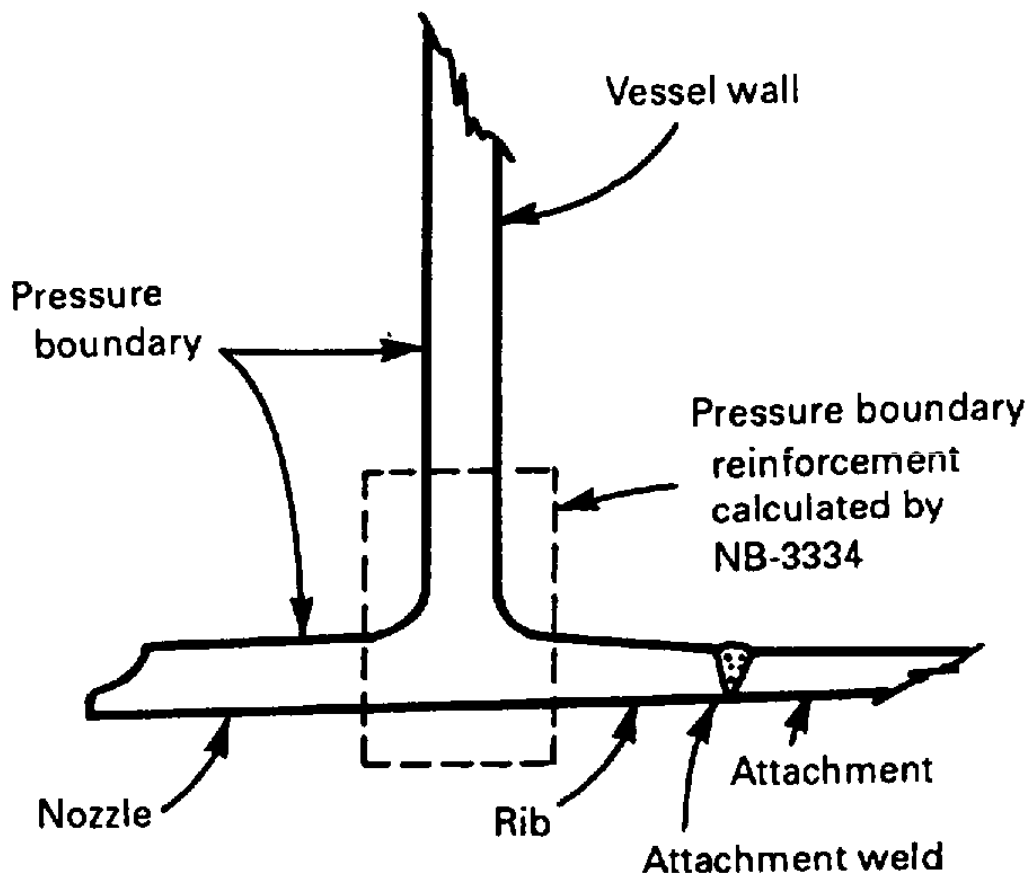


FIG. NH-3354-1 PERMISSIBLE ATTACHMENT WELD LOCATION

FIG. NH-3354-1 PERMISSIBLE ATTACHMENT WELD LOCATION

(2) The attachment weld shall comply with the rules for Class 1 pressure boundary welds.

Page 41

(3) Loads on the pressure boundary from all permanent attachments shall be considered in the analysis in the Stress Report.

NH-3355 Welding Grooves

The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint

penetration.

NH-3356 Fillet Welds

NH-3356.1 At Pressure Loaded Joints.

Fillet welds are not permitted for pressure-retaining joints [see NH-3337.3 and NH-3352(g)].

NH-3356.2 At Structural Attachment Joints

(a) Fillet welds conforming to Fig. NB-4427-1 may be used for structural attachments to components, except as restricted and limited by the rules of NB-4433.

(b) Analysis limits for stress limits, strain limits, and damage limits shall be one-half of the allowable values under NH-3200 rules for the weaker of the two base materials being joined.

(c) Evaluation for fatigue shall use a fatigue strength reduction factor of four, and shall include consideration of temperature differences between the component and the attachment and of expansion (or contraction) of the component as a result of internal (or external) pressure.

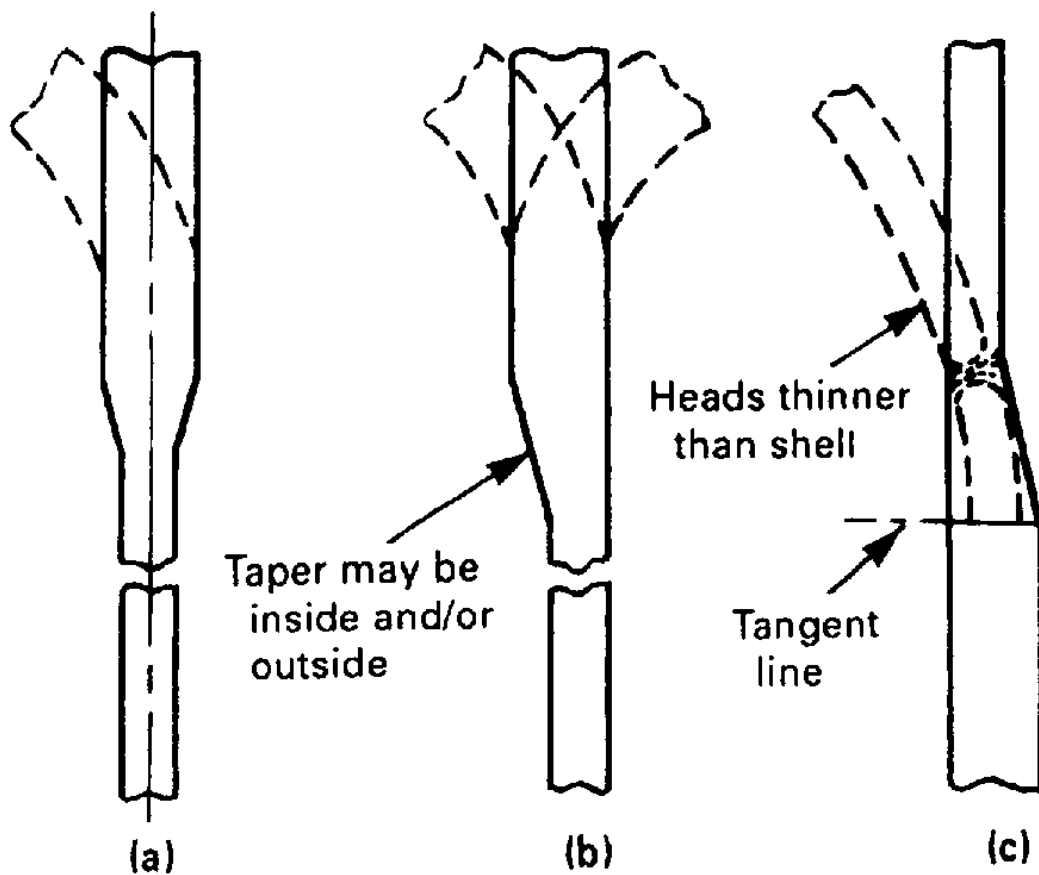
NH-3357 Thermal Treatment

All pressure vessels and pressure vessel parts shall be given the appropriate postweld heat treatment prescribed in NB-4620.

NH-3360 SPECIAL VESSEL REQUIREMENTS

NH-3361 Category A or B Joints Between Sections of Unequal Thickness

In general, a tapered transition section as shown in Fig. NH-3361-1, which is a type of gross structural discontinuity (NH-3213.2), shall be provided at joints of Categories A and B between sections that differ in thickness by more than one-fourth the thickness of the thinner section. The transition section may be formed by any process that will provide a uniform taper. An ellipsoidal or hemispherical head which has a greater thickness than a cylinder of the same inside diameter may be machined to the outside diameter of the cylinder provided the remaining thickness is at least as great as that required for a shell of the same diameter. The adequacy of the transition shall be evaluated by stress analysis. See NH-3200 for stress intensity limitations and other rules. The requirements of this paragraph do not apply to flange hubs.



GENERAL NOTE: Length of taper may include the width of the weld.

**FIG NH-3361-1 CATEGORY A AND B JOINTS
BETWEEN SECTIONS OF UNEQUAL THICKNESS**

FIG. NH-3361-1 CATEGORY A AND B JOINTS BETWEEN SECTIONS OF UNEQUAL THICKNESS

NH-3362 Bolted Flange Connections

It is recommended that the dimensional requirements of bolted flange connections to external piping conform to ANSI B16.5, Steel Pipe Flanges and Flanged Fittings.

NH-3363 Access Openings

Access openings, where provided, shall preferably consist of handhole or manhole openings having removable covers.

These covers may be located on either the inside or outside of the shell or head openings and may be attached by studs or bolts in combination with gaskets and/or welded membrane seals or strength welds. Plugs using pipe threads are not permitted.

NH-3364 Supports

All vessels shall be so supported and the supporting members shall be arranged and attached to the vessel wall in such a way as to provide for the maximum imposed loadings. The stresses produced in the vessel by such loadings and by steady state and transient

Page 42

thermal conditions shall be subjected to the stress limits of Subsection NH (NCA-3240 and Subsection NF).

NH-3400 DESIGN OF CLASS 1 PUMPS

NH-3410 GENERAL REQUIREMENTS

NH-3410.1 Scope.

The rules of this Subarticle constitute requirements for the design of Class 1 pumps.

(a) The scope of these rules covers the strength and pressure integrity of the structural parts of pumps whose failure would violate the pressure boundary.

(b) Such parts include:

(1) pump casing

(2) pump inlets and outlets

(3) pump cover

(4) clamping ring

(5) seal housings

(6) related bolting

(7) pump internal heat exchanger piping

(8) pump auxiliary nozzle connections up to the face of the first flange or circumferential joint, except as noted below

(9) piping identified with the pump and external to or forming a part of the pressure retaining boundary and supplied with the pump

(10) mounting feet or pedestal supports when integrally attached to the pump pressure retaining boundary and supplied with the pump

(c) The requirements of this Subarticle do not apply to the pump shaft, nonstructural internals, or the seal package. Compliance with the requirements of this Subarticle does not guarantee proper functioning of the component.

NH-3410.2 Definitions

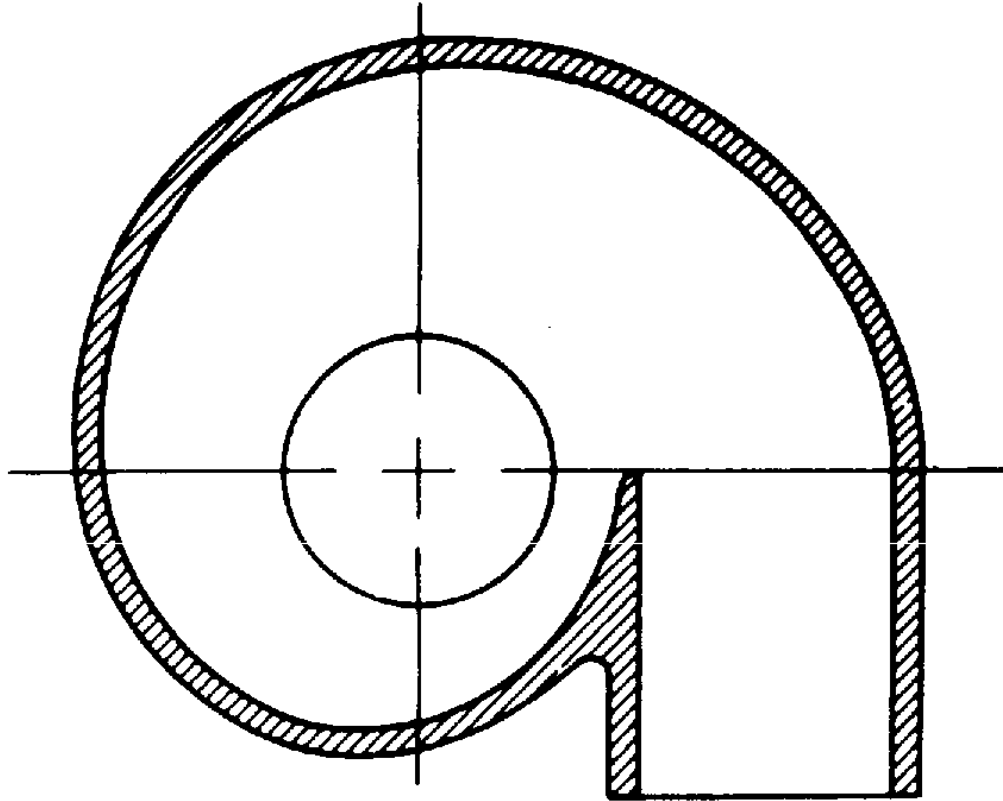
(a) A radially split casing shall be interpreted as one in which the primary sealing joint is radially disposed around the shaft.

(b) An axially split casing shall be interpreted as one in which the primary sealing joint is axially disposed with respect to the shaft.

(c) Seal housing is defined as that portion of the pump cover or casing which forms the primary pressure boundary.

(d) The figures accompanying the pump types are intended to be typical examples to aid in the determination of a pump type and are not to be considered as limiting. Bearing locations and inlet and outlet orientations are optional.

(e) The seal gland plate is to be considered a part of the seal housing and therefore is subject to Code requirements. The seal chamber pressure shall be specified in the Design Specification.



**FIG. NH-3410.2-1 TYPICAL SINGLE VOLUTE
CASING**

FIG. NH-3410.2-1 TYPICAL SINGLE VOLUTE CASING

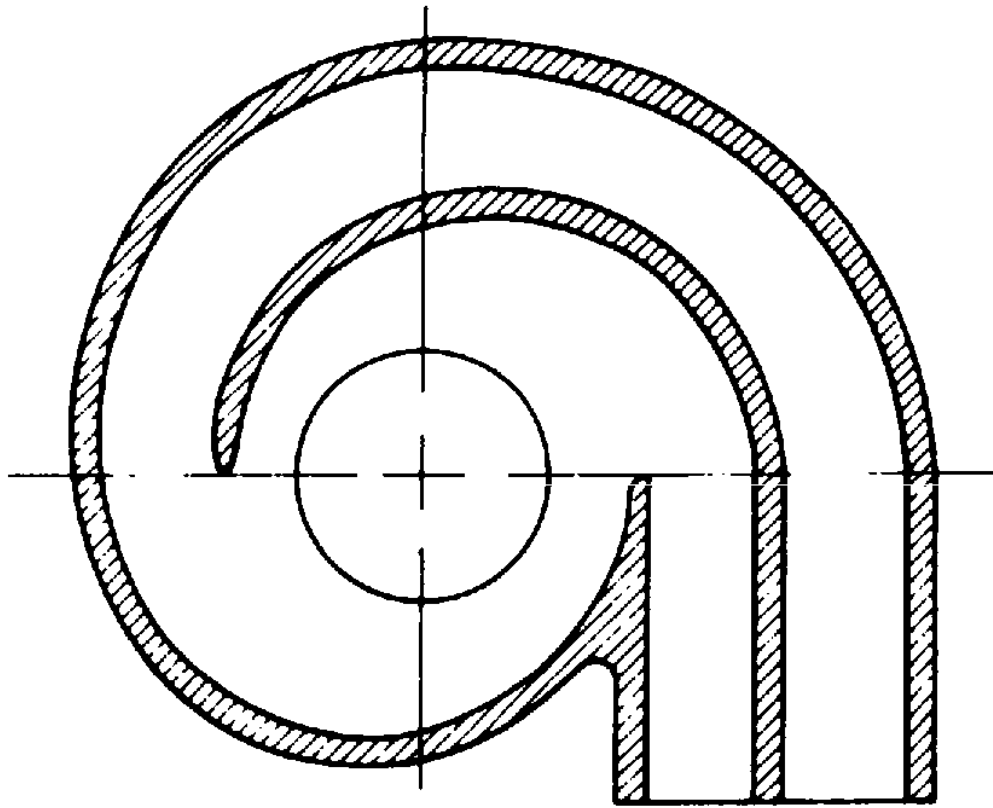


FIG. NH-3410.2-2 TYPICAL DOUBLE VOLUTE CASING

FIG. NH-3410.2-2 TYPICAL DOUBLE VOLUTE CASING

(f) Figures NH-3410.2-1 and NH-3410.2-2 show typical single and double volute casings, respectively.

NH-3411 Acceptability of Large Pumps

(a) The requirements for the design of a Class 1 pump having an inlet connection greater than 4 in. nominal pipe size diameter are stated in NH-3411.1.

(b) In cases of conflict between this Subarticle and the rules of Subarticles NH-3100 and NH-3200, the requirements of NH-3400 shall govern.

NH-3412 Acceptability of Small Pumps

(a) The requirements for the design of a Class 1 pump having an inlet connection 4 in. nominal pipe size diameter or smaller are stated in NH-3111.1.

(b) In cases of conflict between this Subarticle and the rules of Subarticles NH-3100 and NH-3200, the requirements of NH-3400 shall govern.

NH-3413 Alternative Design Rules

For any size Class 1 pump, an experimental stress analysis may be used to determine elastic stresses and strains used with NH-3200 limits and/or Appendix T limits provided (a) and (b) below are satisfied.

(a) The experimental stress analysis is in accordance with the procedures of Section III, Appendix II.

(b) The NH-3421 design requirements are met.

NH-3420 DESIGN CONSIDERATIONS

NH-3421 Design Requirements

NH-3421.1 Loadings.

Loadings, design and service conditions, special considerations, and general design rules are described in Subarticle NH-3100.

NH-3421.2 Piping Under External Pressure.

Piping located within the pressure retaining boundary of the pump shall be designed in accordance with NH-3250.

NH-3421.3 Piping Under Internal Pressure.

Piping identified with the pump and external to or forming a part of the pressure retaining boundary, such as auxiliary water connections, shall be designed in accordance with NH-3600.

NH-3421.4 Piping Connections Using Partial Penetration Welds.

Partial penetration welds are permitted for piping connections 2 in. and under in nominal pipe diameter (DN 50) when used in accordance with the rules of NH-3337.3 and NH-3352.

NH-3421.5 Bolting - Radially Split Configurations.

Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with the procedure described in NH-3230.

NH-3421.7 Supports.

Pump supports shall be designed in accordance with the requirements of Subsection NF if negligible creep effects are present during the cycle. Otherwise, the supports shall comply with NH-3200.

NH-3421.8 Axially Oriented Inlets and Outlets

(a) An axially oriented pump casing inlet or outlet shall be considered an opening in a vessel and will require reinforcement. It shall be treated as required in NH-3331 through NH-3336.

(b) To avoid stress concentrations, the outside radius r_2 Fig. NB-3441.3-2, shall not be less than one-half the thickness of the inlets and outlets as reinforced.

NH-3421.9 Radially Oriented Inlets and Outlets.

Reinforcement of radially oriented inlets and outlets is required. NH-3330 and NH-3421.11 shall apply.

NH-3421.10 Tangential Inlets and Outlets.

Reinforcement of tangential inlets and outlets is required. NH-3330 and NH-3421.11 shall apply.

NH-3421.11 Stress Analysis, Nozzle Loads, and Reinforcement

(a) *Stress Analysis.* The analysis methods in NB-3400 shall apply only to elastic analysis. In particular, stress equations may be used in satisfying the limits on load controlled stresses, and they may be applied to analysis under NH-3250 when creep effects are insignificant [NH-3211(c)].

(b) *Nozzle Loads.* The forces and moments produced by the connected piping on the pump inlet and outlet shall be furnished to the pump supplier by the user in accordance with NCA-3254.

(c) *Reinforcement.* The distance.. in Fig. NH-3421.11-1 is the limit of reinforcement. The value of.. shall be determined from the relationship:

$$.. = 0.5 \sqrt{r_m t_m} \text{ in., where}$$
$$r_m = r_i + 0.5 t_m \text{ in.}$$

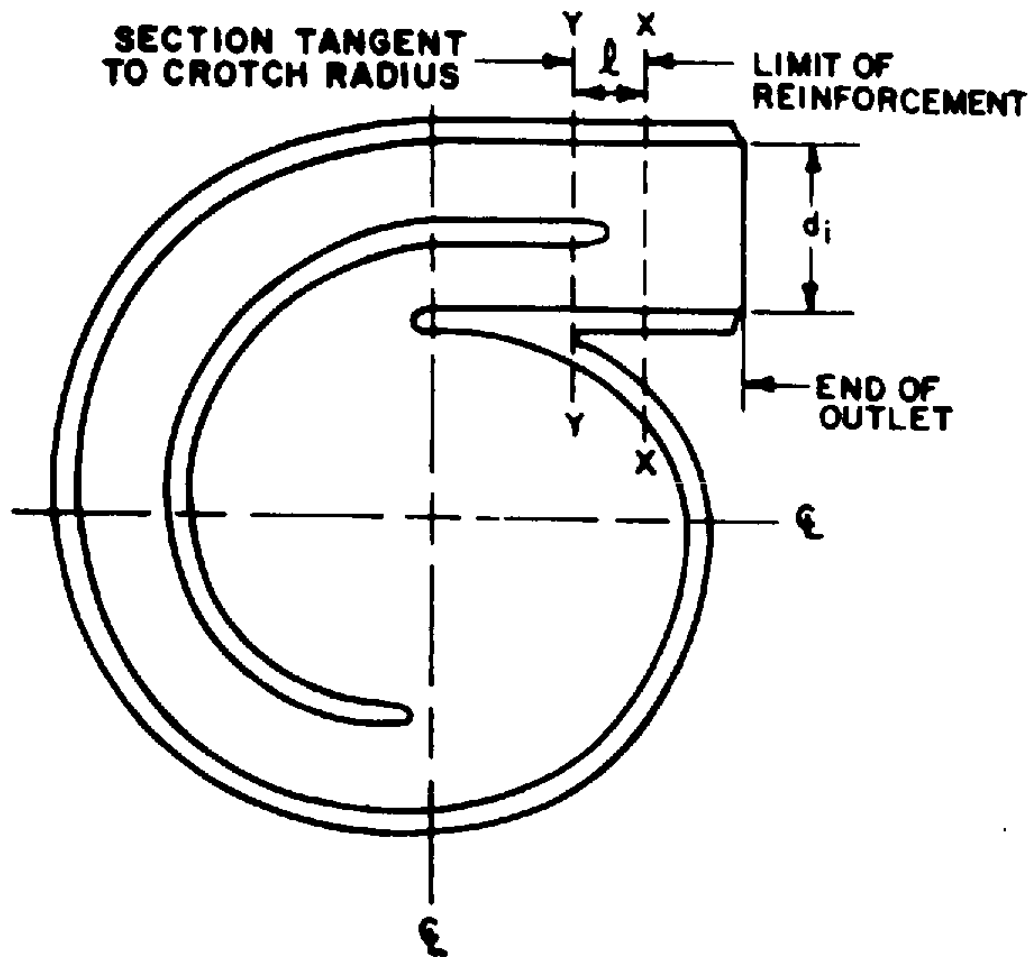
r_i	= inlet or outlet inside radius, = $d_i/2$, in.
t_m	= mean inlet or outlet wall thickness, in., taken between section x-x and a parallel section y-y tangent to crotch radius

NH-3421.12 Earthquake Design Analysis.

When earthquake loadings are specified in the Design Specification (NCA-3250), the designer shall assess the ability of the pump to withstand such loadings while maintaining the integrity of the pressure retaining materials. For example, the assessment should include inertia effects from moving parts and piping reactions.

NH-3421.13 Attachments.

Attachments are permitted when designed in accordance with NH-3135 and NB-4430.



**FIG. NH-3421.11-1 MINIMUM TANGENTIAL
INLET AND OUTLET WALL THICKNESS**

FIG. NH-3421.11-1 MINIMUM TANGENTIAL INLET AND OUTLET WALL THICKNESS

NH-3421.14 Appurtenances.

Appurtenances as defined in NCA-1260 are permitted provided the requirements for documentation are fulfilled as described in NCA-1231.

NH-3421.15 Pump Covers.

Pump covers shall be designed in accordance with NH-3200.

NH-3421.17 Cladding.

The design of clad pressure retaining parts shall be in accordance with NH-3227.8.

NH-3421.19 Cutwater Tip Stresses.

It is recognized that localized high stresses can occur at the cutwater tip of volute casings (Fig. NB-3441.3-2). Adequacy of the design in this area shall be demonstrated as follows:

(a) an evaluation of load controlled stresses showing that sufficient area is available in the volute casing to meet the stress limit of NH-3220; and

(b) an evaluation of the localized stress at the cutwater tip by:

(1) an investigation through experimental analysis in accordance with Section III, Appendix II; or by

(2) a detailed stress analysis; or by

(3) a combination of the above.

(c) Where experimental and/or detailed stress analysis is used, stress and strain intensity at this point shall meet the requirements of NH-3250.

NH-3430 PUMP TYPES

Design requirements for specific pump types are listed in NB-3430.

NH-3500 DESIGN OF CLASS 1 VALVES

NH-3510 DESIGN REQUIREMENTS

NH-3511 Acceptability

(a) The requirements for acceptability of a Class 1 valve design are stated in NH-3111.1.

(b) Compliance with the requirements of this Subarticle does not guarantee proper functioning of the component.

(c) In cases of conflict between this Subarticle and the rules of Subarticles NH-3100 and NH-3200, the requirements of NH-3500 shall govern.

NH-3512 Stress Analysis

The analysis methods in NB-3500 shall apply only to elastic analysis. In particular, the stress indices and stress equations may be used in satisfying the limits on load controlled stresses, or they may be applied to analyses under NH-3250 when creep effects are insignificant [NH-3211(c)].

NH-3524 Earthquake Design Analysis

(a) When earthquake loadings are specified in the Design Specifications (NCA-3250), the designer shall assess the ability of the valve to withstand such loadings while maintaining the integrity of the pressure boundary materials. For example, the assessment should include inertia effects from moving parts and piping reactions.

(b) Where valves are provided with operators having extended structures and the Design Specifications state that these structures are essential to maintaining pressure integrity, an analysis may be based on static forces resulting from equivalent earthquake accelerations acting at the centers of gravity of the extended masses.

NH-3526 Level C Service Limits

(a)

used in evaluating these conditions shall be those of NH-3510.

(b) If valve function must be assured during Level C Service Loadings, this requirement shall be included in the Design Specifications and the specified emergency

Page 45

conditions for the plant shall be considered as the Level A Service Loadings for the valve.

NH-3544 Body Shape Rules

The rules of NB-3544 provide a convenient guide for design of valve bodies for elevated temperature service. However, specific rules may be bypassed when justified by analysis.

NH-3546 Other Valve Parts

(a) For valve stems, stem retaining structures, and other significantly stressed valve parts whose failure can lead to gross violation of the pressure retaining boundary, the primary stresses shall not exceed the stress intensity limit, S_o . For materials not covered in Tables I-14.1 but allowed under the rules of NB-2121(c), the S_o values are those given in Tables 2A and 2B of Section II, Part D, Subpart 1.

(b) Valve designs requiring solenoid plunger type or electromagnetic indicator type core tubes may substitute NH-3600 rules to govern the requirements for the extension.

NH-3550 CYCLIC LOADING REQUIREMENTS

When cyclic conditions exist, the rules for analysis are covered by NH-3250 and NH-3512.

NH-3600 PIPING DESIGN

NH-3610 GENERAL REQUIREMENTS

NH-3611 Acceptability

(a) The requirements for acceptability of a Class 1 piping system design are stated in NH-3111.1.

(b) In cases of conflict between this Subarticle and the rules of Subarticles NH-3100 and NH-3200, the requirements of NH-3600 shall govern.

(c) The designer is cautioned to note that dimensional standards for pipe fittings control the minimum wall thickness, but do not establish maximum wall or contour. These additional dimensional controls may have to be imposed by the designer when significant thermal transients must be considered.

NH-3612 Pressure-Temperature Ratings for Piping Components

(a) Where piping systems operating at different pressures are connected by a valve, the valve shall be designed for the higher pressure system requirements of pressure and temperature. The lower pressure system may be designed to the higher pressure system requirements. If the lower pressure system is not designed to the higher pressure system requirements, pressure relief devices or safety valves shall be provided to protect the lower pressure system. The pressure relief devices or safety valves shall adjoin or be as close as possible to the interconnecting valve. All valves, devices, and piping related to pressure relief functions shall meet requirements for overpressure protection of systems operating at elevated temperatures.

(b) Where pressure reducing valves are used and one or more pressure relief devices or safety valves are provided, bypass valves may be provided around the pressure reducing valves. The combined relieving capacity requirements and operational requirements shall be given by the rules on overpressure protection.

(c) Drip lines from steam headers, mains, separators, or other equipment operating at different pressures shall not discharge through the same trap. Where several traps discharge into a single header that is or may be under pressure, a stop valve and a check valve shall be provided in the discharge line from each trap. The design pressure of trap discharge

piping shall not be less than the maximum discharge pressure to which it may be subjected. Trap discharge piping shall be designed for the same pressure as the trap inlet piping unless the discharge piping is vented to a system operated under lower pressure and has no intervening stop valves.

(d) Pump discharge piping shall be designed to withstand the maximum pressure exerted by the pump at any load, including that with a closed discharge valve, and for the highest coincident metal temperature.

(e) Where a fluid passes through heat exchangers in series, the design temperature of the piping in each section of the system shall conform to the most severe temperature condition expected to be produced by heat exchangers in that section of the system.

NH-3620 DESIGN CONSIDERATIONS

NH-3622 Dynamic Effects

NH-3622.1 Impact.

Impact forces caused by either external or internal conditions shall be considered in the piping design.

Page 46

NH-3622.2 Earthquake.

The effects of earthquake shall be considered in the design of piping supports and restraints. The loadings, movements (earthquake anchor movements), and number of cycles to be used in the analysis shall be part of the Design Specifications (NCA-3250). The stresses resulting from these earthquake effects must be included with weight, pressure, or other applied loads when making the required analysis.

NH-3622.3 Vibration.

Piping shall be arranged and supported so that vibration will be minimized. The designer shall be responsible, by design and by observation under startup or initial operating conditions, for ensuring that vibration of piping systems is within acceptable levels.

NH-3623 Weight Effects

Piping systems shall be supported to provide for the dynamic effects of any contained fluid and for the fixed weights of piping, insulation, and other imposed mechanical loads in the piping.

NH-3624 Loadings, Displacements, and Restraints

The design of piping systems shall take into account the forces and moments resulting from thermal expansion and contraction, equipment displacements and rotations, and the restraining effects of hangers, supports, and other localized loadings.

NH-3626 Special Drainage Problems

(a) For piping systems which must be drained, consideration shall be given to creep induced sag which may develop between pipe supports in elevated temperature systems.

(b) For piping systems which drain at intermediate or elevated temperatures, consideration shall be given to load cycles associated with this condition.

NH-3627 Considerations for Liquid Metal Piping

NH-3627.1 Location.

Routing of liquid metal piping in the vicinity of steam and water piping shall be avoided.

NH-3627.2 Heat Tracing.

Liquid metal piping shall be provided with heat tracing which shall be capable at least of maintaining the liquid metal in a molten condition. The use of steam or water for heat tracing shall not be permitted. Control of heat tracing shall provide for melting solidified liquid metal progressively from a free surface so that overpressure protection for the expansion of melting will not be required. Control shall also be adequate to assure that design rate of temperature change and temperature limits will not be exceeded.

NH-3627.3 Filling and Draining

(a) Liquid metal fill and drain shall be accommodated by means of an inert cover-gas purge and vent system. Volumetric expansion of liquid metal shall be provided for by a free liquid surface and a vented cover-gas space.

(b) All liquid metal piping shall be sloped to permit complete drainage by gravity into drain reservoirs. The use of small auxiliary drain lines shall be avoided.

NH-3640 PRESSURE DESIGN OF COMPONENTS

NH-3641.1 Straight Pipe.

The minimum wall thickness of pipe shall not be less than t_m , where t_m is determined from the requirements for Design Loadings analysis in NH-3222.1.

NH-3642 Curved Segments of Pipe

NH-3642.1 Pipe Bends.

The design of pipe bends shall provide that the completed bend will satisfy the analysis requirements of NH-3200. In addition to the basic dimensions of the bend (i.e., pipe diameter, wall thickness, and bend radius), the designer shall consider the secondary deformations and irregularities inherent to the bending process and shall define tolerances as needed to ensure conformance of the finished piping with the rules for analysis. In particular, the considerations of (a) through (e) below shall be taken into account.

(a) *Wall thickness* after bending shall not be less than the minimum wall thickness required for straight pipe.

(b) *Wall thinning and thickening.* Experience has shown that with good shop practices the relationship of the finished bend thickness to that of the straight pipe from which it is bent will be in accordance with Table NH-3642.1-1.

(c) *Ovality*

(d) *Wrinkling*, defined as the difference between the average outside diameter of any two adjacent wrinkles and the outside diameter of the enclosed valley, shall normally be held to 3%.

(e) *Surface irregularities*

**TABLE NH-3642.1-1
BEND RADIUS VS THICKNESS**

Radius of Bends	Minimum Thickness Recommended Prior to Bending [Note (1)]
6 pipe diameters or greater	1.06 t_m
5 pipe diameters	1.08 t_m
4 pipe diameters	1.16 t_m
3 pipe diameters	1.25 t_m

NOTE:

(1) t_m is the required minimum thickness of the finished bend.

TABLE NH-3642.1-1 BEND RADIUS VS THICKNESS

NH-3643 Intersections

The rules of NH-3643 may be satisfied by demonstrating, by analysis or experiment or both, that the component fully complies with the requirements of NH-3200.

NH-3643.1 General Requirements

(a) Openings shall be circular, elliptical, or of any other shape that results from the intersection of a circular or elliptical cylinder with a cylindrical shape.

(b) All references to dimensions in this and succeeding paragraphs apply to the finished dimensions, excluding material added for corrosion allowance.

(c) Any type of opening permitted in these rules may be located in a welded joint.

(d) The requirements of NB-3643.3 shall be met for the branch connections listed in NH-3642.1(b), (c) and (d), except that S_o and NH-3641.1 should be used instead of callouts (NB-3643.3) to S_m and NB-3641.1, respectively.

NH-3643.2 Branch Connections.

Branch connections in piping may be made by using one of the products or methods set forth in (a), (b), and (c) below.

(a) flanged, butt weld, or socket weld in accordance with the applicable ANSI standards listed in Table NB-3132-1, subject to the limitations or requirements stated elsewhere in this Subsection [for example, see NH-3660(b)];

(b) contour outlet fittings having integral reinforcement and attached by butt welding, or flanged ends for attachment to the branch pipe. These are limited to types that have integral reinforcement and are attached to the main run by welding, as illustrated in figures contained in the rules of NH-4000;

(c) an extruded outlet at right angles to the run pipe;

(d) For conditions where creep effects are insignificant [NH-3211(c)], intersecting pipes may be joined by welding the branch pipe to the run pipe as shown in Fig. NB-3643.3(a)-2. For such intersections, the intersection angle shall not be less than 60 nor greater than 120 deg.

NH-3644 Miters

Mitered joints may be used for elevated temperature service subject to meeting analysis requirements of NH-3200 and also complying with the requirements for fabrication. Maximum angles shall be $22\frac{1}{2}$ deg. or less.

NH-3645 Attachments

The rules of NH-3135 apply.

NH-3646 Closures

(a) Closures in piping systems may be made by use of closure fittings, such as blind flanges or welded plugs or caps.

(b) The use of such closures in elevated temperature service shall be subject to meeting the analysis requirements of NH-3200.

(c) For closures not subjected to elevated temperatures, the rules of NB-3646 shall apply.

NH-3647 Flanged Joints

(a) The use of flanged joints should be minimized.

(b) Any flanged joint shall be located where regular maintenance can be performed.

(c) Flanged joints exposed to elevated temperature service shall comply with the analysis requirements of NH-3200.

(d) Flanged joints not exposed to elevated temperatures shall meet the requirements of NB-3647.

NH-3648 Reducers

Reduced fittings shall be considered suitable for use subject to complying with the analysis requirements of NH-3200.

NH-3649 Pressure Design of Other Pressure Retaining Components

Other pressure retaining components manufactured in accordance with the standards listed in Table NB-3132-1 shall be considered suitable for use provided the design is consistent with the design philosophy embodied in Subsection NH. Pressure retaining components not included in Table NB-3132-1 may be used if they satisfy the requirements of NH-3200. The pressure

Page 48

design shall be based on an analysis consistent with the general design philosophy embodied in Subsection NH, or experimental stress analysis in accordance with NH-3649.1 below.

NH-3649.1 Experimental Analysis

(a) An experimental analysis, if used, shall adhere to the methods and principles in Appendix II, with changes appropriate for elevated temperature conditions.

(b) As part of the experimental analysis, an ANSI B16.9-type burst test shall be performed on the component. The

bursting pressure shall equal or exceed that of the weakest pipe to be attached to the component, where the pipe burst pressure is calculated by the equation:

$$P = 2 St/D_o$$

where

D_o	= outside diameter of pipe, in.
S	= specified minimum tensile strength of pipe material, psi
t	= minimum specified wall thickness of pipe, in.

NH-3650 ANALYSIS OF PIPING COMPONENTS

NH-3651 General Requirements

Until special rules for piping components are developed for elevated temperature service, the analysis requirements are given by (a) and (b) below.

(a) The structural analysis shall demonstrate (by analysis or experiment or both) that the component fully complies with the requirements of NH-3200.

(b) The stress indices and stress equations of NB-3600 may be used to define stress intensities whenever linearly elastic material models are appropriate, for example, in satisfying the limits on load controlled stresses (NH-3220), or in satisfying strain and deformation limits using elastic and simplified inelastic analyses (T-1320, T-1330, and T-1430).

NH-3660 DESIGN OF WELDS

(a) Weld designs shall comply with the requirements of NH-3350 and NH-3337.

(b) Socket welds and seal welded threads are generally not permitted for joints exposed to elevated temperature service. Exceptions shall be allowed only if the analysis requirements of this Subsection are satisfied at each junction and only if each application is specifically described as part of the Design Specifications (NCA-3250). In almost all systems containing nuclear coolant, such crevices and cracks are undesirable due to potential for trapped radioactive particles, problems with cleaning fluids, and impurities in the coolant. Joints allowed under the rules of this paragraph shall be limited to nominal diameters of 1 in. (25 mm) and smaller.

(c) Full penetration corner welds may be used (in addition to butt welds) for attaching branch connections and closures to piping in accordance with NH-3643.2 and NH-3646, respectively.

NH-3670 SPECIAL PIPING REQUIREMENTS

NH-3671 Nonwelded Piping Joints

NH-3671.1 Excluded Designs

(a) Flared, flareless, and compression-type tubing fittings shall not be used.

(b) Expanded joints shall not be used.

(c) Caulked or leaded joints shall not be used.

(d) Soldered joints shall not be used.

NH-3671.6 Brazed Joints.

The rules of NB-3671.6 apply. Any cooling liquid (or gas), including liquid sodium, is acceptable in the proximity of such joints provided the selected brazing material is compatible with the liquid.

NH-3671.7 Patented Joints.

Mechanical joints, for which no standards exist, and other patented joints may be used provided that:

- (a) Provision is made to prevent separation of the joints under all conditions of service;
- (b) They are accessible for maintenance, removal, and replacement after operation;

(c) A prototype joint has been subjected either to performance tests to determine the safety of the joint under simulated service conditions (including the service fluid), or the joint meets all analysis requirements of NH-3200. When vibration, fatigue, cyclic conditions, low temperature, thermal expansion, or hydraulic shock is anticipated, the applicable conditions shall be incorporated in the tests or analyses. The mechanical joints shall be sufficiently leak tight to satisfy the requirements of the Design Specifications (NCA-3250).

NH-3672 Expansion and Flexibility

(a) In addition to meeting the design requirements for pressure, weight, and other loadings, piping systems shall be designed to absorb or resist thermal expansion or contraction or similar movements imposed by other sources, and shall meet the criteria as specified in NH-3200.

Page 49

Piping systems shall be designed to have sufficient flexibility to prevent the movements from causing:

- (1) failure of piping or anchors from overstress or overstrain;
- (2) leakage at joints;
- (3) detrimental distortion of connected equipment resulting from excessive thrusts and moments.

(b) In this Subsection, the effects of stresses, caused by pressure, thermal expansion and other loads, and their stress intensification factors, are considered cumulatively.

(c) When calculating the flexibility of a piping system between anchor points, the system between the anchor points shall be treated as a whole. The significance of all parts of the line and of all restraints, such as supports or guides, including intermediate restraints introduced for the purpose of reducing moments and forces on equipment or small branch lines, shall be considered.

(d) Comprehensive calculations shall take into account the flexibility factors found to exist in components other than straight pipe. Credit may be taken where extra flexibility exists in such components.

(e) Calculations shall consider line expansion as well as linear and angular movements of the equipment and supports attached to the piping.

(f) Where assumptions are used in calculations or model tests, the likelihood of attendant underestimates of forces, moments, and stresses, including the effects of stress intensification, shall be evaluated.

(g) Cold springing may provide a beneficial effect in assisting a system to attain its most favorable position sooner and with the least initial inelastic straining. The effect of cold springing shall be analyzed as any other movement in the system is analyzed. The maximum stress allowed due to cold springing is $2.0 S_m$ at the cold spring temperature. Since the usual erection procedures may not permit accurate determination of cold spring in a piping system, the allowable reduction of forces and moments at anchors or equipment caused by cold springing shall be limited to no more than two-thirds of the calculated reduction. At elevated temperatures, creep and creep relaxation shall be considered in the analysis of the cold sprung piping and in establishing the steady state configuration of the piping system.

NH-3674 Design of Piping Supports

Pipe supports shall be designed in accordance with applicable rules of Subsection NF except for the stress analysis, which shall be in accordance with the rules of NH-3200.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NH-4000

ARTICLE NH-4000 FABRICATION AND INSTALLATION

Page 51

NH-4100 GENERAL REQUIREMENTS

NH-4110 INTRODUCTION

(a) Those portions of the component which do not experience elevated temperature service (as defined by the rules of NH-3000) may use the NB-4000 rules as applicable.

(b) Those portions of the component that do not meet the conditions in (a) above shall comply with the provisions of this Subsection in addition to the rules of NB-4000.

(c) Those portions of the component on which options (a) or (b) above apply shall be identified during all phases of manufacture and installation.

NH-4212 Effects of Forming and Bending Processes

The rules of this paragraph shall supplement those of NB-4212 and NB-4213. Any process may be used to form or bend pressure retaining materials, including weld metal, provided that the requirements of the subparagraphs below are met.

(a) Post fabrication heat treatment [in accordance with (b) below] of materials which have been formed during fabrication, shall be required unless one of the following conditions are met.

(1) Maximum fabrication induced local strains¹ do not exceed 5%,² regardless of the service temperature.

(2) Written technical justification shall be provided in the Design Report for not performing heat treatment, subsequent to straining, or for the use of an alternate heat treatment procedure, to that specified in (b) below, for fabrication induced strains greater than 5%.

1 Strain is defined as the maximum local fiber elongation or contraction per unit length; and where more than one strain increment occurs (e.g., biaxiality or reversed bending), it shall be the sum of the absolute values of all the strain increments.

2 Strain resulting from final straightening operations performed on materials furnished in the solution annealed or heat treated condition need not be included in the computation of strain.

The justification should provide assurance that the resultant material property capabilities are adequate for the intended service (fatigue, creep rupture, impact toughness, etc.) and shall include consideration of property variability through the material section. This option is not permitted for certain materials if the components are subjected during Levels A, B, and C service, or for design conditions when only design conditions are specified, to short-time high temperature excursions that result in accumulated temperature exposures exceeding the maximum permissible values shown in Fig. NH-4212-1. This option is also not permitted for any austenitic material that is subjected to greater than 20% strain.¹

(3) The roll threaded portion of bolting material is exempt from the heat treatment requirement.

(b) When required, the post fabrication heat treatment shall be in accordance with the following:

(1) For ferritic materials, the post fabrication heat treatment shall consist of heating to temperatures listed in Table NB-4622.1-1 for the appropriate alloy P-Number. Holding times shall also be in accordance with this Table based on the material thickness at the point of maximum strain. This heat treatment shall be included in material certification per NB-2211, the forming qualifications as required by NB-4213, and applicable weld procedure qualifications.

Alternatively, the base material and welds may be reheat treated and recertified in accordance with the applicable material specification and requirements in NB-2400. Reheat treatment may entail appropriate cooling from hot working temperatures above the upper critical temperature of the respective material provided required material property levels are recertified.

(2) For austenitic materials, the post fabrication heat treatment shall consist of the heat treatment specified in the base material specification except that Ni-Fe-Cr Alloy 800H shall be heat treated at 2,050°F (1121°C) minimum.

Following reheat treatment, the final grain size of Alloy 800H shall be verified as being not finer than

Page 54

ASTM 5. If reheat treatment is employed, the designer shall be alerted to the possibility for material yield strength reductions, and the effect on buckling analysis must be accommodated as dictated by design rules.

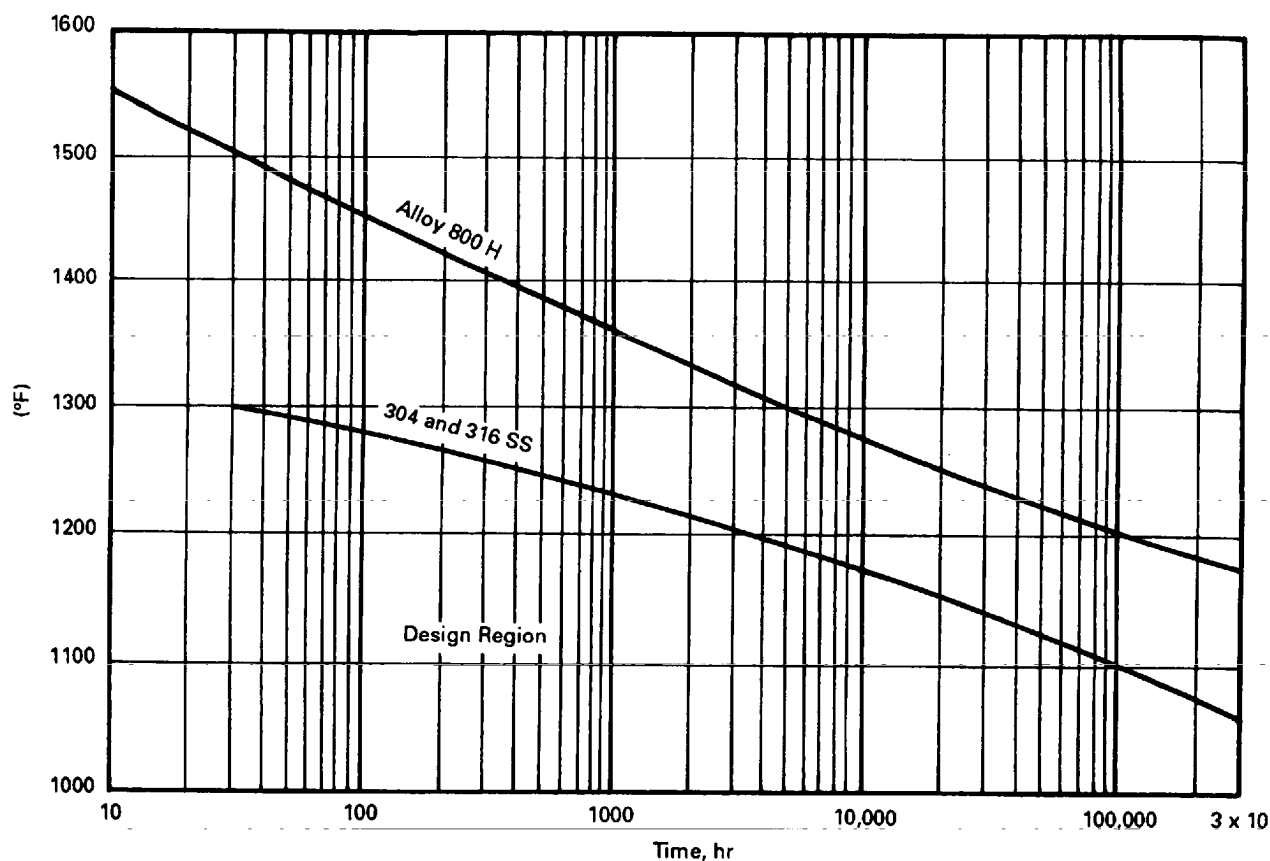


FIG. NH-4212-1 PERMISSIBLE TIME/TEMPERATURE CONDITIONS FOR MATERIAL WHICH HAS BEEN COLD WORKED >5% AND <20% AND SUBJECTED TO SHORT-TIME HIGH TEMPERATURE TRANSIENTS. THE SUM OF TIME AT EVERY TEMPERATURE SHALL DETERMINE A POINT WITHIN THE DESIGN REGION OF THE FIGURE FOR THE SPECIFIC MATERIAL. FOR MULTIPLE TEMPERATURE/TIME COMBINATIONS, THE LINEAR SUMMATION OF LIFE FRACTION SHALL NOT EXCEED 1.0, THE MATERIAL LIMIT

FIG. NH-4212-1 PERMISSIBLE TIME/TEMPERATURE CONDITIONS FOR MATERIAL WHICH HAS BEEN COLD WORKED >5% AND <20% AND SUBJECTED TO SHORT-TIME HIGH TEMPERATURE TRANSIENTS. THE SUM OF TIME AT EVERY TEMPERATURE SHALL DETERMINE A POINT WITHIN THE DESIGN REGION OF THE FIGURE FOR THE SPECIFIC MATERIAL. FOR MULTIPLE TEMPERATURE/TIME COMBINATIONS, THE LINEAR SUMMATION OF LIFE FRACTION SHALL NOT EXCEED 1.0, THE MATERIAL LIMIT

NH-4240 SPECIAL JOINTS AND FITTINGS - ADDED RULES FOR NB-4240

The rules of NH-3000 generally discourage the use of socket weld fittings and seal welded threads. If used, the designer shall evaluate whether assembly of socket welds should allow for an axial gap after welding which will allow free thermal

growth of the male coupling within the socket without bottoming out during the intended service. If a gap is deemed necessary, it shall be verified either by radiographic examination or by following special written procedures (see the rules of NH-3000).

NH-4424 Surfaces of Welds

As-welded surfaces are permitted provided that the surface geometry is considered in the stress analysis in accordance with the rules for design of Class 1 elevated temperature components.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NH-5000

ARTICLE NH-5000 EXAMINATION

Page 57

Page 59

NH-5100 GENERAL REQUIREMENTS FOR EXAMINATION

NH-5110 GENERAL REQUIREMENTS

(a) Those portions of the component designated (in accordance with the rules of NH-3000) as not to experience elevated temperature service may use the NB-5000 rules unchanged by rules in later paragraphs of this Subsection.

(b) Those portions of the component that do not meet the conditions in (a) above shall comply with the provisions of this Subsection in addition to the rules of NB-5000.

(c) Those portions of the component which use option (a) above shall be identified during all steps of examination.

NH-5130 EXAMINATION OF WELD EDGE PREPARATION SURFACES

The rules of this paragraph shall be substituted for the first sentence of NB-5130.

All weld edge preparation surfaces for vessel weld joint Categories A, B, C, and D and similar pressure boundary welds in other components shall be examined by either the magnetic particle or liquid penetrant method. This requirement shall not apply to welds where the nominal thickness is 1 in. (25 mm) or less.

NH-5200 REQUIRED EXAMINATION OF WELDS

NH-5210 CATEGORY A VESSEL WELDED JOINTS AND LONGITUDINAL WELDED JOINTS IN OTHER COMPONENTS

The rules of this paragraph shall be substituted for those of NB-5210.

All longitudinal butt welds of Category A, as defined in NB-3351.1, and all similar pressure boundary welds in other Class 1 components shall be examined in accordance with the requirements of (a) and (b) below.

(a) External weld surfaces, accessible internal weld surfaces, and adjacent base material for at least $\frac{1}{2}$ in. (13 mm) outside the edges of the completed weld shall be examined by either the magnetic particle or liquid penetrant method.

(b) All weld metal and adjacent base material for at least $\frac{1}{2}$ in. (13 mm) outside the edges of each weld shall be volumetrically examined by an appropriate method from the three listed below:

(1) radiography plus ultrasonic examination, where the radiography may be performed prior to any intermediate or required postweld heat treatment, provided the ultrasonic examination is performed after the final postweld heat treatment;

(2) radiography plus eddy current examination, provided the portion of the weld being examined is less than $\frac{1}{4}$ in. (6 mm)

thick;

(3) radiography at two different angles - one angle within 15 deg. of perpendicular to the surface, the other at some angle appropriate for revealing any lack of fusion and cracking defects at the weld metal/base material interface near the root pass.

NH-5220 CATEGORY B VESSEL WELDED JOINTS AND CIRCUMFERENTIAL WELDED JOINTS IN OTHER COMPONENTS

The rules of this paragraph shall be substituted for those of NB-5220.

(a) For component regions with nominal diameter greater than 4 in., all circumferential butt welds similar to Category B, as defined in NB-3351.2, shall be examined in accordance with the requirements of NH-5210.

Page 60

(b) For component regions with nominal diameter of 2 in. or less, all circumferential butt welds similar to Category B, along with adjacent base material for at least $\frac{1}{8}$ in. (3.2 mm) outside the edges of the completed weld, shall be radiographed. For component regions with a nominal diameter over 2 in. (51 mm) but not exceeding 4 in. (102 mm), circumferential butt welds similar to Category B welds shall be radiographed. The adjacent base material for a distance outside the edges of the completed weld equal to the greater of $\frac{1}{8}$ in. (3.2 mm) or t , but not to exceed $\frac{1}{2}$ in. (13 mm) where t is the thickness of the weld, shall also be radiographed. In addition, each completed weld shall undergo surface examination in accordance with the requirements of NH-5210(a).

NH-5230 CATEGORY C VESSEL WELDED JOINTS AND SIMILAR WELDED JOINTS IN OTHER COMPONENTS

The rules of this paragraph shall be substituted for those of NB-5230.

(a) For component regions with nominal diameter greater than 4 in. (102 mm), all full penetration welds similar to Category C, as defined in NB-3351.3, shall be examined in accordance with the requirements of NH-5210.

(b) For component regions with nominal diameter of 4 in. (102 mm) or less, all full penetration welds similar to Category C, along with adjacent base material for at least $\frac{1}{2}$ in. (13 mm) outside the edges of the completed weld, shall be radiographed. In addition, each completed weld shall undergo surface examination in accordance with the requirements of NH-5210(a). For full penetration corner welds, the requirements of (c) and (d) below shall replace the requirements of this paragraph.

(c) For component regions with nominal diameter of 4 in. (102 mm) or less, all full penetration corner welds similar to sketches (a), (b), and (c) of Fig. NB-4243-1 shall be radiographed; this radiography may require special techniques such as the use of multiple exposures. In addition, each completed weld shall undergo surface examination in accordance with the requirements of NH-5210(a).

(d) For component regions with nominal diameter of 4 in. (102 mm) or less, all full penetration corner welds similar to sketches (d), (e), and (f) of Fig. NB-4243-1 shall be examined in accordance with the requirements of (c) above. In addition, the fusion zone and the parent metal beneath the attachment surface shall be ultrasonically examined after welding to reveal any lack of fusion and laminar defects.

NH-5240 CATEGORY D VESSEL WELDED JOINTS AND BRANCH AND PIPING CONNECTIONS IN OTHER COMPONENTS

The rules of this paragraph shall be substituted for those of NB-5240. All welded joints of Category D, as defined in NB-3351.4, and similar pressure boundary welds in other components shall be examined in accordance with the requirements listed below.

NH-5242 Butt Welded Nozzles and Branch and Piping Connections

(a) Butt welded attachment welds for nozzles and branch connections with nominal diameter greater than 4 in. (102 mm) shall be examined in accordance with the requirements of NH-5210. These welds shall be full penetration butt welds

through either the component wall or the nozzle wall, as shown in Fig. NB-4244(a)-1.

(b) Butt welded attachment welds for nozzles and branch connections with nominal diameter of 4 in. (102 mm) or less shall be examined by radiography. The examination shall cover the weld metal and the adjacent base material for at least $\frac{1}{2}$ in. (13 mm) outside the edges of the completed weld. In addition, each completed weld shall undergo surface examination in accordance with the requirements of NH-5210(a).

NH-5243 Full Penetration Corner Welded Nozzles and Branch and Piping Connections

(a) Full penetration corner welded attachment welds for nozzles and branch connections with nominal diameter greater than 4 in. (102 mm) shall be examined in accordance with the requirements of NH-5210.

(b) For nozzles and branch connections with nominal diameter of 4 in. (102 mm) or less, all full penetration corner welded attachment welds similar to sketch (f) of Fig. NB-4244(b)-1 shall be radiographed; this radiography may require special techniques such as the use of multiple exposures. The examination shall cover the weld metal and the adjacent base material for at least $\frac{1}{2}$ in. (13 mm) outside the edges of the completed weld. In addition, each completed weld shall undergo surface examination in accordance with the requirements of NH-5210(a).

Page 61

(c) For nozzles and branch connections with nominal diameter of 4 in. (102 mm) or less, all full penetration corner welded attachment welds similar to sketches (a), (b), (c), (d), (e), and (g) of Fig. NB-4244(b)-1 shall be examined in accordance with the requirements of (b) above. In addition, the fusion zone and the parent material beneath the attachment surface shall be ultrasonically examined after welding to reveal any lack of fusion and laminar defects.

NH-5244 Deposited Weld Metal as Reinforcement for Openings and Attachment of Nozzles, Branch, and Piping Connections

(a) Weld buildup deposits may be made to a surface as shown in Step 1 of Fig. NB-4244(c)-1 for nozzle and branch connections. When such weld deposits are made, the fusion zone and the parent metal beneath the weld shall be ultrasonically examined after welding to reveal any lack of fusion and laminar defects. Nozzles may then be attached as shown in Step 2 of Fig. NB-4244(c)-1.

(b) Full penetration attachment welds, similar to those shown in Fig. NB-4244(c)-1, shall be radiographed; this radiography may require special techniques such as the use of multiple exposures. The examination shall cover the weld metal and the adjacent base material for at least $\frac{1}{2}$ in. (13 mm) outside the edges of the completed weld. In addition, each completed weld shall undergo surface examination in accordance with the requirements of NH-5210(a).

NH-5245 Partial Penetration Welds

Partial penetration welds shall be used only for the small diameter applications allowed by the rules of NH-3000. Partial penetration welds as shown in Figs. NB-4244(d)-1 and NB-4244(d)-2 shall be examined progressively using either the magnetic particle or the liquid penetrant method. The increments of examination shall be the lesser of one-half of the maximum weld dimension measured parallel to the center line of the connections, or $\frac{1}{2}$ in. (13 mm). In addition, each completed weld shall undergo surface examination in accordance with the requirements of NH-5210(a).

NH-5246 Full Penetration Category D Welds at Oblique Connections

(a) Full penetration welds shall be examined in accordance with the requirements of NH-5210. Prior to examination, backing rings shall be removed and the nozzle bore surface finish shall be suitable for the type of examination.

(b) The radiographic examination in (a) above is not required provided all the conditions listed below are met.

(1) The weld is made as per Fig. NB-4244(e)-1, Step 1. After attachment [Step 1, sketch (a)] or after cladding [Step 1, sketch (b) or (c)], the weld, weld fusion zone, and base metal under the attachment shall have been ultrasonically examined.

(2) The weld is made as per Fig. NB-4244(e)-1, Step 2, and the magnetic particle or liquid penetrant method shall have been used to progressively examine the weld at the lesser of one-half the thickness of the weld joint, or each $\frac{1}{2}$ in. (13 mm) of weld thickness.

(3) A surface examination using the magnetic particle or liquid penetrant method shall have been made on the root pass weld.

(4) The angle which the nozzle axis makes with the component wall at the point of attachment is not smaller than 40 deg.

NH-5260 FILLET, SOCKET, AND ATTACHMENT WELDS

NH-5261 Fillet and Socket Welds

The rules of this paragraph shall be substituted for NB-5260. Fillet and socket welds shall be used only for the small diameter applications allowed by the rules of NH-3000. Completed surfaces of fillet and socket welds shall be examined visually and by either the magnetic particle or liquid penetrant methods. To ensure that proper fit-up and clearances were achieved in the as-welded condition, completed socket welds shall either be examined by postweld radiography oriented to verify the axial gap at the base of the socket weld, or they shall be examined in accordance with special instructions described in written procedures which comply with NB-5112.

NH-5262 Permanent Structural Attachment Welds

The rules of this paragraph shall be substituted for NB-5262.

(a) Permanent structural attachment welds, as defined in NB-4433, shall be examined by the methods listed below.

(1) radiography, unless it is excluded by (2) below. The absence of suitable radiographic equipment shall not be the justification for the rules of (2) below excluding the radiography requirements.

Page 62

(2) Where radiography is impractical, the requirements of (1) above may be replaced either by using ultrasonic examination on the completed weld, or by progressively examining the weld using the magnetic particle or the liquid penetrant method.

For progressive examination of multipass welds whose final thickness will be 1 in. (25 mm) or less, the examination shall be performed after completion of one-half the final weld thickness. For progressive examination of welds whose final weld thickness will exceed 1 in., examinations shall be performed after the completion of each $\frac{1}{2}$ in. (13 mm) of weld thickness.

(3) Completed weld surfaces shall be examined by either a magnetic particle method or a liquid penetrant method.

(b) If it becomes necessary to cool a partially completed weld in order to perform the progressive examination of (a)(2) above, then care should be taken to keep the large structural parts from imposing large tensile loadings on partially completed welds.

NH-5263 Nonstructural and Temporary Attachments

All completed weld surfaces on welds of nonstructural and temporary attachments, as defined in NB-4435, shall be examined by either a liquid penetrant or magnetic particle method.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NH-6000

ARTICLE NH-6000 TESTING

Page 63

Page 64

NH-6100 GENERAL REQUIREMENTS

Testing of Section III, Division I, Class 1 components when metal temperatures exceed those for which allowable stress values are given in Section II, Part D, shall be in accordance with the rules of this Subsection.

NH-6110 SCOPE OF TESTING

NH-6111 General Hydrostatic and Pneumatic Test Media

(a) The selection of a particular test medium may depend upon considerations in (b), (c), and (d) below. For some items, a combination of gaseous and liquid test media may be desirable.

(b) Compared to pressurized liquids, gas under a similar pressure has a greater potential energy release. It is therefore recommended that special precautions for protection of personnel be taken when a gas under pressure is used as a test medium.

(c) Some components, appurtenances, or systems are not designed to support the liquid weight required in a hydrotest. Pneumatic tests should be considered for such components.

(d) The use of liquids for testing often results in traces of the liquid left in hard-to-clean places in the system, and these residues may be harmful to the structural material because of reactions involving the residues and the system coolant. Pneumatic tests should be considered under these circumstances.

NH-6112 Pressure Testing of Components and Appurtenances

(a) Except as noted in (b) and (c) below, all components and appurtenances for elevated temperature service shall be static pressure tested in the presence of the Inspector.

(b) Nuts, bolts, studs, and gaskets are exempt from the rules of this Subsection.

(c) A static pressure test of each line valve and pump with inlet piping connections of 4 in. nominal pipe size and smaller shall be performed by the Manufacturer and so noted on the Data Report Form; however, this static pressure test need not be witnessed by the Inspector. The Inspector's review of the Manufacturer's test records will be his authority to sign the report. This takes precedence over NCA-5280.

(d) Under the special conditions of NH-6117 and NH-6118, a helium mass spectrometer leak test (plus other tests) may replace the static pressure test required in (a) above.

(e) The requirements of (a) above are met by meeting the requirement of NH-6113(a).

(f) The component or appurtenance pressure test, when conducted in accordance with the rules of NH-6221 or NH-6321, shall be acceptable as a pressure test for parts and piping subassemblies.

(g) For components and appurtenances which will be subjected to external pressure loads in service, the pressure test requirement in (a) above may be performed on the basis of an internal pressure test using the rules of NH-6221 or NH-6321. The Design Specifications may require further tests to demonstrate structural integrity under external pressure loading.

NH-6113 Pressure Testing of Systems

(a) Prior to initial operation, the installed Class 1 system shall be static pressure tested in the presence of the Inspector.

(b) Under the special restrictions of NH-6117 and NH-6118, a helium mass spectrometer leak test may replace the static pressure test in (a) above.

NH-6115 Time of Pressure Test and Stamping of Components and Appurtenances

(a) The pressure tests of components and appurtenances required by NH-6112(a) shall be performed

prior to installation in the system as specified in NH-6221(a) or NH-6321(a).

(b) The pressure tests of components and appurtenances required by NH-6112(a) may be performed after installation if the system pressure test is used under the provisions of NH-6221(c) or NH-6321(c).

(c) The Data Report Form shall not be completed nor signed by the Inspector and the components shall not be stamped until the component Manufacturer has conducted the static pressure test.

(d) Specially designed welded seals,¹ which are identified on the Data Report Form as being welded by the Installer under the rules of NH-6118, need not be tested prior to the stamping of the component.

(e) Appurtenances containing brazed joints, pumps not designed by detailed analysis,¹ and valves shall be static pressure tested prior to installation in a system.

NH-6116 Machining of Local Areas After Static Pressure Testing

(a) In local regions of the pressure boundary where tight tolerances are required for proper component functioning, extra wall thickness is permitted during pressure testing. If extra wall thickness is provided during fabrication, the excess material may be machined to critical dimensions and tolerances after completion of the static pressure test.

(b) The extra wall thickness permitted during pressure testing in (a) above shall not exceed 10% of the final wall thickness or $\frac{3}{8}$ in. (10 mm), whichever is less.

(c) The final wall thickness, after machining to critical dimensions and tolerances, shall comply with the minimum wall thickness requirements defined in the rules for design of Class 1 components for elevated temperature service.

NH-6117 Alternative Tests of Closure Welds and Access Hatches

(a) Closure welds for access hatches in vessels and closure welds for connecting piping subassemblies may be tested by an alternative procedure for the pressure test requirements of NH-6112 and NH-6113 provided the conditions of (1) through (4) below are met:

(1) If hydrotesting were to be used, residues from the hydrotest liquid could be deleterious to the service;

¹ Definitions are contained in the rules governing the design of Class 1 components in elevated temperature service.

(2) Closure welds are located at least $3\sqrt{RT}$ from major structural discontinuities such as flanges, large nozzles, pumps, or valves. R is the mean radius and T is the nominal thickness of the thicker material adjacent to the weld;

(3) The alternative test procedure in (b) below is specified for the closure welds; and

(4) The closure welds to which the alternative tests shall be applied, and the alternative test procedure shall be included in the Design Specification. The closure welds to which the alternative test procedure has been applied shall be identified on the Data Report.

(b) As an alternative to the pressure test procedure, closure welds may be tested by a mass spectrometer helium leak test.

NH-6118 Alternative Tests at Specially Designed Welded Seals

(a) Specially designed welded seals, such as omega and canopy seals, need not meet the pressure test requirements of NH-6112 and NH-6113 when:

(1) The final weld cannot be completed until after the hydrostatic or pneumatic test because the system test pressure would exceed the limit specified for any system component; and

(2) The seal is subjected to a leak test at the maximum normal operating pressure.

(b) Welds of specially designed welded seals may be tested by a helium leak test in lieu of the pressure test requirements of NH-6112 and NH-6113 provided:

(1) The welds of the seal, and the welds joining the seal to the component or supporting structure, cannot be visually examined during testing due to access restrictions; and

(2) The welds and the alternative test procedures have been mutually agreed to by the Owner and Manufacturer, and the requirements appear in the Design Specifications and in the Installer's Data Report Forms.

NH-6120 PREPARATION FOR TESTING

NH-6121 Exposure of Joints

All mechanical and welded joints, including welds, shall be left uninsulated and exposed for examination during the test.

NH-6122 Addition of Temporary Supports

Components designed for vapor or gas may be provided with additional temporary supports, if necessary, to support the weight of the test liquid.

Page 67

NH-6123 Restraint or Isolation of Expansion Joints

Expansion joints shall be provided with temporary restraint, if required for the additional pressure load under test, or they shall be isolated from the test.

NH-6124 Isolation of Equipment Not Subjected to Pressure Test

Equipment that is not to be subject to the pressure test shall be either disconnected from the component or system, or isolated by a blank flange or similar means. Valves may be used if the valve with its closure is suitable for the proposed test pressure.

NH-6125 Treatment of Flanged Joints Containing Blinds

Flanged joints at which blinds are inserted to blank off other equipment during the test need not be tested until the blinds are removed.

NH-6126 Precautions Against Test Medium Expansion

If a pressure test is to be maintained for a period of time and the test medium in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure. A small relief valve set to 1.33 times the test pressure is recommended during the pressure test.

NH-6200 HYDROSTATIC TESTS

NH-6210 HYDROSTATIC TESTING PROCEDURE

NH-6211 Provision of Air Vents at High Points

Vents shall be provided at all high points of the component or system in the position in which the test is to be conducted to purge air pockets while the component or system is filling.

NH-6212 Test Medium and Test Temperature

(a) Any nonhazardous liquid at any temperature below its boiling point may be used for the hydrostatic test. Combustible liquids having a flash point less than 100°F, such as petroleum distillates, may be used only for tests at near atmospheric temperature.

(b) No hydrostatic test shall be performed at a temperature which exceeds those for which S_m values are listed in Tables 2A and 2B of Section II, Part D, Subpart 1 for any of the materials used in the pressure boundaries of components being tested.

(c) It is recommended that the test be made at a temperature that will minimize the possibility of brittle fracture (NB-2330). The test pressure shall not be applied until the component, appurtenance or system, and the pressurizing medium are

approximately at the same temperature.

(d) For the vessel hydrostatic test before installation, it is recommended that the test be made at a temperature not lower than $[RT_{NDT} + 60^{\circ}\text{F}]$, (NB-2331).

NH-6213 Check of Test Equipment Before Applying Pressure

The test equipment shall be examined before pressure is applied to ensure that it is tight and that all low pressure filling lines and other appurtenances that should not be subjected to the test pressures have been disconnected or isolated by valves or other suitable means.

NH-6215 Examination for Leakage After Application of Pressure

Following the application of the hydrostatic test pressure for a minimum of 10 minutes, as required by NH-6224, examination for leakage shall be made of all joints, connections, and of all regions of high stress such as regions around openings and thickness transition sections. Except in the case of pumps and valves, which shall be examined while at test pressure, this examination shall be made at a pressure equal to the greater of the design pressure or three-fourths of the test pressure and it shall be witnessed by the Inspector. Leakage of temporary gaskets and seals, installed for the purpose of conducting the hydrostatic test and which will be replaced later, may be permitted unless the leakage exceeds the capacity to maintain system test pressure for the required amount of time. Other leaks, such as from permanent seals, seats, and gasketed joints in components, may be permitted when specifically allowed by the Design Specifications. Leakage from temporary seals or leakage permitted by the Design Specifications shall be directed away from the surface of the component to avoid masking leaks from other joints.

Page 68

NH-6220 HYDROSTATIC TEST PRESSURE REQUIREMENTS

NH-6221 Minimum Required System Hydrostatic Test Pressure

(a) Except as may be otherwise required by material specifications and by the requirements of NH-6223, all components and appurtenances shall be subjected to a hydrostatic test at a pressure not less than 1.25 times the system design pressure prior to installation in the nuclear power system.

(b) All pressure retaining components of the completed Class 1 system shall be subjected to a system hydrostatic test at a pressure not less than 1.25 times the system design pressure unless specifically excepted under the provisions of NH-6117 and NH-6118.

(c) The system hydrostatic test of NH-6221(b) may be substituted for a component hydrostatic test of NH-6221(a) provided:

(1) The component can be repaired by welding, if required, as a result of the system hydrostatic test, in accordance with the rules of NB-2500;

(2) The component repair can be postweld heat treated, if required, and nondestructively examined in accordance with rules of NB-2500, NB-5100, and NB-5400, as applicable, subsequent to the system hydrostatic test; and

(3) The component is subjected to the required system hydrostatic test following the completion of repair and examination.

NH-6222 Maximum Permissible Hydrostatic Test Pressure

(a) The stress limits, contained in the rules of NH-3000, shall be used in determining the permissible hydrostatic test pressure. In multichamber components, pressure may be simultaneously applied to the appropriate adjacent chamber to meet these stress limits. The number of test sequences for which the above provisions may be considered applicable shall not exceed ten.

(b) When hydrostatically testing a system, the test pressure shall not exceed the lowest of the maximum test pressures allowed for any of the components in the system.

NH-6223 Hydrostatic Test Pressure for Valves, Pumps, and for Components and Appurtenances Containing Brazed Joints

(a) Prior to installation, valves, pumps not designed by detailed stress analysis, and other components and appurtenances containing brazed joints shall be hydrostatically tested at a pressure 1.5 times the system design pressure.

(b) The inlet (primary pressure containing) portion of safety and safety relief valves shall be hydrostatically tested at a pressure at least 1.5 times the set pressure marked on the valve. For closed system applications, the outlet portion of safety and safety relief valves shall be hydrostatically tested to 1.5 times the design secondary pressure of the outlet system.

NH-6224 Hydrostatic Test Pressure Holding Time

The hydrostatic test pressure shall be maintained for a minimum total time of 10 minutes and for such additional time as may be necessary to conduct the examination for leakage required by NH-6215. When testing pumps, valves, and other components covered by NH-6223, the pressure shall be maintained a minimum of 15 minutes for each inch of design minimum wall thickness, but for not less than 10 minutes.

NH-6300 PNEUMATIC TESTS

NH-6310 PNEUMATIC TESTING PROCEDURES

NH-6311 General Requirements

When a pneumatic test is performed, it shall be conducted in accordance with the requirements of NH-6300 and NH-6112.

NH-6312 Test Medium and Test Temperature

(a) The gas used as the test medium shall be non-flammable;

(b) It is recommended that the test be made at a temperature that will minimize the possibility of brittle fracture (NB-2330). The test pressure shall not be applied until the component, appurtenance or system, and the pressurizing medium are approximately the same temperature.

NH-6313 Check of Test Equipment Before Applying Pressure

The test equipment shall be examined before pressure is applied to ensure that it is tight and that all appurtenances that should not be subjected to the test pressure have been disconnected or isolated by valves or other suitable means.

Page 69

NH-6314 Procedure for Applying Pressure

The pressure in the system shall gradually be increased to not more than one-half of the test pressure, after which the pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached. The pressure shall then be reduced to a value equal to the greater of the design pressure or three-fourths of the test pressure and held for a sufficient time to permit examination of the system in accordance with NH-6315.

NH-6315 Examination for Leakage After Application of Pressure

Following the application of pressure for the time specified in NH-6324, examination of leakage in accordance with NH-6215 shall be made.

NH-6320 PNEUMATIC TEST PRESSURE REQUIREMENTS

NH-6321 Minimum Required System Pneumatic Test Pressure

(a) Except as may be otherwise required by material specifications and by the requirements of NH-6323, all components

and appurtenances shall be subjected to a pneumatic test at a pressure not less than 1.20 times the system design pressure prior to installation in the nuclear power system.

(b) All pressure retaining components of the completed Class 1 system shall be subjected to a system pneumatic test at a pressure not less than 1.20 times the system design pressure unless specifically excepted under the provisions of NH-6117 and NH-6118.

(c) The system pneumatic test of NH-6321(b) may be substituted for a component pneumatic test of NH-6321(a) provided:

(1) The component can be repaired by welding, if required as a result of the system pneumatic test, in accordance with the rules of NB-4400;

(2) The component repair can be postweld heat treated, if required, and nondestructively examined in accordance with the rules of NB-4400, NB-5100, and NB-5400, as applicable, subsequent to the system pneumatic test; and

(3) The component is subjected to the required system pressure test following the completion of repair and examination.

NH-6322 Maximum Permissible Pneumatic Test Pressure

(a) The stress limits contained in the rules of NH-3000 shall be used in determining the permissible pneumatic test pressure. In multichamber components, pressure may be simultaneously applied to the appropriate adjacent chamber to meet these stress limits. The number of test sequences for which the above provisions may be considered applicable shall not exceed ten.

(b) When pneumatically testing a system, the test pressure shall not exceed the lowest of the maximum test pressures allowed for any of the components in the system.

NH-6323 Pneumatic Test Pressure for Valves, Pumps, and for Components and Appurtenances Containing Brazed Joints

(a) Prior to installation, valves, pumps not designed by detailed stress analysis, and other components and appurtenances containing brazed joints shall be pneumatically tested at a pressure 1.5 times the system design pressure.

(b) The inlet (primary pressure containing) portion of safety and safety relief valves shall be pneumatically tested at a pressure at least 1.5 times the set pressure marked on the valve. For closed system applications, the outlet portion of safety and safety relief valves shall be pneumatically tested to 1.5 times the design secondary pressure of the outlet system.

NH-6324 Pneumatic Test Pressure Holding Time

The pneumatic test shall be maintained for a minimum total time of 10 minutes and for such additional time as may be necessary to conduct the examination for leakage required by NH-6215.

NH-6400 PRESSURE TEST GAGES

The rules of NB-6400 shall apply.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NH-7000

ARTICLE NH-7000 OVERPRESSURE PROTECTION

Page 71

Page 73

NH-7100 GENERAL REQUIREMENTS

Overpressure protection for Section III, Class 1 components, when the metal temperature exceeds the Applicability and Max. Temp. Limits listed in Section II, Part D, Tables 2A and 2B, shall be in accordance with the rules of NB-7000 except as modified by Subsection NH.

NH-7110 SCOPE

(a) Subsection NH provides Class 1 overpressure protection rules for those pressure boundary structures which, having been designated by the Owner (NCA-1140 and NCA-3230) as a group of items requiring such protection, are not covered by NB-7000 rules because some of the structures are expecting service temperatures above those currently allowed under the rules of Subsection NB.

(b) Whereas the rules of NB-7000 are oriented toward water and steam cooled reactor systems, the rules of Subsection NH encompass a wider variety of coolant fluids.

(c) The rules of NB-7000 shall govern unless paragraphs are specifically altered by the rules of Subsection NH. All references to other NB-7000 paragraphs are to be interpreted as referring to the NB-7000 paragraphs as modified by Subsection NH.

(d) As with NB-7000, the rules of this Subsection require that all system conditions, including transients, are described in the Design Specifications for the components being protected.

(e) In the evaluation of the effects of overpressure events, structural loadings shall include, but not be limited to, the types of events listed below.

(1) system overpressure due to a closed valve, a blocking object, or a solid core of metal coolant;

(2) overpressure due to the addition of heat to an isolated portion of the system;

(3) overpressure due to nuclear transients;

(4) overpressure due to failure of a system component, including the effects of leaks from adjacent systems and possible resulting chemical reactions;

(5) overpressure resulting from operator error;

(6) overpressure due to constant pressure in combination with a rising overtemperature condition;

(7) overpressure due to pump overspeed.

(f) Events whose overpressure effects are beyond the Scope of the rules of Subsection NH are covered by NB-7110(b) and include, for example:

(1) Rapid closure of a check valve gate leads to fluid shock conditions in a local region;

(2) Earthquake motions induce sloshing of fluids contained in large tanks;

(3) Nuclear incident induces a severe pressure spike in a local region;

(4) Rapid closure of a valve during high flow rate conditions introduces pressure shocks.

NH-7130 VERIFICATION OF THE OPERATION OF PRESSURE RELIEF DEVICES

Revise NB-7131 to read:

(a) Pressure relief devices shall be designed so that potential impairment of the overpressure protection function from service exposure to fluids can be determined by test or examination.

NH-7170 PERMITTED USE OF PRESSURE RELIEF DEVICES

Revise title of NB-7173 to read:

Valve Types Permitted for Water Service

Revise NB-7174 to read:

NB-7174 Nonreclosing Devices

Rupture disk devices may be used in air, gas, or liquid metal service in accordance with NB-7600.

Page 74

NH-7200 CONTENT OF OVERPRESSURE PROTECTION REPORT

Add to NB-7220, the listing below:

- (n) the effects of any thermal dissipation or discharge storage system on the pressure relief devices;
- (o) the disposition of effluent from pressure relief devices for both primary and secondary reactor coolant fluids.

NH-7300 RELIEVING CAPACITY

Revise NB-7321(c) to read:

The system overpressure established for setting the required total rated relieving capacity of (b) above shall be such that the calculated stress intensity and other design limitations for Service Limit C, as specified in the rules of NH-3000, are not exceeded for each of the components in the protected system.

NH-7600 NONRECLOSING PRESSURE RELIEF DEVICES

NH-7610 USE OF RUPTURE DISK DEVICES

Revise NB-7610 as shown below:

Rupture disk devices certified in accordance with NB-7720 may be used as sole protection against overpressure loadings. Rupture disks shall use materials of construction approved in NH-2000. Rupture disks may be used in conjunction with pressure relief valves on either the discharge side or the inlet side of the valve, provided the requirements of NB-7700 are met.

NH-7621 Provisions for Venting or Draining Near Rupture Disks

Revise NB-7621 as shown below:

The space between the rupture disk and any associated pressure relief valve shall be connected to a controlled disposal system as provided for the associated pressure relief valve. This space, if it exists, shall be provided with means to monitor its internal pressure during service periods.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NH SI

SI UNITS

Page 195

The 1998 Edition of the Boiler and Pressure Vessel Code is based on U.S. Customary (ft-lb) units of measurement which are to be regarded as the standard. This supplement is provided as a convenience to the Code user and contains SI conversion factors for units contained in the Code.

Page 196

Page 197

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

Quantity	Unit	Symbol	Other Units or Limitations
Space and Time			
plane angle	radian	rad	degree (decimalized)
length	meter	m	
area	square meter	m ²	
volume	cubic meter	m ³	liter (L) for liquid only (use without prefix other than in milliliter, mL)
time	second	s	minute (min), hour (h), day (d), week, and year
Periodic and Related Phenomena			
frequency	hertz	Hz	revolutions per second (r/s)
rotational frequency	revolutions per second	s ⁻¹	revolutions per minute (r/m)
Mechanics			
mass	kilogram	kg	
density	kilogram per cubic meter	kg/m ³	
moment of inertia	kilogram · meter ²	kg · m ²	
force	newton	N	
moment of force (torque)	newton-meter	N · m	
pressure and stress	pascal	Pa	(pascal = newton per square meter)
energy, work	joule	J	kilowatt-hour (kW · h)
power	watt	W	
impact strength	joule	J	
section modulus	meter ³	m ³	
moment of section (second moment of area)	meter ⁴	m ⁴	
fracture toughness	Pa · √m		
Heat			
temperature — thermodynamic [Note (2)]	kelvin	K	degree Celsius (°C)
temperature — other than thermodynamic	degree Celsius	°C	kelvin (K)
linear expansion coefficient	meter per meter-kelvin	K ⁻¹	°C ⁻¹
quantity of heat	joule	J	
heat flow rate	watt	W	
thermal conductivity	watt per meter-kelvin	W/(m · K)	W/(m · °C)
thermal diffusivity	square meter per second	m ² /s	
specific heat capacity	joule per kilogram-kelvin	J/(kg · K)	J/(kg · °C)
Electricity and Magnetism			
electric current	ampere	A	
electric potential	volt	V	
current density	ampere per meter ²	A/m ²	
magnetic field strength	ampere per meter	A/m	

NOTES:

- (1) Conversion factors between SI units and U.S. customary are given in SI-1, "ASME Orientation and Guide for Use of SI (Metric) Units," and ASTM E 380.
- (2) Preferred use for temperature and temperature interval is degrees Celsius (°C), except for thermodynamic and cryogenic work where kelvins may be more suitable. For temperature interval, 1 K = 1°C exactly.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

COMMONLY USED CONVERSION FACTORS
(For Others See ASTM E 380) [See Note (1)]

Quantity	To Convert From	To	Multiply by [Note (2)]	
plane angle	degree	rad	1.745 329	E-02
length	in	m	2.54*	E-02
	ft	m	3.048*	E-01
	yd	m	9.144*	E-01
area	in ²	m ²	6.451 6*	E-04
	ft ²	m ²	9.290 304*	E-02
	yd ²	m ²	8.361 274	E-01
volume	in ³	m ³	1.638 706	E-05
	ft ³	m ³	2.831 685	E-02
	US gallon	m ³	3.785 412	E-03
	Imperial gallon	m ³	4.546 09	E-03
	liter	m ³	1.0*	E-03
mass	lbm	kg	4.535 924	E-01
	ton (metric) (mass)	kg	1.000 00*	E+03
	ton (short 2000 lbm)	kg	9.071 847	E+02
force	kgf	N	9.806 65*	E+00
	lbf	N	4.448 222	E+00
bending, torque	kgf · m	N · m	9.806 65*	E+00
	lbf · in	N · m	1.129 848	E-01
	lbf · ft	N · m	1.355 818	E+00
pressure, stress	kgf/m ²	Pa	9.806 65*	E+00
	lbf/ft ²	Pa	4.788 026	E+01
	lbf/in ² (psi)	Pa	6.894 757	E+03
	kips/in ²	Pa	6.894 757	E+06
	bar	Pa	1.0*	E+05
energy, work	Btu (IT) [Note (3)]	J	1.055 056	E+03
	ft · lbf	J	1.355 818	E+00
power	hp (550 ft · lbf/s)	W	7.456 999	E+02
fracture toughness	ksi · $\sqrt{\text{in}}$	Pa · $\sqrt{\text{m}}$	1.098 843	E+06
temperature	°C	K	$t_K = t_C + 273.15$	
	°F	K	$t_K = (t_F + 459.67)/1.8$	
	°F	°C	$t_C = (t_F - 32)/1.8$	
temperature interval	°C	K	1.0*	E+00
	°F	K or °C	5.555 555	E-01

NOTES:

- (1) Care should be taken when converting formulas or equations that contain constant terms or factors. The value of these terms must be understood and may also require conversion.
- (2)(a) Relationships that are exact in terms of the base units are followed by a single asterisk.
- (b) The factors are written as a number greater than 1 and less than 10 with 6 or less decimal places. The number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example: 3.523 907 E-02 is $3.523\ 907 \times 10^{-2}$ or 0.035 239 07.
- (3) International Table

COMMONLY USED CONVERSION FACTORS

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NH MA I-14

APPENDIX I-14 TABLES I-14.0

Mandatory Appendix

Page 77

Page 81

TABLE I-14.1(a)
PERMISSIBLE BASE MATERIALS FOR STRUCTURES OTHER THAN BOLTING

Base Material	Spec. No.	Product Form	Types, Grades, or Classes
Type 304 SS and 316 SS [Notes (1)–(3)]	SA-182	Fittings & Forgings	F 304, F 304H, F 316, F 316H
	SA-213	Smls. Tube	TP 304, TP 304H, TP 316, TP 316H
	SA-240	Plate	304, 316, 304H, 316H
	SA-249	Welded Tube	TP 304, TP 304H, TP 316, TP 316H
	SA-312	Welded & Smls. Pipe	TP 304, TP 304H, TP 316, TP 316H
	SA-358	Welded Pipe	304, 316, 304H, 316H
	SA-376	Smls. Pipe	TP 304, TP 304H, TP 316, TP 316H
	SA-403	Fittings	WP 304, WP 304H, WP 316, WP 316H WP 304W, WP 304HW WP 316W, WP 316HW
	SA-479	Bar	304, 304H, 316, 316H
	SA-336	Forgings	F 304, F 304H, F 316, F 316H
	SA-430	Forged & Bored Pipe	FP 304, FP 304H, FP 316, FP 316H
Ni-Fe-Cr (Alloy 800H) [Note (4)]	SB-163	Smls. Tubes	Alloy 800H
	SB-407	Smls. Pipe & Tube	Alloy 800H
	SB-408	Rod & Bar	Alloy 800H
	SB-409	Plate, Sheet, & Strip	Alloy 800H
	SB-564	Forgings	Alloy 800H
2¼Cr-1Mo [Note (5)]	SA-182	Forgings	F 22, Class 1
	SA-213	Smls. Tube	T 22
	SA-234	Piping Fittings	WP 22, WP 22W [Note (6)]
	SA-335	Forg. Pipe	P 22
	SA-336	Fittings, Forgings	F 22a
	SA-369	Forg. Pipe	FP 22
	SA-387	Plate	Gr 22, Class 1
	SA-691	Welded Pipe	Pipe 2¼ CR (SA-387, Gr. 22, Cl. 1)

NOTES:

- (1) These materials shall have a minimum specified room temperature yield strength of 30,000 psi and a minimum specified carbon content of 0.04%.
- (2) For use at temperatures above 1,000°F, these materials may be used only if the material is heat treated by heating to a minimum temperature of 1,900°F and quenching in water or rapidly cooling by other means.
- (3) Appendix X provides nonmandatory guidelines on additional specification restrictions to improve performance in certain service applications.
- (4) These materials shall have a total aluminum-plus-titanium content of at least 0.50% and shall have been heat treated at a temperature of 2,050°F or higher.
- (5) This material shall have a minimum specified room temperature yield strength of 30,000 psi, a minimum specified room temperature ultimate strength of 60,000 psi, a maximum specified room temperature ultimate strength of 85,000 psi, and a minimum specified carbon content of 0.07%.
- (6) The material allowed under SA-234 shall correspond to one of:
SA-335, Grade P 22
SA-387, Grade 22, Class 1
SA-182, Grade F 22, Class 1 in compliance with Note (4).

TABLE I-14.1(a) PERMISSIBLE BASE MATERIALS FOR STRUCTURES OTHER THAN BOLTING

TABLE I-14.1(b)
PERMISSIBLE WELD MATERIALS

Base Material	Spec. No.	Class
Type 304 SS and 316 SS	SFA-5.4	E 308, E 308L, E 316, E 316L, E 16-8-2
	SFA-5.9	ER 308, ER 308L, ER 316, ER 316L, ER 16-8-2
	SFA-5.22	E 308, E 308T, E 308LT, E 316T, E316LT-1 EXXXT-G (16-8-2 chemistry)
Ni-Fe-Cr (Alloy 800H)	SFA-5.11	ENiCrFe-2
	SFA-5.14	ERNiCr-3
2 $\frac{1}{4}$ Cr-1Mo	SFA-5.5	E 90XX-B3 (>0.05% Carbon)
	SFA-5.23	EB 3, ECB 3
	SFA-5.28	E 90C-B3 (>0.05% Carbon), ER 90S-B3
	SFA-5.29	E 90T-B3 (>0.05% Carbon)

TABLE I-14.1(b) PERMISSIBLE WELD MATERIALS

TABLE I-14.2
 S_o — MAXIMUM ALLOWABLE STRESS INTENSITY, ksi,
FOR DESIGN CONDITION CALCULATIONS

Temp., °F	304 SS	316 SS	Ni-Fe-Cr Alloy 800H (Solution Annealed)	2¼Cr-1Mo
700	...	...	...	17.9
750	...	...	...	17.9
800	15.2	15.9	15.3	16.1
850	14.9	15.7	15.1	14.4
900	14.7	15.6	14.8	13.1
950	14.4	15.5	14.6	11.0
1,000	13.8	15.3	14.4	7.8
1,050	12.2	14.5	13.7	5.8
1,100	9.8	12.4	12.3	4.2
1,150	7.7	9.8	9.8	3.0
1,200	6.1	7.4	7.8	1.6
1,250	4.7	5.5	6.2	...
1,300	3.7	4.1	5.0	...
1,350	2.9	3.1	3.9	...
1,400	2.3	2.3	3.1	...
1,450	1.8	1.7	...	...
1,500	1.4	1.3	...	...

TABLE I-14.2 S_o - MAXIMUM ALLOWABLE STRESS INTENSITY, ksi, FOR DESIGN CONDITION CALCULATIONS

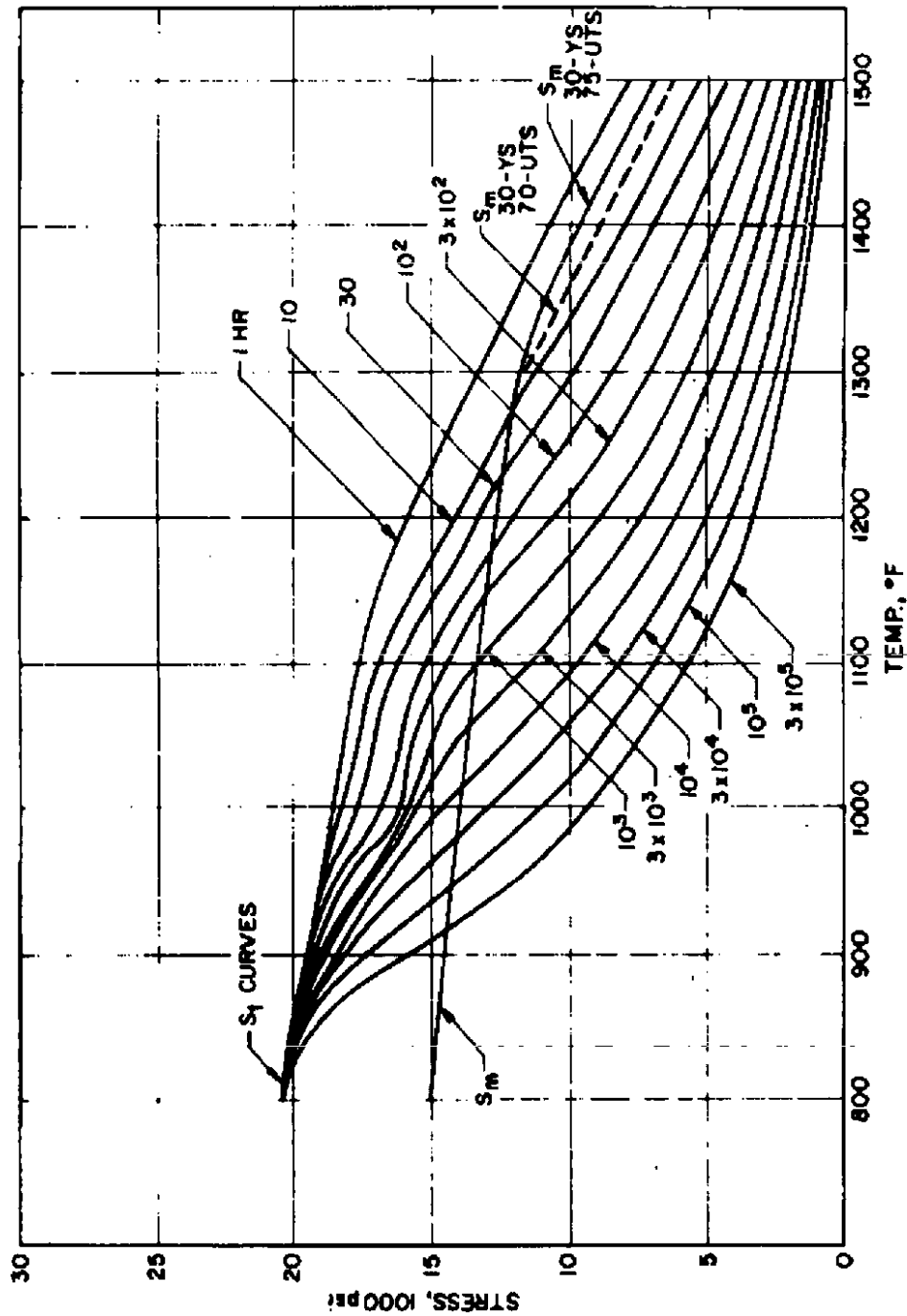


FIG. I-14.3A S_m — TYPE 304 SS

TABLE I-14.3A¹
 S_{mt} — ALLOWABLE STRESS INTENSITY VALUES, 1,000 psi, TYPE 304 SS — 30-YR, 75-UTS (30-YR, 70-UTS)

Temp., °F	1 hr	10 hr	30 hr	10 ² hr	3 × 10 ² hr	10 ³ hr	3 × 10 ³ hr	10 ⁴ hr	3 × 10 ⁴ hr	10 ⁵ hr	3 × 10 ⁵ hr
800	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2
850	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
900	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
950	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.2	12.2
1,000	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	13.1	11.1	9.3
1,050	13.6	13.6	13.6	13.6	13.6	13.6	13.6	12.2	10.3	8.7	7.3
1,100	13.2	13.2	13.2	13.2	13.2	13.2	11.5	9.7	8.2	6.8	5.7
1,150	12.9	12.9	12.9	12.9	12.9	11.0	9.3	7.7	6.4	5.3	4.4
1,200	[12.1] 12.7 [(11.3)]	[12.1] 12.7 [(11.3)]	[12.1] 12.7 [(11.3)]	[12.1] 12.2 [(11.3)]	10.6	8.9	7.4	6.1	5.1	4.1	3.4
1,250	[11.1] 12.3 [(10.2)]	[11.1] 12.3 [(10.2)]	[11.1] 11.9 [(10.2)]	10.3 [(10.2)]	8.7	7.2	5.9	4.9	4.0	3.2	2.7
1,300	[10.1] 11.9 [(9.4)]	[10.1] 11.4 [(9.4)]	[11.1] 11.9 [(10.2)]	8.5	7.0	5.9	4.8	3.9	3.2	2.5	2.1
1,350	[8.8] 10.9 [(8.3)]	[8.8] 9.7 [(8.3)]	10.0 [(9.4)]	7.1	5.9	4.8	3.9	3.1	2.5	2.0	1.6
1,400	[7.7] 9.5 [(7.2)]	[7.7] 8.1 [(7.2)]	8.4 [(8.3)]	5.9	4.8	3.9	3.1	2.5	2.0	1.6	1.2
1,450	[6.6] 8.2 [(6.2)]	[6.6] 6.8 [(6.2)]	6.9	4.6	3.8	3.0	2.4	1.9	1.5	1.2	0.9
1,500	[5.5] 7.0 [(5.1)]	[5.5] 5.3 [(5.1)]	4.4	3.5	2.8	2.2	1.7	1.3	1.0	0.8	0.6

NOTE:

(1) Values in square parentheses [] reflect the effects of service at the indicated temperature for 300,000 hr.

TABLE I-14.3A¹ S_{mt} - ALLOWABLE STRESS INTENSITY VALUES, 1,000 psi, TYPE 304 SS - 30-YS, 75-UTS (30-YS, 70-UTS)

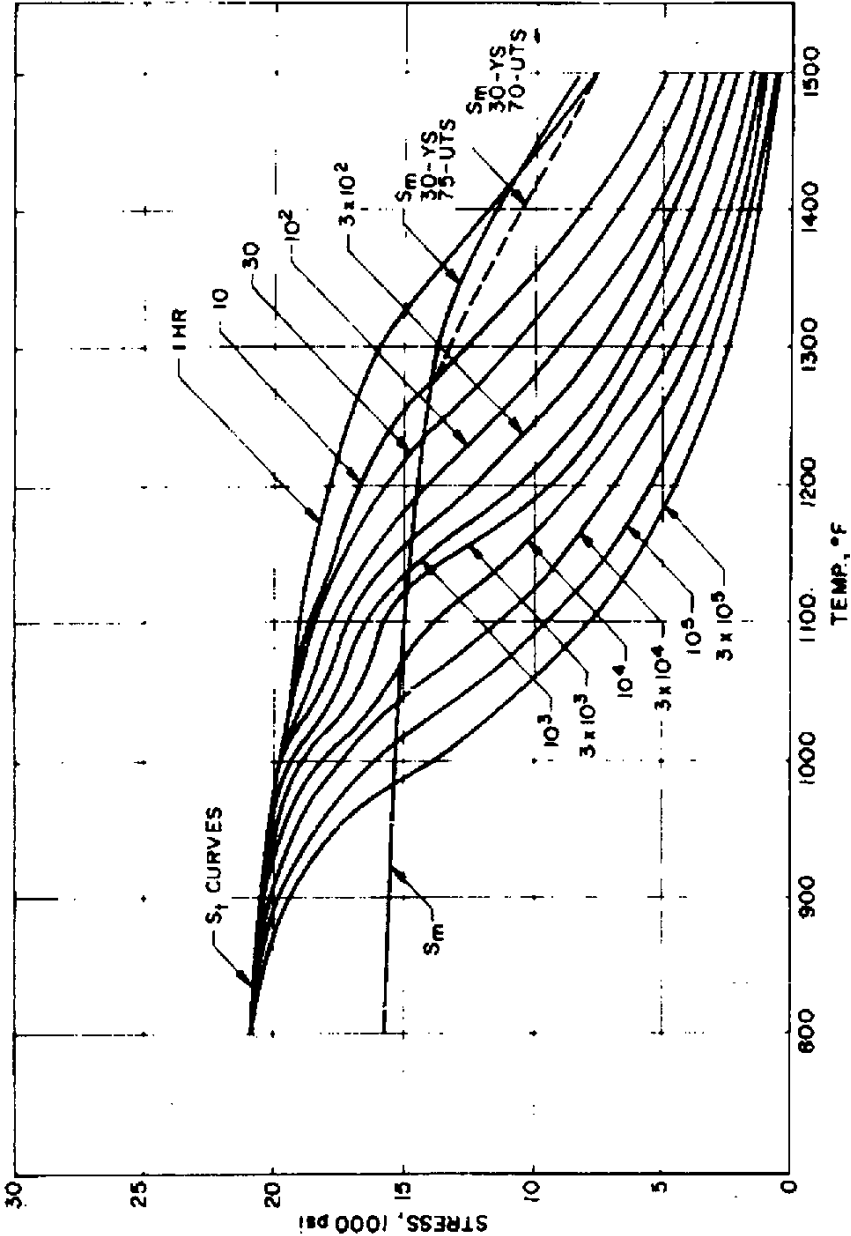


FIG. I-14.3B S_{mt} — TYPE 316 SS

TABLE I-14.3B¹
 S_{mt} — ALLOWABLE STRESS INTENSITY VALUES, 1,000 psi, TYPE 316 SS — 30-YS, 75-UTS (30-YS, 70-UTS)

Temp., °F	1 hr	10 hr	30 hr	10 ² hr	3 × 10 ² hr	10 ³ hr	3 × 10 ³ hr	10 ⁴ hr	3 × 10 ⁴ hr	10 ⁵ hr	3 × 10 ⁵ hr
800	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9
850	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7
900	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
950	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
1,000	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4
1,050	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	14.9	12.5	10.7
1,100	14.8	14.8	14.8	14.8	14.8	14.8	14.8	13.9	11.5	9.5	7.8
1,150	14.7 [(14.6)]	14.7 [(14.6)]	14.7 [(14.6)]	14.7 [(14.6)]	14.7 [(14.6)]	14.2	13.0	10.9	8.9	7.2	5.9
1,200	[13.6] 14.6 [(12.7)]	[13.6] 14.6 [(12.7)]	[13.6] 14.6 [(12.7)]	[13.6] 14.2 [(12.7)]	14.7 [(14.6)]	10.6	9.4	8.3	6.9	5.5	4.5
1,250	[12.2] 14.2 [(11.7)]	[12.2] 14.2 [(11.7)]	[12.2] 14.2 [(11.7)]	11.5	9.8	8.3	7.3	6.3	5.4	4.2	3.3
1,300	[11.4] 13.8 (13.4) [(10.7)]	[11.4] 12.8 [(10.7)]	[11.4] 12.8 [(10.7)]	9.1	7.5	6.4	5.6	4.7	3.9	3.1	2.5
1,350	[10.1] 12.8 (11.9) [(9.5)]	[10.1] 10.3 [(9.5)]	10.9 [(10.7)]	7.0	5.9	5.0	4.2	3.4	2.8	2.1	1.8
1,400	[9.0] 11.3 (10.5) [(8.4)]	8.2	6.7	5.4	4.5	3.8	3.1	2.5	2.0	1.5	1.2
1,450	[7.8] 9.7 (9.0) [(7.3)]	6.4	5.1	4.1	3.4	2.9	2.2	1.7	1.4	1.0	0.9
1,500	[6.2] 7.8 (7.7) [(5.6)]	4.9	3.9	3.2	2.6	2.1	1.6	1.2	0.9	0.65	0.5

NOTE:

(1) Values in square parentheses [] reflect the effects of service at the indicated temperature for 300,000 hr.

TABLE I-14.3B¹ S_{mt} - ALLOWABLE STRESS INTENSITY VALUES, 1,000 psi, TYPE 316 SS - 30-YS, 75-UTS (30-YS, 70-UTS)

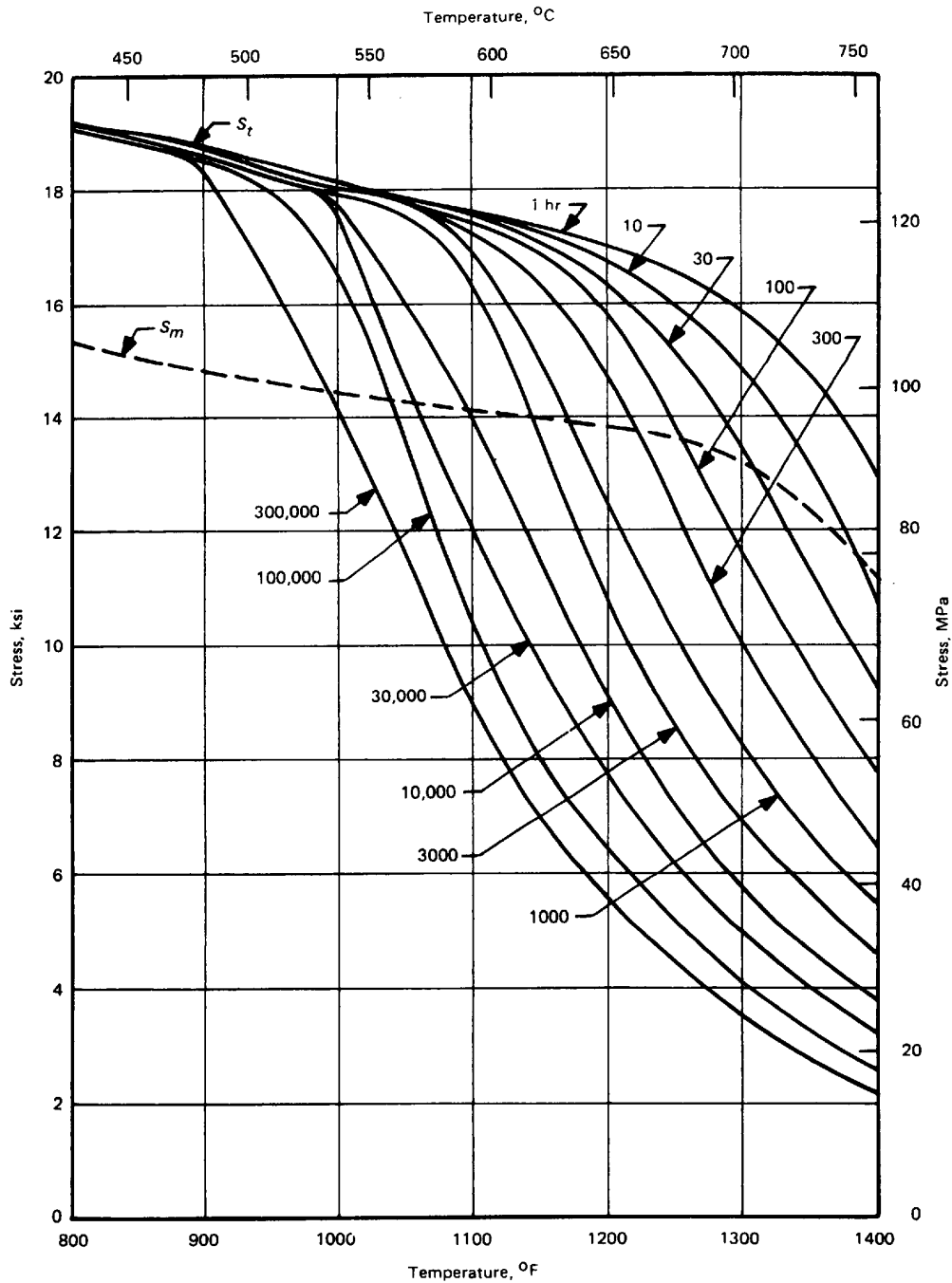


FIG. I-14.3C S_{mt} — Ni-Fe-Cr (ALLOY 800H)

TABLE I-14.3C¹
 S_{mt} — ALLOWABLE STRESS INTENSITY VALUES, ksi, Ni-Fe-Cr (ALLOY 800H)

Temp., °F	1 hr	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
800	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
850	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
900	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
950	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
1,000	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.1
1,050	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	12.8	11.2
1,100	14.1	14.1	14.1	14.1	14.1	14.1	14.1	13.9	12.0	10.2	8.9
1,150	13.9	13.9	13.9	13.9	13.9	13.9	13.2	11.2	9.6	8.2	7.0
1,200	13.8	13.8	13.8	13.8	13.8	12.4	10.7	9.0	7.7	6.5	5.6
1,250	13.5	13.5	13.5	13.5	12.0	10.1	8.6	7.2	6.2	5.2	4.4
1,300	[12.5] 13.2	[12.5] 13.2	[12.5] 13.2	11.6	9.8	8.2	7.0	5.8	5.0	4.1	3.5
1,350	[10.0] 12.0	[10.0] 12.0	[10.0] 11.3	9.5	8.0	6.7	5.7	4.7	4.0	3.3	2.8
1,400	[8.4] 11.0	[8.4] 10.8	[8.4] 9.3	7.8	6.5	5.4	4.6	3.8	3.2	2.6	2.2

NOTE:

(1) Values in square parentheses [] reflect the effects of service at the indicated temperature for 300,000 hr.

TABLE I-14.3C¹ S_{mt} - ALLOWABLE STRESS INTENSITY VALUES, ksi, Ni-Fe-Cr (ALLOY 800H)

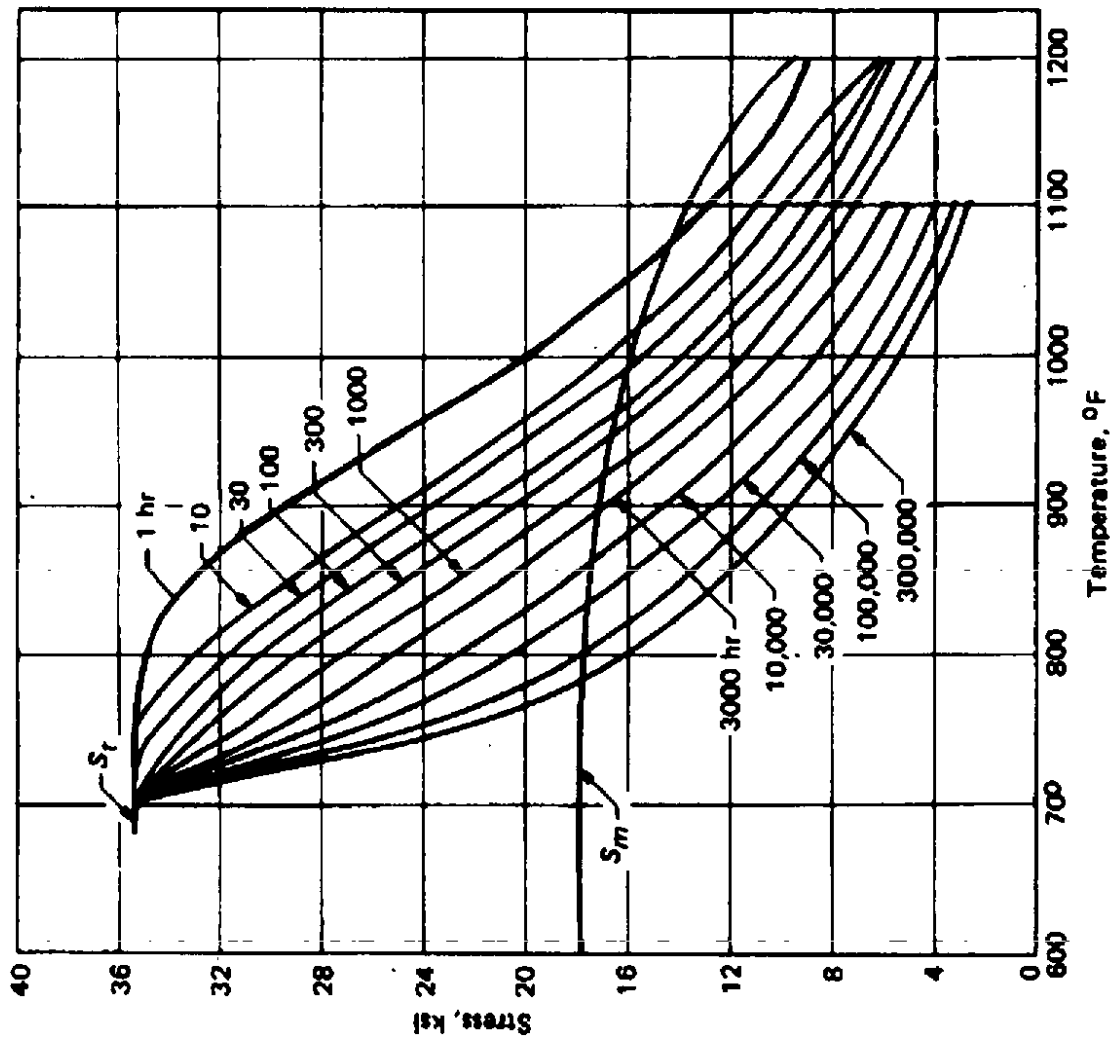


FIG. I-14.3D S_{mt} - $2\frac{1}{4}\text{Cr-1Mo}$

FIG. I-14.3D S_{mt} - $2\frac{1}{4}\text{Cr-1Mo}$

TABLE I-14.3D¹
 S_m — ALLOWABLE STRESS INTENSITY VALUES, ksi, 2½Cr-1Mo

Temp., °F	1 hr	10 hr	30 hr	10 ² hr	3 × 10 ² hr	10 ³ hr	3 × 10 ³ hr	10 ⁴ hr	3 × 10 ⁴ hr	10 ⁵ hr	3 × 10 ⁵ hr
700	...	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9
750	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9
800	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	16.1
850	[15.6] 17.6	[16.5] 17.6	[16.5] 17.6	[16.5] 17.6	[16.5] 17.6	[16.5] 17.6	[16.5] 17.6	[16.5] 17.6	16.3	14.0	12.3
900	[15.0] 17.2	[15.0] 17.2	[15.0] 17.2	[15.0] 17.2	[15.0] 17.2	[15.0] 17.2	[15.0] 17.2	[15.0] 17.2	12.5	10.9	9.6
950	[13.5] 16.7	[13.5] 16.7	[13.5] 16.7	[13.5] 16.7	[13.5] 16.3	[13.5] 14.8	13.2	11.3	9.7	8.4	7.3
1,000	[11.7] 15.9	[11.7] 15.9	[11.7] 15.5	[11.7] 14.2	[11.7] 13.1	[11.7] 11.9	10.4	8.7	7.5	6.3	5.2
1,050	[10.3] 14.9	[10.3] 13.8	[10.3] 12.5	[10.3] 11.2	10.2	9.3	7.9	6.7	5.7	4.7	4.0
1,100	[8.6] 13.6	[8.6] 11.0	[8.6] 10.0	[8.6] 9.0	8.2	7.2	6.2	5.0	4.1	3.3	2.7
1,150	[10.2] 10.8	8.8	8.0	7.2	6.3	5.4	...	...	...	...	...
1,200	[8.0] 9.0	6.2	6.1	5.9	5.1	4.1	...	...	...	...	...

NOTE:

(1) Values in square parentheses [] reflect the effects of service at the indicated temperature for 300,000 hr.

TABLE I-14.3D¹ S_{mt} - ALLOWABLE STRESS INTENSITY VALUES, ksi, 2¹/₄Cr-1Mo

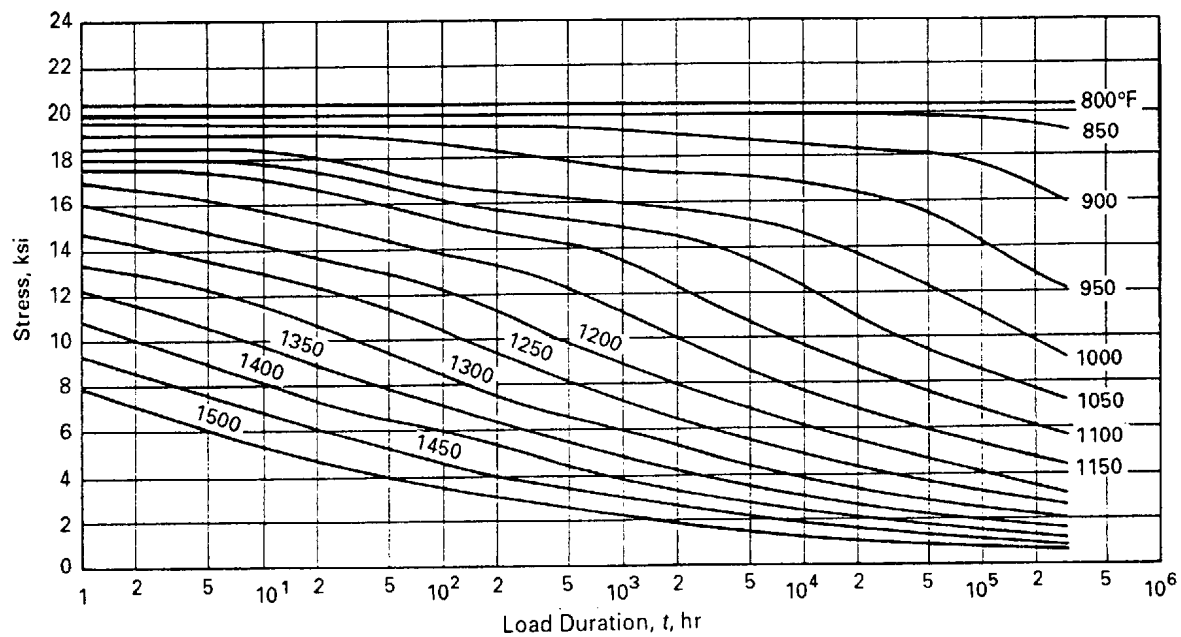


FIG. I-14.4A S_t — TYPE 304 SS

FIG. I-14.4A S_t - TYPE 304 SS

TABLE I-14.4A
 S_t — ALLOWABLE STRESS INTENSITY VALUES, 1,000 psi, TYPE 304 SS

Temp., °F	1 hr	10 hr	30 hr	10 ² hr	3 × 10 ² hr	10 ³ hr	3 × 10 ³ hr	10 ⁴ hr	3 × 10 ⁴ hr	10 ⁵ hr	3 × 10 ⁵ hr
800	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4
850	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	19.9	19.8	19.3
900	19.6	19.6	19.5	19.5	19.4	19.2	18.8	18.5	18.3	17.7	16.0
950	19.1	19.1	19.0	18.7	18.2	17.5	17.2	16.9	16.2	14.2	12.2
1,000	18.5	18.4	17.8	16.9	16.2	15.9	15.5	14.7	13.1	11.1	9.3
1,050	18.0	17.7	17.1	16.2	15.5	14.9	14.1	12.2	10.3	8.7	7.3
1,100	17.6	17.1	16.3	15.3	14.5	13.5	11.5	9.7	8.2	6.8	5.7
1,150	17.0	15.7	14.8	13.8	12.9	11.0	9.3	7.7	6.4	5.3	4.4
1,200	16.0	14.2	13.3	12.2	10.6	8.9	7.4	6.1	5.1	4.1	3.4
1,250	14.7	12.9	11.9	10.3	8.7	7.2	5.9	4.9	4.0	3.2	2.7
1,300	13.4	11.4	10.0	8.5	7.0	5.9	4.8	3.9	3.2	2.5	2.1
1,350	12.2	9.7	8.4	7.1	5.9	4.8	3.9	3.1	2.5	2.0	1.6
1,400	10.8	8.1	6.9	5.9	4.8	3.9	3.1	2.5	2.0	1.6	1.2
1,450	9.3	6.8	5.9	4.6	3.8	3.0	2.4	1.9	1.5	1.2	0.9
1,500	7.9	5.3	4.4	3.5	2.8	2.2	1.7	1.3	1.0	0.8	0.6

TABLE I-14.4A S_t — ALLOWABLE STRESS INTENSITY VALUES, 1,000 psi, TYPE 304 SS

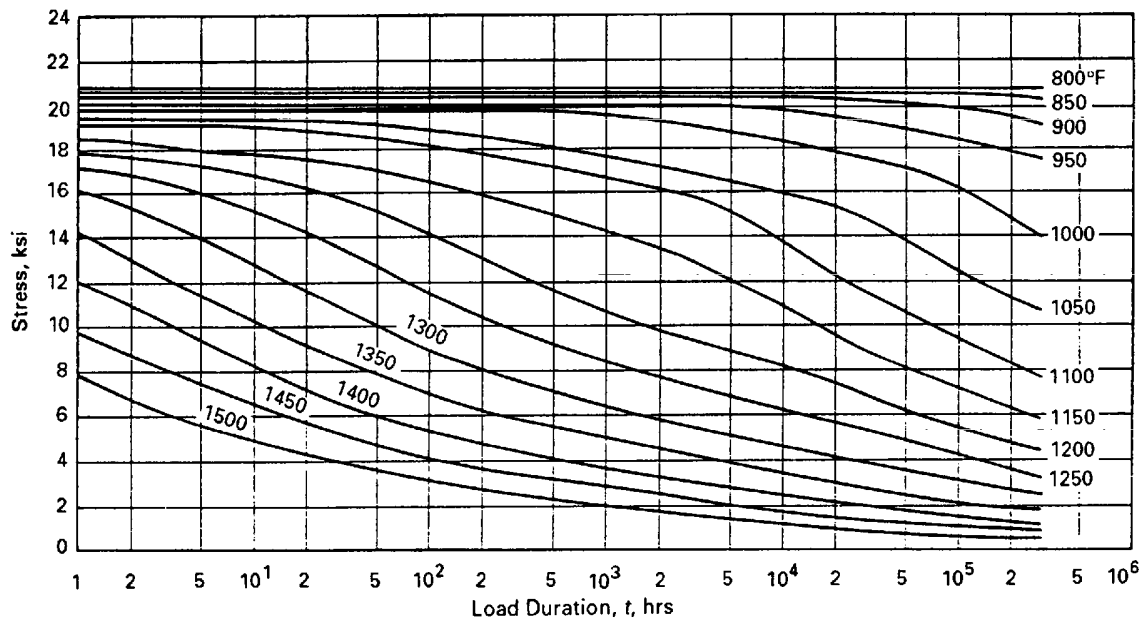


FIG. I-14.4B S_t — TYPE 316 SS

TABLE I-14.4B
 S_t — ALLOWABLE STRESS INTENSITY VALUES, 1,000 psi, TYPE 316 SS

Temp., °F	1 hr	10 hr	30 hr	10 ² hr	3 × 10 ² hr	10 ³ hr	3 × 10 ³ hr	10 ⁴ hr	3 × 10 ⁴ hr	10 ⁵ hr	3 × 10 ⁵ hr
800	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8
850	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.3
900	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.2	19.9	19.3
950	20.1	20.1	20.1	20.1	20.1	20.0	20.0	19.7	19.2	18.4	17.6
1,000	19.8	19.8	19.8	19.8	19.8	19.5	19.0	18.2	17.5	16.2	14.0
1,050	19.4	19.4	19.2	18.7	18.3	17.6	16.8	15.9	14.9	12.5	10.7
1,100	19.1	19.0	18.5	17.8	17.3	16.6	15.9	13.9	11.5	9.5	7.8
1,150	18.5	17.7	17.3	16.4	15.4	14.2	13.0	10.9	8.9	7.2	5.9
1,200	17.8	16.8	15.8	14.2	12.4	10.6	9.4	8.3	6.9	5.5	4.5
1,250	17.1	15.2	13.5	11.5	9.8	8.3	7.3	6.3	5.4	4.2	3.3
1,300	16.1	12.8	10.9	9.1	7.5	6.4	5.6	4.7	3.9	3.1	2.5
1,350	14.2	10.3	8.6	7.0	5.9	5.0	4.2	3.4	2.8	2.1	1.8
1,400	12.0	8.2	6.7	5.4	4.5	3.8	3.1	2.5	2.0	1.5	1.2
1,450	9.7	6.4	5.1	4.1	3.4	2.9	2.2	1.7	1.4	1.0	0.8
1,500	7.8	4.9	3.9	3.2	2.6	2.1	1.6	1.2	0.9	0.65	0.5

TABLE I-14.4B S_t - ALLOWABLE STRESS INTENSITY VALUES, 1,000 psi, TYPE 316 SS

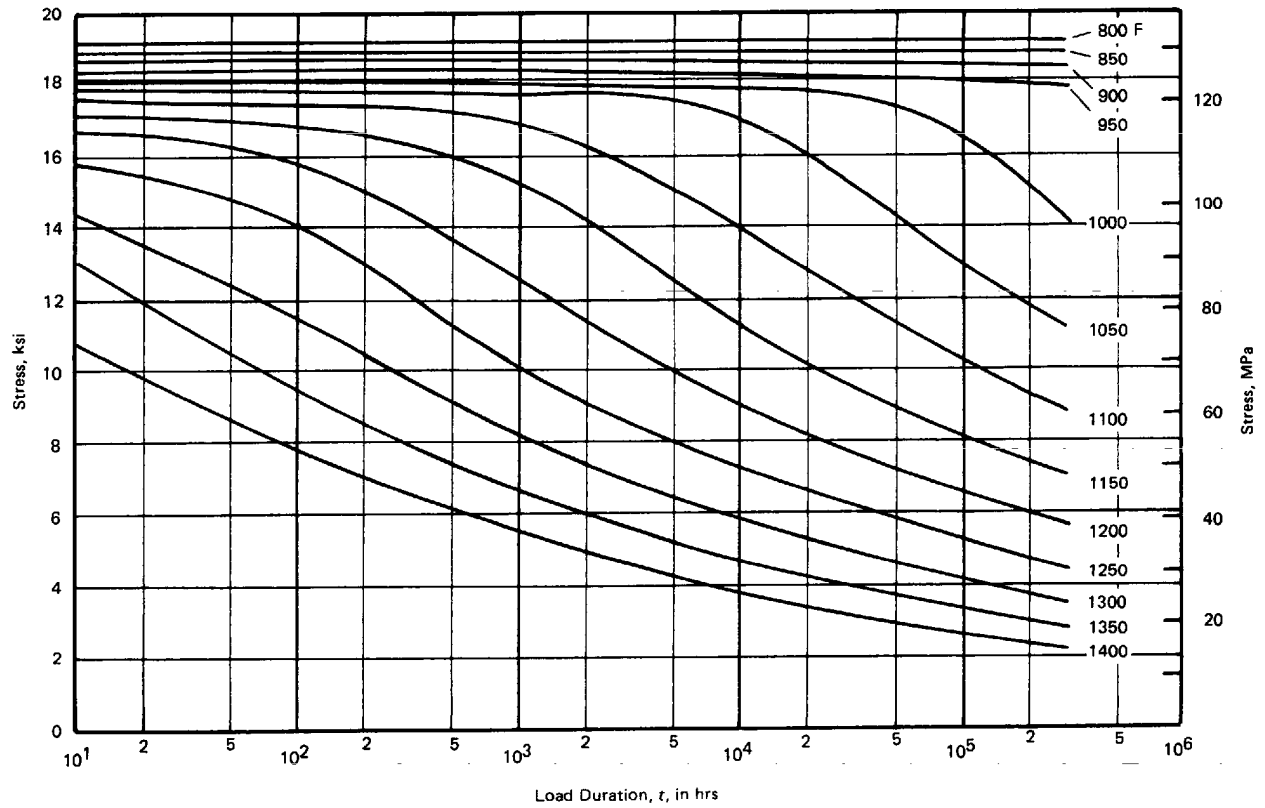


FIG. I-14.4C S_t — Ni-Fe-Cr (ALLOY 800H)

FIG. I-14.4C S_t - Ni-Fe-Cr (ALLOY 800H)

TABLE I-14.4C
 S_t — ALLOWABLE STRESS INTENSITY VALUES, ksi, Ni-Fe-Cr (ALLOY 800H)

Temp. °F	1 hr	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
800	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.1	19.1
850	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.8	18.8
900	18.7	18.7	18.7	18.7	18.7	18.7	18.6	18.6	18.6	18.5	18.4
950	18.4	18.4	18.4	18.4	18.4	18.4	18.3	18.2	18.2	18.0	17.8
1,000	18.2	18.1	18.1	18.1	18.1	18.0	17.9	17.8	17.6	16.5	14.1
1,050	17.9	17.9	17.8	17.8	17.7	17.6	17.4	17.1	15.0	12.9	11.1
1,100	17.6	17.6	17.5	17.4	17.2	16.9	16.3	13.9	12.0	10.3	8.9
1,150	17.3	17.2	17.0	16.8	16.4	15.3	13.2	11.2	9.6	8.1	7.0
1,200	17.0	16.7	16.3	15.8	14.7	12.4	10.7	9.0	7.7	6.5	5.6
1,250	16.5	15.8	15.2	14.1	12.0	10.1	8.6	7.2	6.2	5.2	4.4
1,300	15.8	14.4	13.4	11.5	9.8	8.2	7.0	5.8	5.0	4.1	3.5
1,350	14.7	13.1	11.3	9.5	8.0	6.7	5.7	4.7	4.0	3.3	2.8
1,400	13.0	10.8	9.3	7.8	6.5	5.4	4.6	3.8	3.2	2.6	2.2

TABLE I-14.4C S_t — ALLOWABLE STRESS INTENSITY VALUES, ksi, Ni-Fe-Cr (ALLOY 800H)

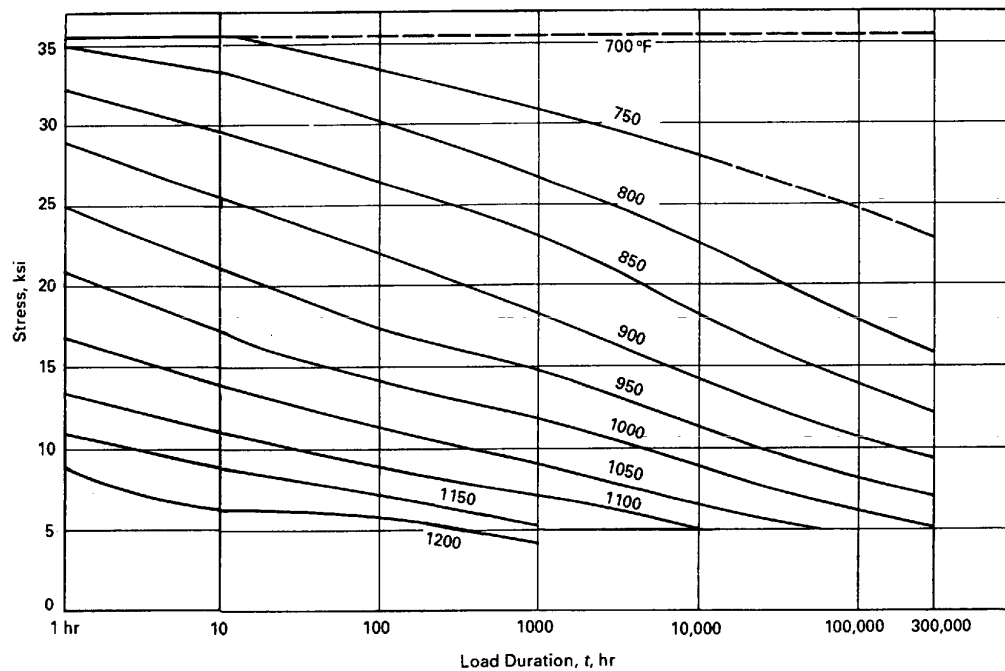


FIG. I-14.4D S_t — $2\frac{1}{4}$ Cr-1Mo

TABLE I-14.4D
 S_t — ALLOWABLE STRESS INTENSITY VALUES, ksi, $2\frac{1}{4}$ Cr-1Mo

Temp., °F	1 hr	10 hr	30 hr	10 ² hr	3 × 10 ² hr	10 ³ hr	3 × 10 ³ hr	10 ⁴ hr	3 × 10 ⁴ hr	10 ⁵ hr	3 × 10 ⁵ hr
700	...	35.5	35.5	35.5	35.5	35.5	35.5	35.5	35.5	35.5	35.5
750	35.3	35.2	34.6	33.5	32.5	31.3	29.7	28.4	26.6	25.0	23.3
800	35.0	33.2	31.8	30.4	28.8	26.8	25.0	23.0	20.5	18.0	16.1
850	32.3	29.4	28.0	26.4	25.0	23.2	21.0	18.3	16.3	14.0	12.3
900	29.0	25.5	23.7	22.0	20.2	18.5	16.5	14.4	12.5	10.9	9.6
950	25.0	21.0	19.3	17.5	16.3	14.8	13.2	11.3	9.7	8.4	7.3
1,000	20.7	17.1	15.5	14.2	13.1	11.9	10.4	8.7	7.5	6.3	5.2
1,050	16.8	13.8	12.5	11.2	10.2	9.3	7.9	6.7	5.7	4.7	4.0
1,100	13.6	11.0	10.0	9.0	8.2	7.2	6.2	5.0	4.1	3.3	2.7
1,150	10.8	8.8	8.0	7.2	6.3	5.4	...	...	...	...	...
1,200	9.0	6.2	6.1	5.9	5.1	4.1	...	...	...	...	...

TABLE I-14.4D S_t - ALLOWABLE STRESS INTENSITY VALUES, ksi, $2\frac{1}{4}$ Cr-1Mo

TABLE I-14.5
YIELD STRENGTH VALUES, S_y , VS TEMPERATURE

Temp., °F	(Stresses, ksi Units)				
	304 SS	316 SS	Ni-Fe-Cr Alloy 800H	2 $\frac{1}{4}$ Cr-1Mo	Ni-Cr-Fe-Mo-Cb Alloy 718
RT	30.0	30.0	25.0	30.0	150.0
100	30.0	30.0	24.3	30.0	148.4
200	25.0	25.8	22.5	27.8	143.9
300	22.5	23.3	21.1	27.1	140.7
400	20.7	21.4	20.0	26.9	138.3
500	19.4	19.9	19.0	26.9	136.7
600	18.2	18.8	18.3	26.9	135.4
700	17.7	18.1	17.5	26.9	134.3
750	17.3	17.8	17.2	26.9	133.7
800	16.8	17.6	17.0	26.7	133.1
850	16.5	17.4	16.6	26.2	132.4
900	16.2	17.3	16.5	25.7	131.5
950	15.9	17.1	16.2	24.8	130.5
1,000	15.6	17.0	16.0	23.7	129.4
1,050	15.2	16.7	15.8	22.4	128.0
1,100	14.7	16.5	15.6	20.6	...
1,150	14.4	16.4	15.5	18.5	...
1,200	14.1	16.2	15.3	16.2	...
1,250	13.7	15.8	15.1	...	...
1,300	13.2	15.3	14.7	...	...
1,350	12.5	14.9	14.5	...	...
1,400	11.6	14.4	14.0	...	...
1,450	10.6	13.8	13.5	...	...
1,500	9.5	13.1	13.0	...	...
1,550	...	...	12.0	...	...
1,600	...	...	11.2	...	...

GENERAL NOTE:

The tabulated values of yield strength are those which are suitable for use in design calculations required by this Subsection. At temperatures above room temperature, the yield strength values correspond to the yield strength trend curve adjusted to the minimum specified room temperature yield strength. The yield strength values do not correspond exactly to either *average* or *minimum* as these terms are applied to a statistical treatment of a homogeneous set of data.

Neither the ASME Materials Specifications nor the rules of this Subsection require elevated temperature testing for yield strengths of production material for use in Code components. It is not intended that results of such tests, if performed, be compared with these tabulated yield strength values for ASME Code acceptance/rejection purposes for materials. If some elevated temperature test results on production material appear lower than the tabulated values by a large amount (more than the typical variability of material and suggesting the possibility of some error) further investigation by retests or other means should be considered.

TABLE I-14.5 YIELD STRENGTH VALUES, S_y , VS TEMPERATURE

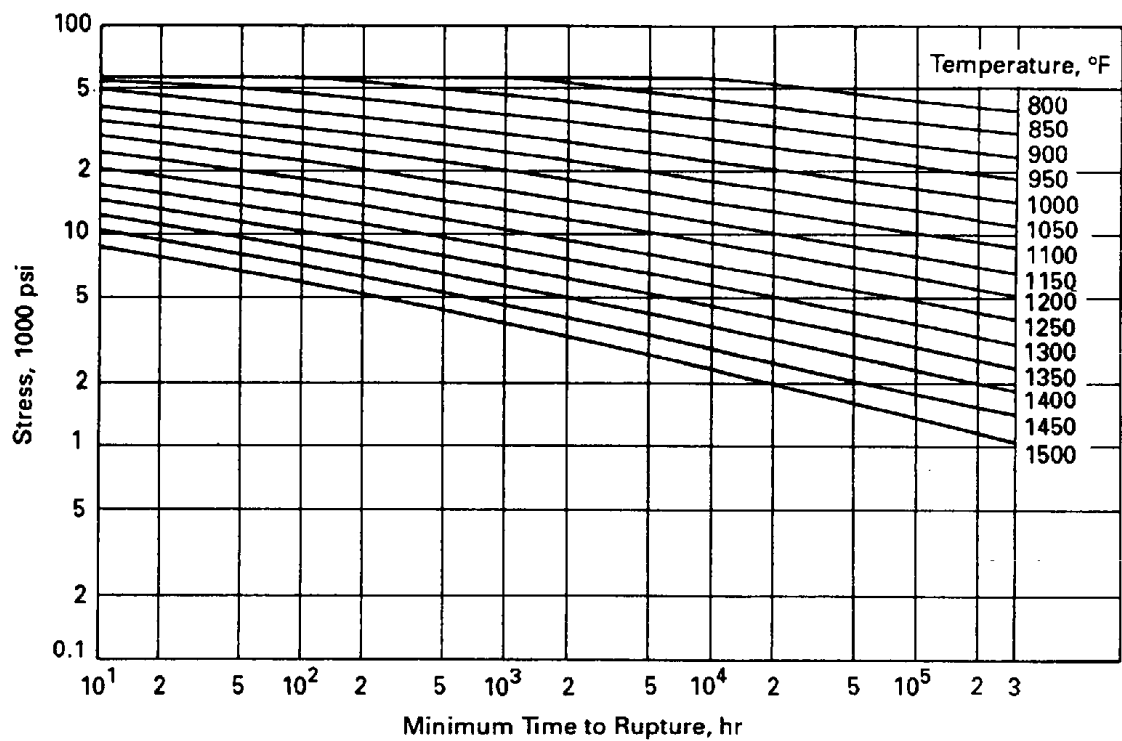


FIG. I-14.6A MINIMUM STRESS-TO-RUPTURE

FIG. I-14.6A MINIMUM STRESS-TO-RUPTURE

TABLE I-14.6A
EXPECTED MINIMUM STRESS-TO-RUPTURE VALUES, 1,000 psi, TYPE 304 SS

Temp., °F	1 hr	10 hr	30 hr	10 ² hr	3 × 10 ² hr	10 ³ hr	3 × 10 ³ hr	10 ⁴ hr	3 × 10 ⁴ hr	10 ⁵ hr	3 × 10 ⁵ hr
800	57	57	57	57	57	57	57	57	51	44.3	39
850	56.5	56.5	56.5	56.5	56.5	56.5	50.2	45.4	40	34.7	30.5
900	55.5	55.5	55.5	55.5	51.5	46.9	41.2	36.1	31.5	27.2	24
950	54.2	54.2	51	48.1	43	38.0	33.5	28.8	24.9	21.2	18.3
1,000	52.5	50	44.5	39.8	35	30.9	26.5	22.9	19.7	16.6	14.9
1,050	50	41.9	37	32.9	28.9	25.0	21.6	18.2	15.5	13.0	11.0
1,100	45	35.2	31	27.2	23.9	20.3	17.3	14.5	12.3	10.2	8.6
1,150	38	29.5	26	22.5	19.3	16.5	13.9	11.6	9.6	8.0	6.6
1,200	32	24.7	21.5	18.6	15.9	13.4	11.1	9.2	7.6	6.2	5.0
1,250	27	20.7	17.9	15.4	13	10.8	8.9	7.3	6.0	4.9	4.0
1,300	23	17.4	15	12.7	10.5	8.8	7.2	5.8	4.8	3.8	3.1
1,350	19.5	14.6	12.6	10.6	8.8	7.2	5.8	4.6	3.8	3.0	2.4
1,400	16.5	12.1	10.3	8.8	7.2	5.8	4.7	3.7	3.0	2.3	1.9
1,450	14.0	10.2	8.8	7.3	5.8	4.6	3.8	2.9	2.3	1.8	1.4
1,500	12.0	8.6	7.2	6.0	4.9	3.8	3.0	2.4	1.8	1.4	1.1

TABLE I-14.6A EXPECTED MINIMUM STRESS-TO-RUPTURE VALUES, 1,000 psi, TYPE 304 SS

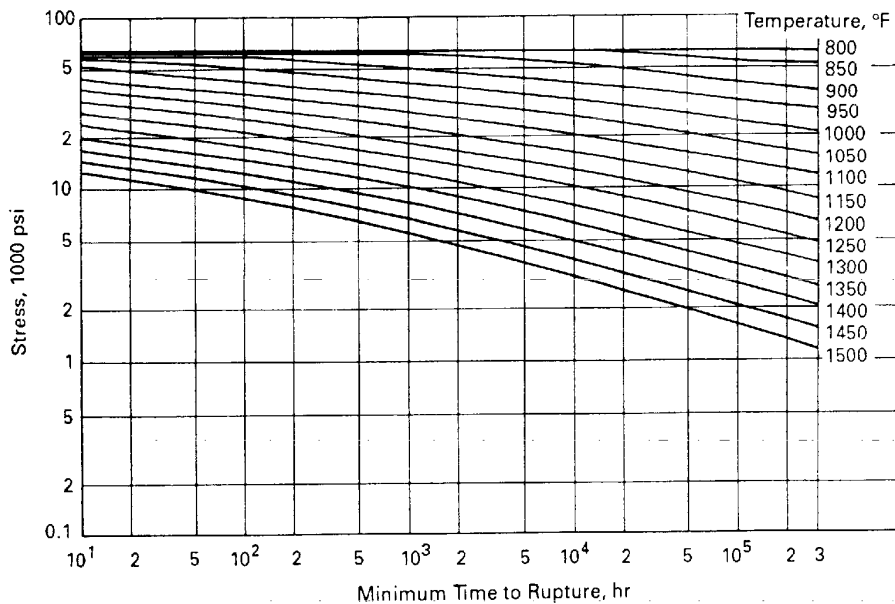


FIG. I-14.6B MINIMUM STRESS-TO-RUPTURE

TABLE I-14.6B
EXPECTED MINIMUM STRESS-TO-RUPTURE VALUES, 1,000 psi, TYPE 316 SS

Temp., °F	1 hr	10 hr	30 hr	10 ² hr	3 × 10 ² hr	10 ³ hr	3 × 10 ³ hr	10 ⁴ hr	3 × 10 ⁴ hr	10 ⁵ hr	3 × 10 ⁵ hr
800	64.5	64.5	64.5	64.5	64.5	64.5	64.5	64.5	64.5	64.5	64.5
850	63.3	63.3	63.3	63.3	63.3	63.3	63.3	63.3	60	56	52
900	62.2	62.2	62.2	62.2	62.1	62	58	54.1	48	42.6	38
950	60	60	60	60	56	51.6	46.5	42.6	37.5	32.4	28.3
1,000	58.5	58.5	55	51.7	47	42.1	37.5	33.6	28.8	24.6	21
1,050	56	52.9	47.5	43.4	38.2	34.4	30.2	26.4	22.3	18.8	16
1,100	53.5	45.1	40	36.4	32.2	28.1	24.2	20.8	17.3	14.3	11.7
1,150	46.5	38.4	34	30.5	26.6	23.0	19.5	16.4	13.4	10.9	8.8
1,200	40	32.7	29	25.6	22	18.8	15.6	12.9	10.3	8.3	6.7
1,250	35	27.8	24.3	21.4	18.1	15.4	12.7	10.2	8.1	6.3	4.9
1,300	30	23.7	20.8	18.0	15	12.5	10.0	8.0	6.2	4.8	3.7
1,350	26	20.0	17.5	15.0	12.7	10.4	8.2	6.4	4.9	3.6	2.7
1,400	22.5	17.1	14.8	12.4	10.2	8.4	6.6	5.0	3.8	2.8	2.1
1,450	19.5	14.6	12.6	10.5	8.6	6.8	5.2	3.9	2.9	2.1	1.5
1,500	17	12.5	10.6	8.8	7.2	5.6	4.2	3.1	2.3	1.6	1.2

TABLE I-14.6B EXPECTED MINIMUM STRESS-TO-RUPTURE VALUES, 1,000 psi, TYPE 316 SS

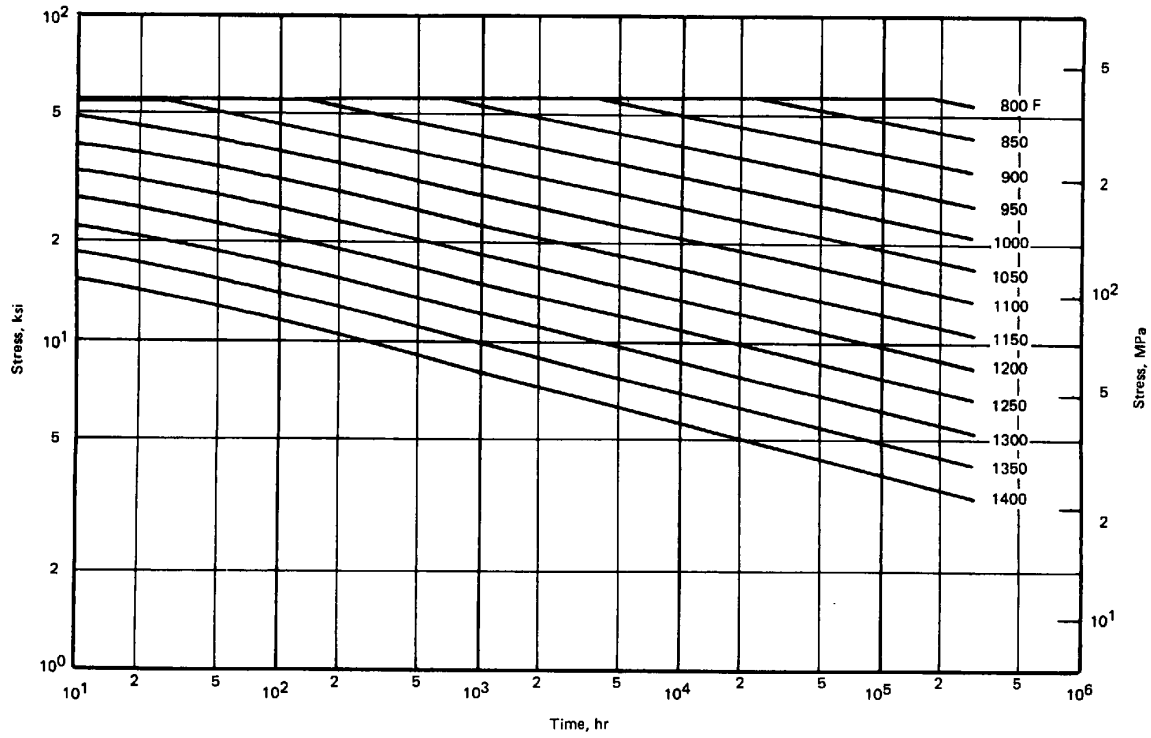


FIG. I-14.6C MINIMUM STRESS-TO-RUPTURE — Ni-Fe-Cr (ALLOY 800H)

FIG. I-14.6C MINIMUM STRESS-TO-RUPTURE - Ni-Fe-Cr (ALLOY 800H)

TABLE I-14.6C
EXPECTED MINIMUM STRESS-TO-RUPTURE VALUES, ksi, Ni-Fe-Cr (ALLOY 800H)

Temp., °F	1 hr	3 hr	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
800	56.2	56.2	56.2	56.2	56.2	56.2	56.2	56.2	56.2	56.2	56.2	53.2
850	55.9	55.9	55.9	55.9	55.9	55.9	55.9	55.9	55.9	54.5	47.7	42.2
900	55.6	55.6	55.6	55.6	55.6	55.6	55.6	55.6	49.6	43.7	38.0	33.5
950	55.3	55.3	55.3	55.3	55.3	55.3	52.6	46.1	39.9	35.0	30.3	26.6
1,000	54.7	54.7	54.7	54.7	54.7	49.6	42.7	37.3	32.1	28.1	24.2	21.1
1,050	53.9	53.9	53.9	53.8	46.5	40.5	34.8	30.2	25.9	22.5	19.3	16.7
1,100	52.5	52.5	50.2	44.4	38.2	33.1	28.2	24.4	20.8	18.0	15.4	13.3
1,150	48.9	46.2	41.6	36.6	31.3	27.0	23.0	19.8	16.8	14.4	12.2	10.5
1,200	40.7	38.4	34.4	30.2	25.7	22.1	18.7	16.0	13.5	11.6	9.8	8.4
1,250	33.8	31.9	28.5	24.9	21.1	18.1	15.2	12.9	10.9	9.3	7.8	6.6
1,300	28.2	26.5	23.6	20.5	17.3	14.8	12.3	10.5	8.7	7.4	6.2	5.3
1,350	23.4	22.0	19.6	16.9	14.2	12.1	10.0	8.5	7.0	6.0	4.9	4.2
1,400	19.5	18.3	16.2	14.0	11.7	9.8	8.2	6.9	5.7	4.8	3.9	3.3

TABLE I-14.6C EXPECTED MINIMUM STRESS-TO-RUPTURE VALUES, ksi, Ni-Fe-Cr (ALLOY 800H)

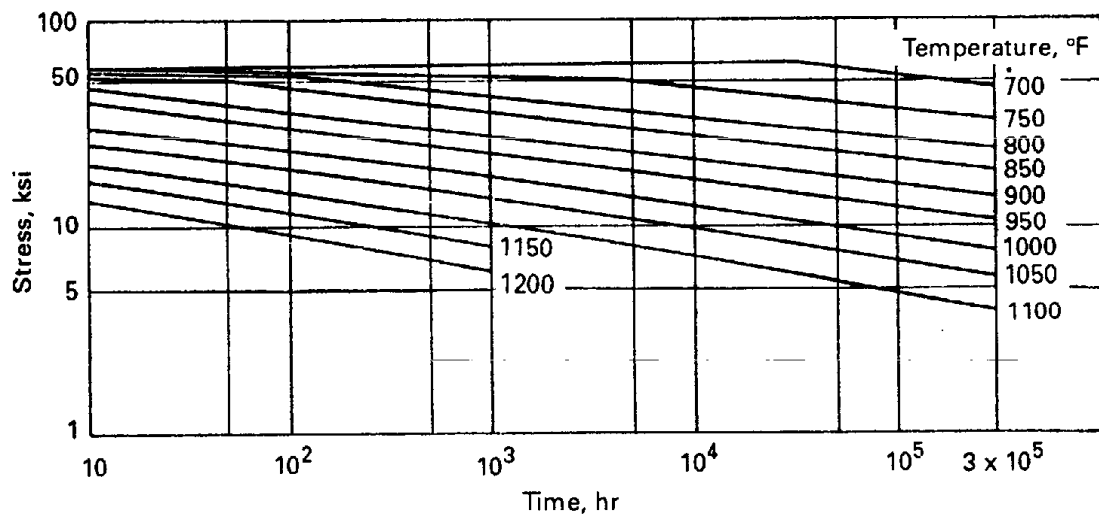


FIG. I-14.6D 2¹/₄Cr-1Mo — 100% OF THE MINIMUM STRESS-TO-RUPTURE

TABLE I-14.6D
 $2\frac{1}{4}$ Cr-1Mo -- EXPECTED MINIMUM STRESS-TO-RUPTURE VALUES, ksi

Temp., °F	10 hr	30 hr	10 ² hr	3 × 10 ² hr	10 ³ hr	3 × 10 ³ hr	10 ⁴ hr	3 × 10 ⁴ hr	10 ⁵ hr	3 × 10 ⁵ hr
700	59.0	59.0	59.0	59.0	59.0	59.0	59.0	59.0	54.0	49.0
750	58.0	57.0	56.0	54.6	53.0	51.2	48.0	43.3	37.5	34.1
800	56.0	55.5	54.0	48.5	43.0	37.5	34.5	30.5	27.0	24.0
850	52.0	50.5	46.0	40.5	35.0	31.0	27.5	24.0	21.0	18.5
900	46.0	41.0	36.0	32.0	28.0	25.0	21.6	19.0	16.4	14.1
950	40.0	35.0	30.0	26.0	22.2	19.5	17.0	14.6	12.6	11.0
1,000	31.5	27.5	24.0	21.0	17.9	15.2	13.1	11.0	9.4	7.9
1,050	26.0	22.5	19.0	16.5	14.0	12.0	10.0	8.3	7.0	5.8
1,100	21.0	18.0	15.1	13.0	10.8	9.1	7.5	6.2	5.0	4.1
1,150	17.0	14.1	11.8	9.8	8.0	...	...	...	...	...
1,200	13.5	11.1	9.2	7.6	6.2	...	...	...	...	...

TABLE I-14.6D $2\frac{1}{4}$ Cr-1Mo - EXPECTED MINIMUM STRESS-TO-RUPTURE VALUES, ksi

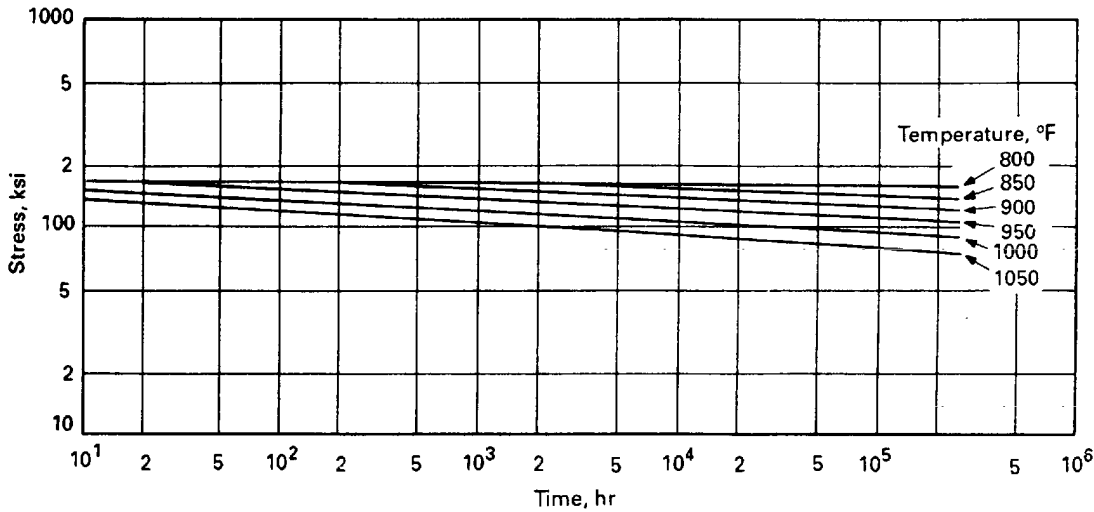


FIG. I-14.6E MINIMUM STRESS-TO-RUPTURE, ALLOY 718

FIG. I-14.6E MINIMUM STRESS-TO-RUPTURE, ALLOY 718

TABLE I-14.6E
EXPECTED MINIMUM STRESS-TO-RUPTURE VALUES, ksi, Ni-Cr-Fe-Mo-Cb (ALLOY 718)

Temp., °F	10 hr	30 hr	10 ² hr	3 × 10 ² hr	10 ³ hr	3 × 10 ³ hr	10 ⁴ hr	3 × 10 ⁴ hr	10 ⁵ hr	3 × 10 ⁵ hr
800	168	168	168	168	168	168	168	168	160	154
850	172	172	172	172	172	166	159	151	146	140
900	170	170	170	166	158	151	144	138	130	124
950	170	166	158	150	144	136	129	122	114	106
1,000	160	150	144	136	130	122	114	106	98	90
1,050	146	138	130	124	114	106	98	91	81	74

TABLE I-14.6E EXPECTED MINIMUM STRESS-TO-RUPTURE VALUES, ksi, Ni-Cr-Fe-Mo-Cb (ALLOY 718)

TABLE I-14.7
MODULUS OF ELASTICITY VS TEMPERATURE

(Static) Modulus of Elasticity, psi × 10 ⁻⁶				
Temp., °F	304 SS and 316 SS	Ni-Fe-Cr Alloy 800H	2 ¹ / ₄ Cr-1Mo	Ni-Cr-Fe-Mo-Cb Alloy 718
950	23.2	24.5	25.1	24.9
1,000	22.8	24.2	24.6	24.7
1,050	22.5	24.1	24.2	24.5
1,100	22.1	23.8	23.7	
1,150	21.6	23.5	23.1	
1,200	21.2	23.2	22.5	
1,250	20.8	22.9		
1,300	20.2	22.7		
1,350	19.8	22.2		
1,400	19.2	21.9		
1,450	18.7	21.7		
1,500	18.1	21.2		

GENERAL NOTE: Moduli of elasticity at 900°F and below are provided in Section II, Part D, Subpart 2, Tables TM.

TABLE I-14.7 MODULUS OF ELASTICITY VS TEMPERATURE

TABLE I-14.8
INSTANTANEOUS COEFFICIENT OF THERMAL EXPANSION VS TEMPERATURE

Temp., °F	Instantaneous Coefficient of Thermal Expansion, in./in. — °F × 10 ⁶				
	304 SS	316 SS	Ni-Fe-Cr Alloy 800H	2 ¹ / ₄ Cr-1Mo	Ni-Cr-Fe-Mo-Cb Alloy 718
850	10.87	11.09	9.65	8.45	8.68
900	10.97	11.20	9.80	8.50	8.82
950	11.06	11.31	9.97	8.55	8.95
1,000	11.14	11.40	10.16	8.60	9.11
1,050	11.23	11.49	10.37	8.63	9.30
1,100	11.31	11.58	10.60	8.65	9.49
1,150	11.38	11.65	10.80	8.68	
1,200	11.47	11.72	11.00	8.70	
1,250	11.55	11.78	11.20		
1,300	11.63	11.82	11.37		
1,350	11.71	11.86	11.54		
1,400	11.78	11.90	11.68		
1,450	11.86	11.94	11.80		
1,500	11.94	11.97	11.92		
1,550		12.00	12.00		
1,600		12.03	12.10		

GENERAL NOTE: Thermal expansion coefficients at 800°F and below are provided in Section II, Part D, Subpart 2, Tables TE.

TABLE I-14.8 INSTANTANEOUS COEFFICIENT OF THERMAL EXPANSION VS TEMPERATURE

**TABLE I-14.9
MEAN COEFFICIENT OF THERMAL EXPANSION [NOTE (1)] VS TEMPERATURE**

Mean Coefficient of Thermal Expansion, in./in. — °F × 10 ⁶					
Temp., °F	304 SS	316 SS	Ni-Fe-Cr Alloy 800H	2¼Cr-1Mo	Ni-Cr-Fe-Mo-Cb Alloy 718
850	9.89	9.95	9.25	7.68	7.92
900	9.95	10.02	9.30	7.73	7.97
950	10.01	10.09	9.35	7.78	8.02
1,000	10.07	10.16	9.40	7.82	8.07
1,050	10.13	10.22	9.45	7.86	8.12
1,100	10.18	10.29	9.50	7.90	8.18
1,150	10.24	10.35	9.55	7.94	
1,200	10.29	10.40	9.60	7.97	
1,250	10.34	10.47	9.65		
1300	10.39	10.52	9.70		
1,350	10.44	10.58	9.77		
1,400	10.49	10.62	9.84		
1,450	10.54	10.67	9.91		
1,500	10.59	10.71	10.00		
1,550		10.74	10.10		
1,600		10.78	10.20		

GENERAL NOTE: Thermal expansion coefficients at 800°F and below are provided in Section II, Part D, Subpart 2, Tables TE.

NOTE:

(1) The mean coefficient of thermal expansion at temperature, T , is given by:

$$\frac{\text{Length at } T - \text{length at } 70^{\circ}\text{F}}{(\text{Length at } 70^{\circ}\text{F}) (T - 70^{\circ}\text{F})}$$

TABLE I-14.9 MEAN COEFFICIENT OF THERMAL EXPANSION [NOTE (1)] VS TEMPERATURE

TABLE I-14.10 A-1
STRESS RUPTURE FACTORS FOR TYPE 304 STAINLESS STEEL WELDED WITH SFA-5.22 E 308T AND E 308LT;
SFA-5.4 E 308 AND E 308L; AND SFA-5.9 ER 308 AND ER 308L

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.97	0.97
900	1.00	0.99	0.98	0.97	0.97	0.97	0.97	0.97	0.95	0.94
950	1.00	0.98	0.97	0.96	0.95	0.95	0.95	0.95	0.93	0.91
1,000	1.00	0.98	0.96	0.94	0.93	0.93	0.93	0.93	0.91	0.88
1,050	1.00	0.99	0.98	0.97	0.97	0.97	0.97	0.95	0.91	0.85
1,100	1.00	0.99	0.98	1.00	1.00	1.00	0.99	0.95	0.89	0.82
1,150	1.00	1.00	1.00	1.00	1.00	0.99	0.95	0.90	0.81	0.72
1,200	1.00	1.00	1.00	1.00	0.98	0.95	0.88	0.81	0.71	0.60
1,250	1.00	1.00	0.97	0.97	0.92	0.87	0.78	0.69	0.57	0.46

TABLE I-14.10 A-1 STRESS RUPTURE FACTORS FOR TYPE 304 STAINLESS STEEL WELDED WITH SFA-5.22 E 308T AND E 308LT; SFA-5.4 E 308 AND E 308L; AND SFA-5.9 ER 308 AND ER 308L

TABLE I-14.10 A-2
STRESS RUPTURE FACTORS FOR TYPE 304 STAINLESS STEEL WELDED WITH SFA-5.22 EXXXT-G
(16-8-2 CHEMISTRY); SFA-5.4 E 16-8-2; AND SFA-5.9 ER 16-8-2

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
950	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1,000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1,050	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1,100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1,150	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1,200	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE I-14.10 A-2 STRESS RUPTURE FACTORS FOR TYPE 304 STAINLESS STEEL WELDED WITH SFA-5.22 EXXXT-G (16-8-2 CHEMISTRY); SFA-5.4 E 16-8-2; AND SFA-5.9 ER 16-8-2

TABLE I-14.10 A-3
STRESS RUPTURE FACTORS FOR TYPE 304 STAINLESS STEEL WELDED WITH SFA-5.22 E 316T AND
E 316LT-1, -2, AND -3; SFA-5.4 E 316 AND E 316L; AND SFA-5.9 ER 316 AND ER 316L

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.98	0.94
900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.95	0.90
950	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.92	0.86
1,000	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.95	0.89	0.82
1,050	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.89	0.80
1,100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.89	0.79
1,150	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.83	0.74
1,200	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.92	0.79	0.68
1,250	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.85	0.72	0.61
1,300	1.00	1.00	1.00	1.00	1.00	1.00	0.89	0.78	0.65	0.54
1,350	1.00	1.00	1.00	1.00	1.00	0.92	0.81	0.70	0.59	0.49
1,400	1.00	1.00	1.00	1.00	0.93	0.85	0.73	0.63	0.51	0.45

TABLE I-14.10 A-3 STRESS RUPTURE FACTORS FOR TYPE 304 STAINLESS STEEL WELDED WITH SFA-5.22 E 316T AND E 316LT-1, -2, AND -3; SFA-5.4 E 316 AND E 316L; AND SFA-5.9 ER 316 AND ER 316L

TABLE I-14.10 B-1
STRESS RUPTURE FACTORS FOR TYPE 316 STAINLESS STEEL WELDED WITH SFA 5.22 E 308T AND
E 308LT; SFA 5.4 E 308 AND E 308L; AND SFA 5.9 ER 308 AND ER 308L

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850	1.00	0.98	0.95	0.95	0.95	0.94	0.92	0.92	0.92	0.92
900	1.00	0.94	0.88	0.88	0.88	0.87	0.84	0.84	0.82	0.82
950	1.00	0.90	0.81	0.81	0.81	0.80	0.77	0.76	0.73	0.72
1,000	1.00	0.87	0.75	0.75	0.74	0.73	0.70	0.68	0.64	0.62
1,050	1.00	0.89	0.78	0.78	0.77	0.76	0.74	0.72	0.67	0.60
1,100	1.00	0.90	0.81	0.81	0.79	0.79	0.76	0.73	0.69	0.63
1,150	0.90	0.88	0.86	0.82	0.79	0.77	0.74	0.70	0.64	0.57
1,200	0.81	0.80	0.79	0.79	0.76	0.75	0.70	0.64	0.57	0.49
1,250	0.79	0.78	0.76	0.74	0.72	0.68	0.63	0.56	0.48	0.39
1,300	0.75	0.73	0.70	0.68	0.63	0.59	0.53	0.46	0.38	0.30

TABLE I-14.10 B-1 STRESS RUPTURE FACTORS FOR TYPE 316 STAINLESS STEEL WELDED WITH SFA 5.22 E 308T AND E 308LT; SFA 5.4 E 308 AND E 308L; AND SFA 5.9 ER 308 AND ER 308L

TABLE I-14.10 B-2
STRESS RUPTURE FACTORS FOR TYPE 316 STAINLESS STEEL WELDED WITH SFA-5.22 EXXXT-G
(16-8-2 CHEMISTRY); SFA-5.4 E 16-8-2; AND SFA-5.9 ER 16-8-2

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850	1.00	0.96	0.91	0.91	0.91	0.90	0.89	0.88	0.87	0.86
900	1.00	0.94	0.88	0.82	0.81	0.80	0.77	0.76	0.74	0.72
950	1.00	0.93	0.86	0.86	0.85	0.83	0.83	0.81	0.79	0.78
1,000	1.00	0.93	0.90	0.90	0.90	0.89	0.87	0.87	0.85	0.85
1,050	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.93	0.90	0.86
1,100	0.91	0.91	0.93	0.94	0.94	0.96	0.96	0.96	0.97	0.96
1,150	0.91	0.91	0.93	0.95	0.95	0.96	0.98	0.99	0.99	1.00
1,200	0.89	0.89	0.90	0.92	0.93	0.97	0.99	1.00	1.00	1.00

TABLE I-14.10 B-2 STRESS RUPTURE FACTORS FOR TYPE 316 STAINLESS STEEL WELDED WITH SFA-5.22 EXXXT-G (16-8-2 CHEMISTRY); SFA-5.4 E 16-8-2; AND SFA-5.9 ER 16-8-2

TABLE I-14.10 B-3
STRESS RUPTURE FACTORS FOR TYPE 316 STAINLESS STEEL WELDED WITH SFA-5.22 E 316T AND E 316LT-1
AND -2; SFA-5.4 E 316 AND E 316L; AND SFA-5.9 ER 316 AND ER 316L

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850	1.00	1.00	0.99	0.98	0.97	0.96	0.95	0.94	0.92	0.88
900	1.00	1.00	0.97	0.94	0.91	0.89	0.88	0.86	0.82	0.78
950	1.00	1.00	0.95	0.90	0.87	0.84	0.81	0.78	0.72	0.68
1,000	1.00	1.00	0.88	0.86	0.83	0.79	0.74	0.70	0.62	0.58
1,050	1.00	1.00	0.92	0.89	0.87	0.83	0.78	0.74	0.66	0.56
1,100	1.00	1.00	0.96	0.94	0.90	0.87	0.81	0.75	0.68	0.61
1,150	1.00	1.00	1.00	0.96	0.91	0.87	0.81	0.75	0.66	0.59
1,200	1.00	1.00	0.96	0.95	0.90	0.87	0.81	0.72	0.64	0.55
1,250	1.00	1.00	0.96	0.93	0.89	0.84	0.77	0.69	0.60	0.51
1,300	1.00	0.98	0.93	0.89	0.83	0.79	0.72	0.65	0.56	0.48
1,350	0.99	0.96	0.89	0.84	0.77	0.72	0.65	0.59	0.52	0.45
1,400	0.95	0.90	0.82	0.77	0.71	0.66	0.60	0.55	0.47	0.42

TABLE I-14.10 B-3 STRESS RUPTURE FACTORS FOR TYPE 316 STAINLESS STEEL WELDED WITH SFA-5.22 E 316T AND E 316LT-1 AND -2; SFA-5.4 E 316 AND E 316L; AND SFA-5.9 ER 316 AND ER 316L

TABLE I-14.10 C-1
STRESS RUPTURE FACTORS FOR ALLOY 800H WELDED WITH SFA-5.11 ErNiCrFe-2 (INCO A)

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850-900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
950	1.00	1.00	1.00	1.00	0.98	0.95	0.92	0.90	0.86	0.83
1,000	1.00	1.00	1.00	1.00	0.98	0.94	0.90	0.86	0.82	0.78
1,050	1.00	1.00	1.00	1.00	0.98	0.94	0.89	0.85	0.81	0.76
1,100	1.00	1.00	1.00	1.00	0.98	0.94	0.89	0.84	0.79	0.75
1,150	1.00	1.00	1.00	1.00	0.98	0.93	0.88	0.83	0.77	0.72
1,200	1.00	1.00	1.00	1.00	0.98	0.93	0.87	0.81	0.75	0.70
1,250	1.00	1.00	1.00	1.00	0.98	0.92	0.85	0.80	0.73	0.68
1,300	1.00	1.00	1.00	1.00	0.97	0.91	0.84	0.77	0.71	0.65
1,350	1.00	1.00	1.00	1.00	0.96	0.89	0.82	0.75	0.68	0.62
1,400	1.00	1.00	1.00	1.00	0.95	0.87	0.80	0.73	0.65	0.59

TABLE I-14.10 C-1 STRESS RUPTURE FACTORS FOR ALLOY 800H WELDED WITH SFA-5.11 ErNiCrFe-2 (INCO A)

TABLE I-14.10 C-2
STRESS RUPTURE FACTORS FOR ALLOY 800H WELDED WITH SFA-5.14 ErNiCr-3 (INCO 82)

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850-900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
950	0.89	0.90	0.90	0.90	0.89	0.89	0.88	0.87	0.86	0.86
1,000	0.85	0.86	0.86	0.86	0.85	0.85	0.84	0.84	0.82	0.81
1,050	0.88	0.88	0.88	0.88	0.87	0.86	0.85	0.84	0.83	0.81
1,100	0.91	0.91	0.91	0.90	0.89	0.88	0.87	0.85	0.83	0.81
1,150	0.94	0.93	0.93	0.92	0.90	0.89	0.87	0.85	0.83	0.81
1,200	0.96	0.96	0.95	0.93	0.92	0.90	0.88	0.86	0.83	0.81
1,250	0.99	0.98	0.96	0.95	0.93	0.91	0.88	0.85	0.82	0.80
1,300	1.00	1.00	0.98	0.96	0.93	0.91	0.88	0.85	0.82	0.78
1,350	1.00	1.00	0.99	0.96	0.94	0.91	0.87	0.84	0.77	0.68
1,400	1.00	1.00	1.00	0.97	0.94	0.89	0.79	0.71	0.62	0.54

TABLE I-14.10 C-2 STRESS RUPTURE FACTORS FOR ALLOY 800H WELDED WITH SFA-5.14 ErNiCr-3 (INCO 82)

TABLE I-14.10 D-1
STRESS RUPTURE FACTORS FOR 2 $\frac{1}{4}$ Cr-1Mo (60/30) WELDED WITH SFA-5.28 E 90C-B3; SFA-5.28 ER 90S-B3;
SFA-5.5 E 90XX-B3 (>0.05C); SFA 5.23 EB 3; SFA-5.23 ECB 3 (>0.05C); SFA-5.29 E 90T1-B3 (>0.05C)

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
750–850	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99
950	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.96
1,000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.96	0.93
1,050	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.95	0.91	0.87
1,100	1.00	1.00	1.00	1.00	1.00	0.98	0.94	0.90	0.86	0.81
1,150	1.00	1.00	1.00	1.00	0.98	0.94	0.89	0.85	0.79	0.74
1,200	1.00	1.00	1.00	0.98	0.93	0.89	0.83	0.78	0.71	0.66

TABLE I-14.10 D-1 STRESS RUPTURE FACTORS FOR 2 $\frac{1}{4}$ Cr-1Mo (60/30) WELDED WITH SFA-5.28 E 90C-B3; SFA-5.28 ER 90S-B3; SFA-5.5 E 90XX-B3 (>0.05C); SFA 5.23 EB 3; SFA-5.23 ECB 3 (>0.05C); SFA-5.29 E 90T1-B3 (>0.05C)

TABLE I-14.11
PERMISSIBLE MATERIALS FOR BOLTING

Material	Spec. No.	Grades
Type 304 SS	SA-193	B8, Class 1 and B8A, Class 1A [Note (1)]
Type 316 SS	SA-193	B8M, Class 1 and B8MA, Class 1A [Note (1)]
Ni-Cr-Fe-Mo-Cb Alloy 718 [Notes (2), (3), (4)]	SB-637	N0 7718

GENERAL NOTE: If bolting temperatures do not exceed those given in Table 4 of Section II, Part D for the bolting material, the S_m values in Table 4 of Section II, Part D shall apply. For elevated temperatures, the list of materials shown below can be used in bolting applications.

NOTES:

- (1) For use at temperatures above 1,000°F, these materials may be used only if the material is heat treated by heating to a minimum temperature of 1,900°F and quenching in water or rapidly cooling by other means.
- (2) Maximum forging diameter shall be limited to 6 in.
- (3) Welding is not permitted.
- (4) Precautionary Note: In use of Alloy 718, consideration shall be given to a reduction in toughness caused by long-term exposure at a temperature of 1,000°F or greater.

TABLE I-14.12
 S_o VALUES FOR DESIGN CONDITIONS
CALCULATION OF BOLTING MATERIALS
 S_o MAXIMUM ALLOWABLE STRESS INTENSITY,
ksi

For Metal Temperature Not Exceeding, °F	304 SS	316 SS	Alloy 718
800	5.5	5.8	33.3
850	5.5	5.8	33.1
900	5.4	5.7	32.9
950	5.3	5.7	32.6
1,000	5.2	5.6	32.3
1,050	5.1	5.6	32.0
1,100	4.9	5.5	
1,150	4.8	5.4	
1,200	4.7	5.4	
1,250	4.7	5.3	
1,300	3.7	4.1	

TABLE I-14.12 S_o VALUES FOR DESIGN CONDITIONS CALCULATION OF BOLTING MATERIALS S_o MAXIMUM ALLOWABLE STRESS INTENSITY, ksi

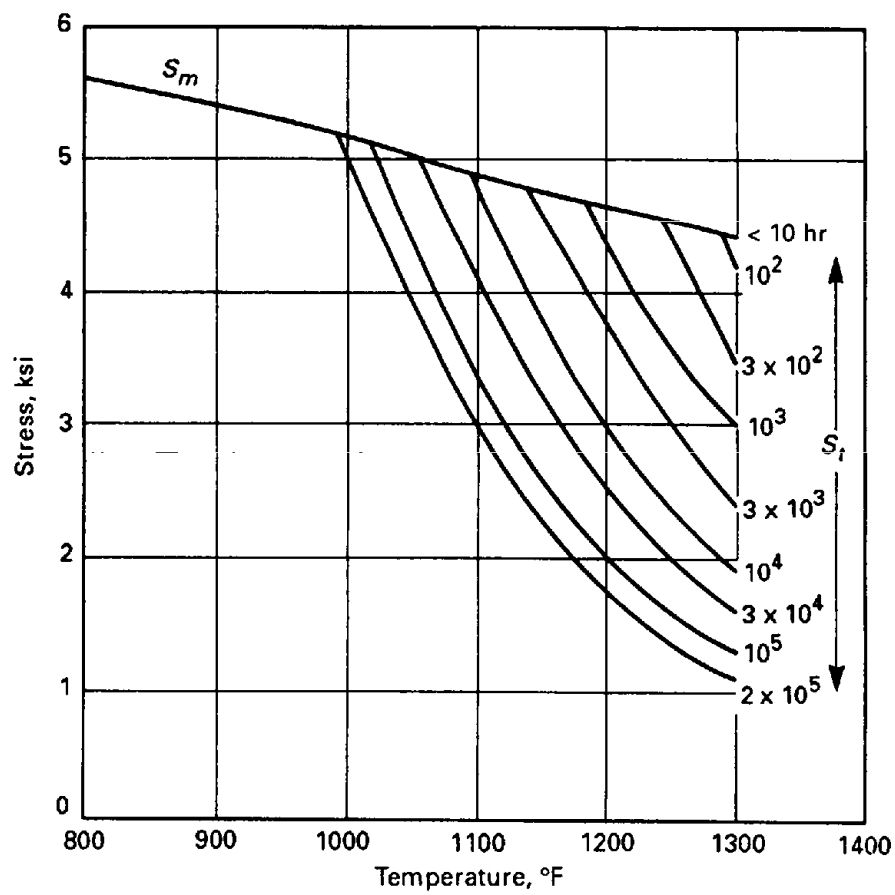


FIG. I-14.13A S_{mt} — ALLOWABLE STRESS INTENSITY, TYPE 304 SS, BOLTING

FIG. I-14.13A S_{mt} - ALLOWABLE STRESS INTENSITY, TYPE 304 SS, BOLTING

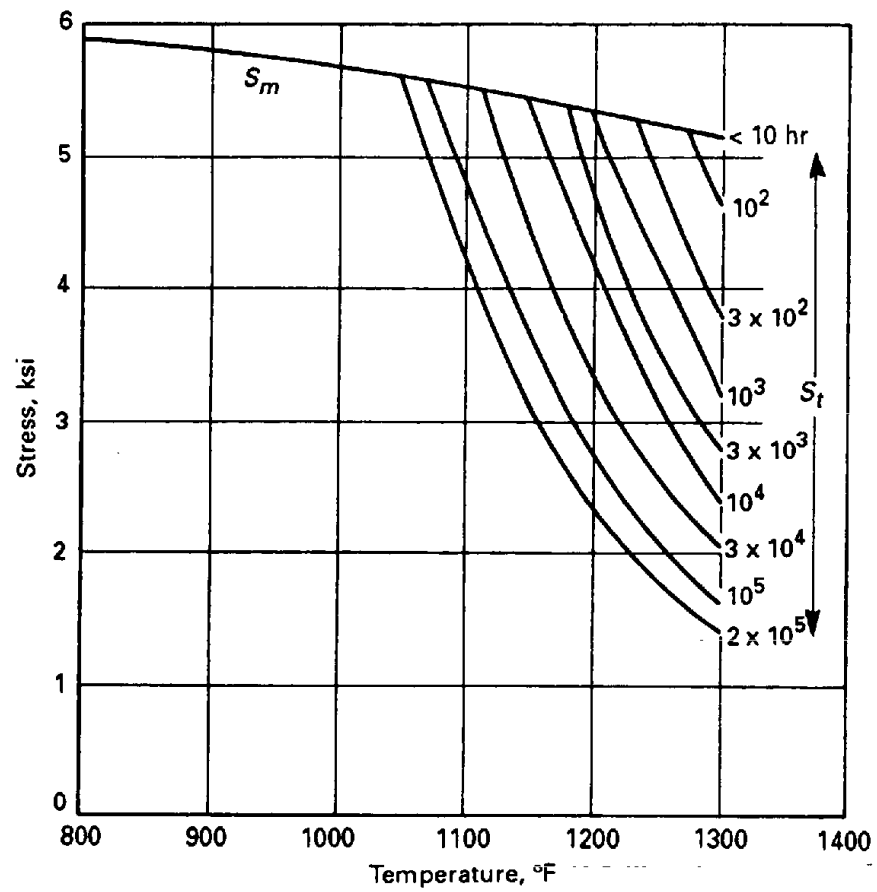


FIG. I-14.13B S_{mt} — ALLOWABLE STRESS INTENSITY, TYPE 316 SS, BOLTING

FIG. I-14.13B S_{mt} - ALLOWABLE STRESS INTENSITY, TYPE 316 SS, BOLTING

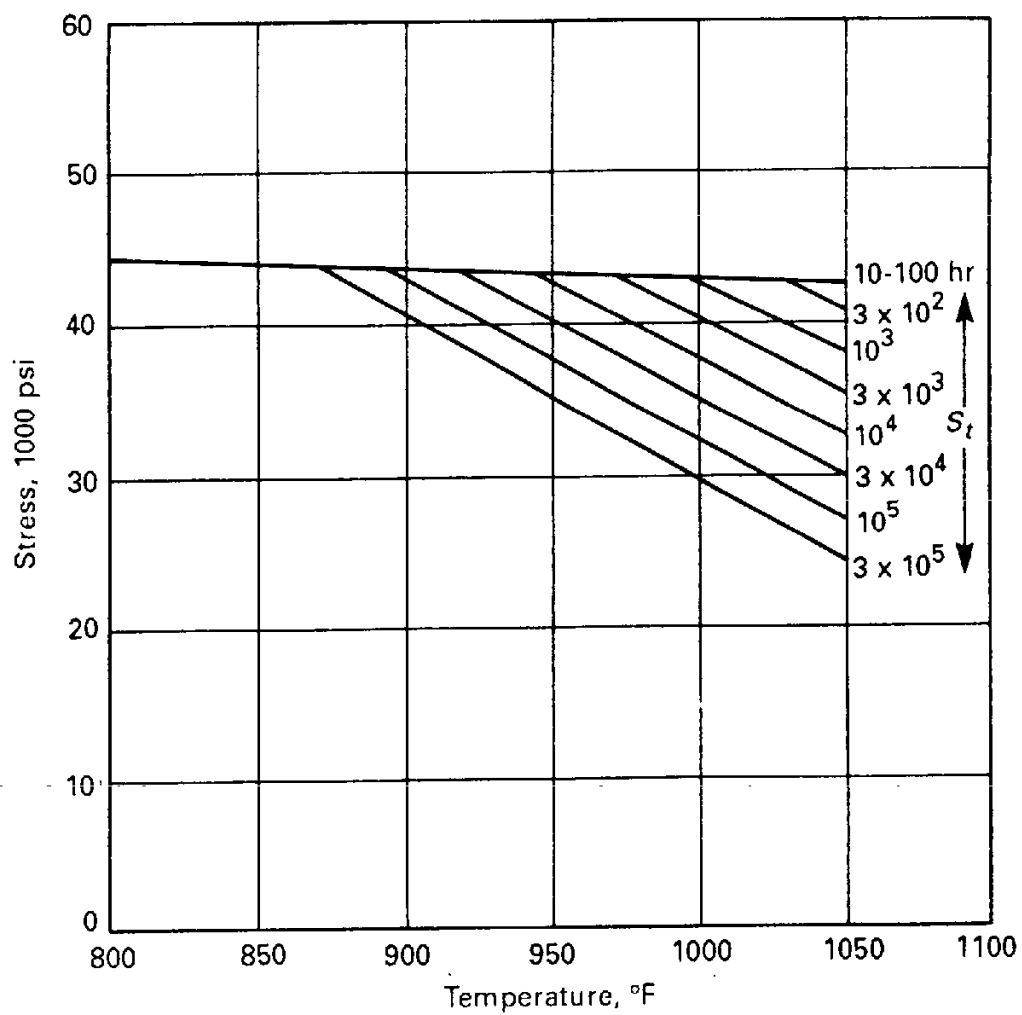


FIG. I-14.13C S_{mt} — ALLOWABLE STRESS, ALLOY 718, BOLTING

FIG. I-14.13C S_{mt} - ALLOWABLE STRESS, ALLOY 718, BOLTING

TABLE I-14.13C
 S_{mt} — ALLOWABLE STRESS VALUES, ksi, ALLOY 718, BOLTING

Temp., °F	10 hr	30 hr	10 ² hr	3 × 10 ² hr	10 ³ hr	3 × 10 ³ hr	10 ⁴ hr	3 × 10 ⁴ hr	10 ⁵ hr	3 × 10 ⁵ hr
800	44.4	44.4	44.4	44.4	44.4	44.4	44.4	44.4	44.4	44.4
850	44.1	44.1	44.1	44.1	44.1	44.1	44.1	44.1	44.1	44.1
900	43.8	43.8	43.8	43.8	43.8	43.8	43.8	43.8	43.3	43.3
950	43.5	43.5	43.5	43.5	43.5	43.5	43.0	40.7	38.0	35.3
1,000	43.1	43.1	43.1	43.1	43.1	40.7	38.0	35.3	32.7	30.0
1,050	42.7	42.7	42.7	41.3	38.0	35.3	32.7	30.3	27.0	24.7

TABLE I-14.13C S_{mt} - ALLOWABLE STRESS VALUES, ksi, ALLOY 718, BOLTING

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NH NMA T

APPENDIX T RULES FOR STRAIN, DEFORMATION, AND FATIGUE LIMITS AT ELEVATED TEMPERATURES

Page 107

T-1100 INTRODUCTION

T-1110 OBJECTIVE

The objective of this Appendix is to provide rules which may be used by Owners and N Certificate Holders with respect to evaluation by analysis of strain, deformation, and fatigue limits for components whose load controlled stresses are evaluated by the rules of Subsection NH.

T-1120 GENERAL REQUIREMENTS

T-1121 Type of Analysis

Where creep effects are presumed significant, inelastic analysis is generally required to provide a quantitative assessment of deformations and strains. However, elastic and simplified inelastic methods of analysis may sometimes be justified and used to establish conservative bounds for deformations, strains, strain ranges, and maximum stress in order to reduce the number of locations in a structure requiring detailed inelastic analysis.

T-1122 Analysis Required

The rules for design against gross distortion and fatigue are illustrated in Fig. NH-3221-1. The Design Loadings and Level D Service Loadings are exempted from strain and deformation limits as summarized below.

Loadings

Design

Service Levels A, B, and C

Requirement

No deformation analysis required.

Apply the strain and deformation limits of Appendix T.

Regions not expecting any service time under elevated temperatures may use the secondary stress and fatigue limits of

Service Level D	NB-3222.2 and NB-3222.4 in place of the rules in T-1300, T-1400, and T-1700.
Test	Strain and deformation limits not applicable except as necessary to satisfy Level D Service Loadings functional requirements. Consider as additional Level B Service Loadings.

T-1200 DEFORMATION LIMITS FOR FUNCTIONAL REQUIREMENTS

T-1210 STATEMENT IN DESIGN SPECIFICATION

Deformation limits to ensure proper component functioning shall be specified in the Design Specification (NCA-3250) for the component or shall be established by the N Certificate Holder for the proper performance of the component. Any such limits may restrict the design more severely than those specified for load controlled stresses in NH-3220.

T-1220 ELASTIC ANALYSIS METHOD

The limitations on loads from the rules and the other limits contained in NH-3200 are intended to restrict the accumulated inelastic strain (averaged across a wall thickness) to 1% or less. However, when elastic analysis is used, the occurrence of inelastic strains of this magnitude may not be apparent. If functional deformation requirements are specified, the designer shall ensure that they are not violated by assuming that strains of 1% occur within the structure in that distribution which leads to the worst possible deformation state consistent with the directions of loading. If this deformation state does not lead to deformations greater than the specified limits, then all functional requirements shall be considered as demonstrated for the design.

Page 114

T-1230 USE OF INELASTIC ANALYSIS

Inelastic analysis of deformations shall be used to demonstrate that deformations do not exceed specified limits, unless the elastic method of T-1220 has demonstrated compliance.

T-1300 DEFORMATION AND STRAIN LIMITS FOR STRUCTURAL INTEGRITY

T-1310 LIMITS FOR INELASTIC STRAINS

In regions expecting elevated temperatures, the maximum accumulated inelastic strain shall not exceed the following values.

- (a) strains averaged through the thickness, 1%;
- (b) strains at the surface, due to an equivalent linear distribution of strain through the thickness, 2%;
- (c) local strains at any point, 5%.

The above limits apply to computed strains accumulated over the expected operating lifetime of the element under consideration, and computed for some steady-state period at the end of this time during which significant transients are not occurring. These limits apply to the maximum positive value of the three principal strains. A positive strain is defined as one for which the length of the element in the direction of the strain is increased. The principal strains are computed for the strain components $(\epsilon_x, \epsilon_y, \epsilon_z, \epsilon_{xy}, \epsilon_{xz}, \epsilon_{yz})$. When the strain is computed at several locations through the thickness, the strains are first averaged and linearized on a component level and then combined to determine the principal strains for comparison to the limits on average and surface strains defined above. The limits for local strains are based on the computed strains at the point of interest.

T-1320 SATISFACTION OF STRAIN LIMITS USING ELASTIC ANALYSIS

T-1321 General Requirements

The strain limits of T-1310 are considered to have been satisfied if the limits of any one of T-1322, T-1323, or T-1324 are satisfied. The guidelines of (a) through (d) below should be used in establishing the appropriate cycle to be evaluated in T-1322 and T-1323.

(a) An individual cycle, as defined in the Design Specification, cannot be split into subcycles to satisfy these requirements.

(b) At least one cycle must be defined that includes the maximum secondary stress intensity range, Q_R , and the maximum value of $(P_L + P_b/K_t)$, which occur during *all* Level A, B, and C Service Loadings. The value of K_t may be determined using Eq. (6) of NH-3223.

(c) Any number of cycles can be grouped together and evaluated according to the conditions of T-1322 or T-1323, whichever is applicable.

(d) The following definitions apply to T-1322 and T-1323:

$$X \equiv \left(P_L + \frac{P_b}{K_t} \right)_{\max} \div S_y$$

where

$(P_L + P_b/K_t)_{\max}$

= the maximum value of the primary stress intensity, adjusted for bending via K_p , during the cycle being evaluated

S_y

= the average of the S_y values at the maximum and minimum wall averaged temperatures during the cycle being evaluated

$$Y \equiv \frac{(Q_R)_{\max}}{S_y}$$

where

$(Q_R)_{\max}$

= the maximum range of the secondary stress intensity during the cycle being considered

S_y

= the average of the S_y values at the maximum and minimum wall averaged temperatures during the cycle

T-1322 Test No. A-1

For Test Number A-1:

$$X + Y \leq S_a/S_y \quad (1)$$

(1)

where S_a is the lesser of:

(a) $1.25 S_t$ using the highest wall averaged temperature during the cycle and a time value of 10^4 hr, and

(b) the average of the two S_y values associated with the maximum and minimum wall averaged temperatures during the cycle

TABLE T-1323
TEMPERATURES AT WHICH $S_m = S_t 10^5$

Material	Temp., °F
Type 304 SS	948
Type 316 SS	1,011
Alloy 800H	1,064
2¼Cr-1Mo	801

TABLE T-1323 TEMPERATURES AT WHICH $S_m = S_t 10^5$

T-1323 Test No. A-2

For Test Number A-2:

$$X + Y \leq 1 \quad (2)$$

(2) for those cycles during which the average wall temperature at one of the stress extremes defining the maximum secondary stress range $(Q_R)_{\max}$ is below the applicable temperature of Table T-1323.

T-1324 Test No. A-3

For Test Number A-3, the limits of NB-3222.2, NB-3222.3, and NB-3222.5 shall be met and, in addition, the requirements of (a) through (d) below shall be satisfied.

(a)

$$\sum_i \frac{t_i}{t_{id}} \leq 0.1$$

where

t_i

= total duration of time during the service lifetime that the metal is at temperature, T_i . Note that the service lifetime shall never be greater than the sum of all t_i .

t_{id}

= maximum allowable time as determined by entering Figs. I-14.6 at temperature T_i and a stress value of 1.5 times the S_y associated with T_i , denoted as $1.5 S_{y|T_i}$. If $1.5 S_{y|T_i}$ is above the stress values provided in Figs. I-14.6, this test cannot be satisfied. When $1.5 S_{y|T_i}$ is below the lowest stress value provided in Figs. I-14.6, the constant temperature line may be extrapolated to larger t_{id} values using the steepest slope on Figs. I-14.6 for that material.

(b)

$$\sum \epsilon_i \leq 0.2\%$$

where ϵ_i is the creep strain that would be expected from a stress level of $1.25 S_y|_{T_i}$ applied for the total duration of time during the service lifetime that the metal is at T_i . When the design lifetime is separated into several time periods, then the service lifetime shall not be greater than the sum of all the time periods. That is:

$$\sum_i t_i|T_i \geq \text{service lifetime}$$

(c) For the $3S_m$ limit in NB-3222.2 and NB-3222.3, use the lesser of $3S_m$ and $3\bar{S}_m$, where

$3\bar{S}_m$

$= (1.5 S_m + S_{rH})$ when only one extreme of the stress difference [that produces the maximum range of the primary plus secondary stress intensity, $P + Q$] occurs at a temperature above those covered by Subsection NB rules;

$3\bar{S}_m$

$= (S_{rH} + S_{rL})$ when both extremes of the stress differences (that define the maximum range of $P + Q$) occur at temperatures above those covered by Subsection NB rules;

$S_{rH} S_{rL}$

$=$ relaxation strengths associated with the temperatures at the *hot* and *cold* extremes of the stress cycle. The *hot* temperature condition is defined as the maximum operating temperature of

the stress cycle. The *hot* time is equal to the portion of service life when wall averaged temperatures exceed 800°F (427°C) (700°F (371°C) for 2¹/₄Cr-1Mo). The *cold* temperature is defined as the colder of the two temperatures corresponding to the two stress extremes in the stress cycle. The *cold* time is again equal to the portion of service life when wall averaged temperatures exceed 800°F (700°F for 2¹/₄Cr-1Mo).

In this criterion, total service life may *not* be further subdivided into temperature-time blocks. The two relaxation strengths, S_{rH} and S_{rL} , may be determined by performing a pure uniaxial relaxation analysis starting with an initial stress of $1.5 S_m$ and holding the initial strain throughout the time interval equal to the time of service above 800°F (427°C) [700°F (371°C) for 2¹/₄Cr-1Mo].

(d) The reference to the endurance limit NB-3222.5(b) is not applicable to the materials in this Subsection.

Page 116

T-1325 Special Requirements for Piping Components

(a) Piping evaluations using the provisions of NH-3651(b) to satisfy the limits of T-1322, T-1323, or T-1330 shall include the stress term:

$$\frac{E \propto |\Delta T_1|}{2(1 - \nu)}$$

when computing the secondary stress intensity range, Q_R . The definitions of E , α , ΔT_1 , and ν , are as given in NB-3650.

(b) For purposes of applying the limits of T-1324 to piping components, satisfaction of the NB-3650 requirements may be used in lieu of meeting NB-3222.2, NB-3222.3, and NB-3222.5, provided that S_m is replaced by $\bar{S}_m$ and the ratchet check of NB-3653.7 is satisfied whenever:

$$S_n > 3\bar{S}_m - \frac{E \propto |\Delta T_1|}{2(1 - \nu)}$$

S_n , E , α , ΔT , and ν are defined in NB-3650, and $\bar{S}_m$ is the lesser of S_m or $(3\bar{S}_m) \div 3$, with $3\bar{S}_m$ as defined in T-1324(c).

T-1330 SATISFACTION OF STRAIN LIMITS USING SIMPLIFIED INELASTIC ANALYSIS

T-1331 General Requirements

The strain limits of T-1310 are considered to have been satisfied if the limits of T-1332 are satisfied in addition to (a) through (g) below.

(a) T-1332 contains two tests, B-1 and B-2. Test B-1 can be used only for:

- (1) axisymmetric structures subjected to axisymmetric loadings and away from local structural discontinuities; or
- (2) general structures in which the peak through-the-wall thermal stress is negligible (i.e., the thermal stress distribution is linear through the wall).

Test B-2, which is more conservative, is applicable to any structure and loading.

(b) The individual cycle as defined in the design specification cannot be split into subcycles. Unless otherwise specified (see NH-3114), earthquakes and other transient conditions should be uniformly distributed over the lifetime of the plant for this strain evaluation.

(c) As an alternate to the use of T-1332, the inelastic strains due to any number of selected operational cycles may be evaluated separately by T-1333 or using detailed inelastic analysis. The resulting sum of the inelastic strains must satisfy the limits of T-1310. T-1333 is applicable only to axisymmetric structures subjected to axisymmetric loadings and away from local structural discontinuities.

(d) Secondary stresses with elastic followup (i.e., pressure induced membrane and bending stresses and thermal induced membrane stresses) are classified as primary stresses for purposes of this evaluation. Alternatively, the strains due to such stresses may be calculated separately and added to the strains from T-1332 and T-1333, the sum being limited to the values of T-1310. If the latter is done, stresses with elastic follow-up should be treated as secondary in the σ_c evaluation.

(e) The time used in T-1332 to enter the isochronous curves for individual cycles or timeblocks shall always sum to the entire life regardless of whether all or only part of the cycles are evaluated under these procedures.

(f) For T-1332, the definitions of X and Y in T-1321(d) apply except that the S_y value is replaced by the S_{yL} value which corresponds to the lower of the wall averaged temperatures for the stress extremes defining the secondary stress range, Q_R . The S_{yH} value corresponds to the higher of the wall averaged temperatures for the stress extremes defining the secondary stress range. The above defined extremes denoted by subscripts L and H are also referred to later as the cold and hot ends respectively.

(g) For T-1333, the definitions of X and Y in T-1321(d) apply, but X_L , Y_L , X_H and Y_H are calculated for the cold and hot ends using S_{yL} and S_{yH} respectively.

(h) When applying the procedures of T-1332 (Test No. B-1) and T-1333, wall membrane forces from overall bending of a pipe section or vessel can be conservatively included as axisymmetrical forces.

T-1332 Test Nos. B-1 and B-2

(a) These tests can be used to satisfy the strain limits provided that the average wall temperature at one of the stress extremes defining each secondary stress intensity range Q_R is below the applicable temperature of Table T-1323. The limits of this paragraph restrict the amount of inelastic creep strain that can be accumulated over the service life of the component including Levels A, B, and C Service Loadings so that the strain limits of T-1310 are not exceeded. In this paragraph, the elastically calculated primary and secondary stress intensities are used to determine an effective creep stress $\sigma_e = Z \cdot S_{yL}$ which in turn is used to determine a

Page 117

total ratcheting creep strain. The dimensionless effective creep stress parameter Z for any combination of loading is given in Fig. T-1332-1 for Test No. B-1 and in Fig. T-1332-2 for Test No. B-2.

(b) The creep ratcheting strain is determined by multiplying σ_e by 1.25 and evaluating the creep strain associated with the $1.25 \sigma_e$ stress held constant throughout the temperature-time history of the entire service life. The isochronous stress-strain curves of T-1800 shall be used to obtain the creep ratcheting strain. The total service life may be subdivided into temperature-time blocks. The value of σ_e may differ from one block to another, but remains constant throughout each block service time. When σ_e is reduced at the end of a block of loading, the time of the block of loading must be longer or equal to the time needed for σ_e to relax at constant total strain to the σ_e value for the subsequent block. The creep strain increment for each block may be evaluated separately. The times used in selecting the isochronous curves shall sum to the total service life. For each block, the isochronous curves can be entered at the initial strain accumulated throughout the prior load history. The creep strain increments for each time-temperature block shall be added to obtain the total ratcheting creep strain. The resulting value shall be limited to 1% for parent metal and $1/2\%$ for weld metal.

(c) The dimensionless expressions for the effective creep stress parameter is $Z = \sigma_e / S_{yL}$ in regimes S_1 , S_2 and P of Fig. T-1332-1, and:

$$(3) Z = X \cdot Y$$

in regimes S_2 and P , and:

$$(4) Z = Y + 1 - 2\sqrt{(1-X)Y}$$

in regime S_1 . In regime E , $Z = X$. The equations defining the boundaries of the regimes P , S_1 , and S_2 are shown in Fig. T-1332-1. Test No. B-1 can only be applied when σ_e is less than the yield stress of S_{yH} (see regimes E , S_1 , S_2 and P).

(d) For Test No. B-2, the effective creep stress σ_e shall be obtained from Fig. T-1332-2.

T-1333 Test No. B-3

(a) The procedure of T-1333 may be used for cycles in regimes R_1 and R_2 . This procedure may also be applied to cycles in the S_1 , S_2 and P regimes in order to minimize the conservatism in the calculated strains when there are a few relatively severe cycles. For cycles evaluated using T-1333, the resulting plastic ratchet strains and the enhanced creep strains due to creep relaxation within these cycles must be added to strains bounded by T-1332, Test No. B-1. The total inelastic strains accumulated in the lifetime of the component are given by:

$$\Sigma \epsilon = \Sigma \nu + \Sigma \eta + \Sigma \delta \quad (5)$$

(5)

where

$\Sigma \delta$	= the enhanced creep strain increments due to relaxation of the $[\sigma_c]$ stresses, obtained as explained in T-1333(c)
$\Sigma \eta$	= the plastic ratchet strain increments for cycles in regimes S_1 , S_2 , P , R_1 , and R_2 , obtained as explained in T-1333(b)
$\Sigma \nu$	= the inelastic strains obtained from the isochronous curves as in Test No. B-1 of T-1332, ignoring the increase of σ_c stress for cycles evaluated using T-1333 and detailed inelastic analyses

(b) Plastic ratcheting occurs in cycles when $[\sigma_{cL}] \geq S_{yH}$. The increment of plastic ratchet strain within this cycle is bounded by:

$$\eta_{(n)} = \frac{1}{E_H} \left[([\sigma_{cL}] - S_{yH}) + ([\sigma_{cH}] - S_{yL}) \right] \quad (6)$$

(6) (hot extreme only in regimes S_1 and R_2) for $Z_L < 1.0$, or:

$$\eta_{(n)} = \frac{1}{E_L} ([\sigma_{cL}] - S_{yL}) + \frac{1}{E_H} ([\sigma_{cH}] - S_{yH}) \quad (7)$$

(7) (both extremes in regimes R_1 and R_2) for $Z_L > 1.0$. $[\sigma_{cL}]$ and $[\sigma_{cH}]$ are the effective stresses for the cold and hot extremes of the cycles as given by $[\sigma_{cL}] = Z_L S_{yL}$ and $[\sigma_{cH}] = Z_H S_{yH}$ respectively.

The effective creep stress parameter Z is obtained from Eq. (3) for regimes S_2 , P , and R_2 . Equation (4) is for regimes S_1 and R_1 . Curves resulting from Eqs. (3) and (4) are shown in Fig. T-1332-1. Note that braces indicate $[\sigma_c]$ stress calculated for T-1333 evaluations. E_L and E_H are the elastic moduli at the cold and hot ends of the cycle.

Note that all values in Eqs. (6) and (7) are related to the load cycle (n).

(c) For cycles where $[\sigma_{cL}] \geq S_{yH}$ the enhanced creep strain increment due to stress relaxation is given by:

$$\delta_{(n)} = \frac{1}{E_H} \frac{S_{yH}^2 - \sigma_c^2}{\sigma_c} \quad (8)$$

(8)

For cycles where $[\sigma_{cL}] < S_{yH}$ the enhanced creep

Page 118

Page 119

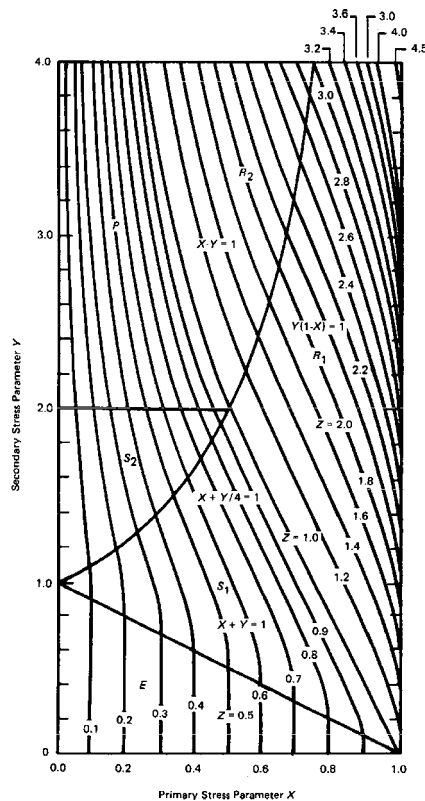


FIG. T-1332-1 EFFECTIVE CREEP STRESS PARAMETER Z FOR SIMPLIFIED INELASTIC ANALYSIS USING TEST NOS. B-1 AND B-3
[For Use Only When the Restrictions of T-1331(a) for Test No. B-1 Are Met]

strain increment due to $[\sigma_{cL}]$ stress relaxation is given by:

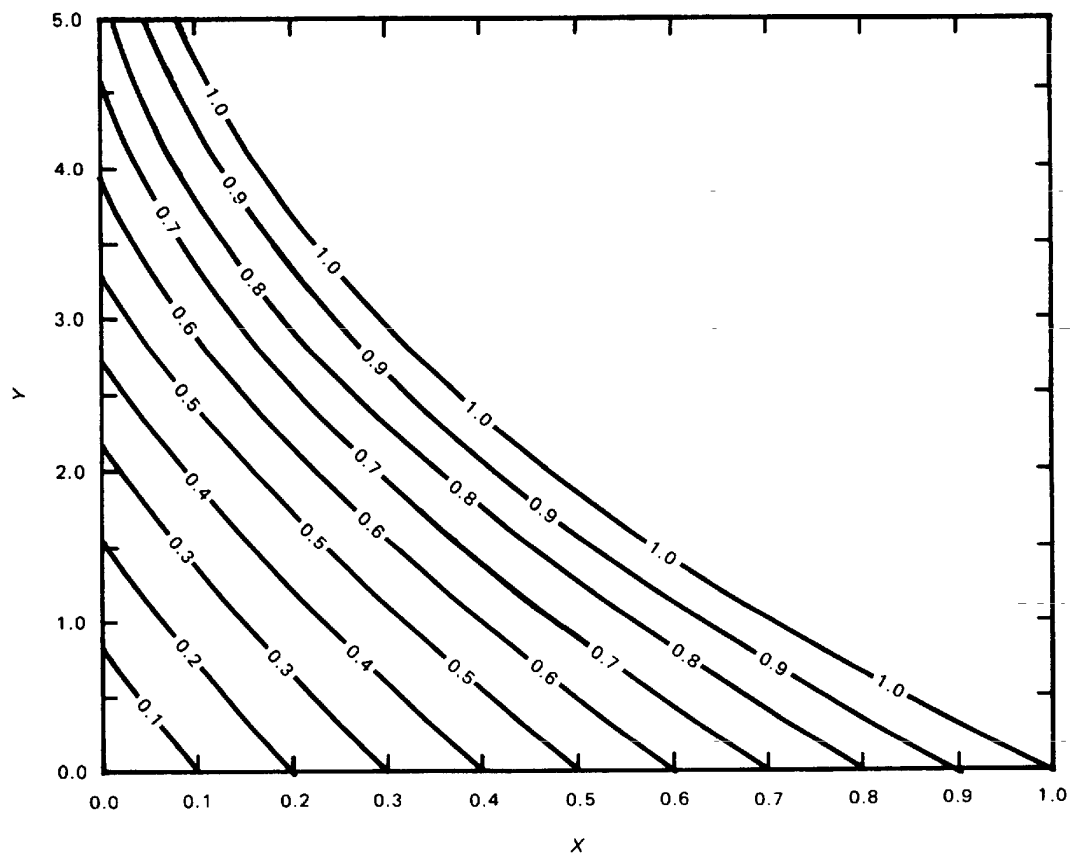


FIG. T-1332-2 EFFECTIVE CREEP STRESS PARAMETER Z FOR SIMPLIFIED INELASTIC ANALYSIS USING TEST NO. B-2
(Applicable to General Structures)

FIG. T-1332-2 EFFECTIVE CREEP STRESS PARAMETER Z FOR SIMPLIFIED INELASTIC ANALYSIS USING TEST NO. B-2

$$\delta_{(n)} = \frac{1}{E_H} \frac{[\sigma_{cL}]^2 - \sigma_c^2}{\sigma_c} \quad (9)$$

(9)

σ_c is the effective creep stress from T-1332 for the next cycle when sequence of loading is specified. Otherwise, the lowest σ_c stress used in the T-1332 evaluation should be used in Eqs. (8) and (9).

Note that all values in Eqs. (8) and (9) are related to the load cycle (n). Only positive $\delta_{(n)}$ increments should be considered.

T-1400 CREEP-FATIGUE EVALUATION

T-1410 GENERAL REQUIREMENTS

T-1411 Damage Equation

The combination of Levels A, B, and C Service Loadings shall be evaluated for accumulated creep and fatigue damage, including hold time and strain rate effects. For a design to be acceptable, the creep and fatigue damage shall satisfy the following relation:

$$\sum_{j=1}^P \left(\frac{n}{N_d} \right)_j + \sum_{k=1}^q \left(\frac{\Delta t}{T_d} \right)_k \leq D \quad (10)$$

(10)

where

D

= total creep-fatigue damage

(N_{dj})

= number of design allowable cycles for cycle type, j , determined from one of the design fatigue curves (Figs. T-1420-1) corresponding to the maximum metal temperature occurring during the cycle. The design fatigue curves were determined from completely reversed loading conditions at strain rates greater than, or equal to, those noted on the curves.

(T_{dk})

= allowable time duration determined from Figs. I-14.6 (stress-to-rupture curves) for a given stress and the maximum temperature at the point of interest and occurring during the time interval, k . For elastic analysis, the appropriate stress measure is defined in T-1433. For inelastic analysis, the following equivalent stress quantity should be used:

$$\sigma_e = \bar{\sigma} \exp \left[C \left(\frac{J_1}{S_s} - 1 \right) \right]$$

where

$$J_1 = \sigma_1 + \sigma_1 + \sigma_3$$

$$S_s = [\sigma_1^2 + \sigma_2^2 + \sigma_3^2]^{1/2}$$

$$\sigma_{\text{eff}} = \frac{1}{\sqrt{2}} [(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{1/2}$$

and σ_i are the principal stresses. The constant C is equal to 0.24 for Types 304 and 316 stainless steels; for Alloy 800H and 2 $\frac{1}{4}$ Cr-1Mo steel, the value is 0.0. For both types of analysis, the allowable time duration is determined by entering Figs. I-14.6 at that stress value determined by dividing the maximum stress (at the point of interest during the time interval, k) by the factor, K' (Table T-1411-1).

$(n)_j$

= number of applied repetitions of cycle type, j

q

= number of time intervals (each with a unique stress-temperature combination) needed to represent the specified elevated temperature service life at the point of

$(\Delta t)_k$

interest for the creep damage calculation

= duration of the time interval, k

TABLE T-1411-1

Material	K'
Austenitic Stainless Steel	0.67
Ni-Fe-Cr (Alloy 800H)	0.67
2¼Cr-1Mo	0.67

TABLE T-1411-1

Note that the sum of the "q" time intervals must equal or exceed the total specified elevated temperature service life.

T-1412 Exemption From Fatigue Analysis

The rules in NB-3222.4(d) which permit exemption from fatigue analysis do not apply to temperatures above the limits of Subsection NB except where the service loadings have been qualified as not introducing significant time-dependent effects under the procedure of NH-3211(c).

Page 121

T-1413 Equivalent Strain Range

An equivalent strain range is used to evaluate the fatigue damage sum for both elastic and inelastic analysis. When the Design Specification contains a histogram delineating a specific loading sequence, the strain range shall be calculated for the cycles described by the histogram. If the sequence of loading is not defined by the Design Specification, then the method of combining cycles described in NB-3222.4(e)(5) shall be applied. The equivalent strain range is computed as follows.

Step 1: Calculate all strain components for each point, i , in time $(\epsilon_{x\bar{i}}, \epsilon_{y\bar{i}}, \epsilon_{z\bar{i}}, \gamma_{xy\bar{i}}, \gamma_{yz\bar{i}}, \gamma_{zx\bar{i}})$ for the complete cycle. When conducting inelastic analysis, the stress and strain concentration effects of local geometric discontinuities are included in this step. When conducting elastic analysis, peak strains arising from geometric discontinuities are not included, since these effects are added in the procedures of T-1432.

Step 2: Select a point when conditions are at an extreme for the cycle, either maximum or minimum. Refer to this time point by a subscript o .

Step 3: Calculate the history of the change in strain components by subtracting the values at the time, o , from the corresponding components at each point in time, i , during the cycle.

$$\Delta \epsilon_{xi} = \epsilon_{xi} - \epsilon_{xo}$$

$$\Delta \epsilon_{yi} = \epsilon_{yi} - \epsilon_{yo}$$

etc;

Step 4: Calculate the equivalent strain range for each point in time as:

$$\Delta \epsilon_{\text{equiv. } i} = \frac{\sqrt{2}}{2(1 + \nu^*)} \left[(\Delta \epsilon_{xi} - \Delta \epsilon_{yi})^2 + (\Delta \epsilon_{yi} - \Delta \epsilon_{zi})^2 + (\Delta \epsilon_{zi} - \Delta \epsilon_{xi})^2 + \frac{3}{2} (\Delta \gamma_{xyi}^2 + \Delta \gamma_{yzi}^2 + \Delta \gamma_{zxi}^2) \right]^{1/2} \quad (11)$$

(11)

where

v^* = 0.5 when using the rules of T-1420

v^* = 0.3 when using the rules of T-1430

Step 5: Define $\Delta\epsilon_{\max}$ as the maximum value of the above calculated equivalent strain ranges, $\Delta\epsilon_{\text{equiv},i}$

The above five step procedure may be used regardless of whether principal strains change directions. When principal strains do not rotate, an alternative to the above sequence is given in T-1414.

T-1414 Alternative Calculation Method - Equivalent Strain Range

An alternative calculational method for equivalent strain range determination - applicable only when principal strains do not rotate - is as follows:

Step 1: No change from Step 1 of T-1413.

Step 2: Determine the principal strains versus time for the cycle.

Step 3: At each time interval of Step 2, determine the strain differences $\epsilon_1 - \epsilon_2$, $\epsilon_2 - \epsilon_3$, $\epsilon_3 - \epsilon_1$.

Step 4: Select a point when conditions are at an extreme for the cycle, either maximum or minimum. Refer to this time point by a subscript o .

Step 5: Determine the history of the change in strain differences by subtracting the values at the time, o , from the corresponding values at each point in time, i , during the cycle. Designate these strain difference changes as:

$$\Delta(\epsilon_1 - \epsilon_2)_i = (\epsilon_1 - \epsilon_2)_i - (\epsilon_1 - \epsilon_2)_o$$

$$\Delta(\epsilon_2 - \epsilon_3)_i = (\epsilon_2 - \epsilon_3)_i - (\epsilon_2 - \epsilon_3)_o$$

$$\Delta(\epsilon_3 - \epsilon_1)_i = (\epsilon_3 - \epsilon_1)_i - (\epsilon_3 - \epsilon_1)_o$$

Step 6: For each time point, i , calculate the equivalent strain range as:

$$\Delta \epsilon_{\text{equiv. } i} = \frac{\sqrt{2}}{2(1 + \nu^*)} \left\{ [\Delta (\epsilon_1 - \epsilon_2)_i]^2 + [\Delta (\epsilon_2 - \epsilon_3)_i]^2 + [\Delta (\epsilon_3 - \epsilon_1)_i]^2 \right\}^{1/2}$$

where ν^* is defined as in T-1413.

Step 7: Define $\Delta \epsilon_{\text{max}}$ as the maximum value of the above calculated equivalent strain ranges, $\Delta \epsilon_{\text{equiv. } i}$.

Page 122

T-1420 LIMITS USING INELASTIC ANALYSIS

When inelastic analysis is used to satisfy the requirements of T-1411, the rules of (a), (b), and (c) below apply.

(a) The creep damage term of Eq. (10) may also be calculated by using the integral form:

$$\int_0^t \frac{dt}{T_d}$$

(b) The fatigue damage term of Eq. (10) is evaluated by entering a design fatigue curve at the strain range ϵ_f . The strain range ϵ_f is defined as $\epsilon_f = \Delta \epsilon_{\text{max}}$; where $\Delta \epsilon_{\text{max}}$ is the value calculated in either T-1413 or T-1414. The appropriate design fatigue curve is selected from Figs. T-1420-1 and corresponds to the maximum metal temperature experienced during the

cycle.

(c) The total damage, D , shall not exceed the creep-fatigue damage envelope of Fig. T-1420-2.

T-1430 LIMITS USING ELASTIC ANALYSIS

T-1431 General Requirements

(a) The elastic analysis rules in this paragraph may be used only when:

- (1) the elastic ratcheting rules of T-1320 or T-1330 with Z less than, or equal to, 1.0 have been satisfied;
- (2) the $3S_m$ limit in NB-3222.2 is met using for $3S_m$ the lesser of $3S_m$ and $3\bar{S}_m$ as defined in T-1324; and
- (3) pressure induced membrane and bending stresses and thermal induced membrane stresses are classified as primary (load controlled) stresses.

The secondary stress range due to radial thermal gradients may be excluded from $(Q_R)_{\max}$ in either T-1322 or T-1323 in determining the applicability of elastic creep-fatigue rules.

(b) Linearly elastic analysis methods may significantly underestimate the actual strain range incurred during plastic or creep deformation. The method of T-1432 may be used to account for these increased strain ranges due to inelastic behavior in the region under consideration. The resulting strain range, ϵ_p , is used to enter a design fatigue curve to evaluate the fatigue damage term of Eq. (10). The appropriate design fatigue curve is selected from Figs. T-1420-1 and corresponds to the maximum metal temperature occurring during the cycle.

(c) The creep damage term of Eq. (10) is evaluated using the procedure of T-1433.

(d) The total damage, D , shall not exceed the creep-fatigue damage envelope of Fig. T-1420-2.

T-1432 Strain Range Determination

(a) Calculate $\Delta\epsilon_{\max}$ using T-1413 or T-1414. The strain components to be used in T-1413 or T-1414 are elastically calculated and do not include local geometric stress concentration effects. Alternatively, calculate $\Delta\epsilon_{\max}$ using the stress difference procedure described in NB-3216. However, for the purpose of calculating $\Delta\epsilon_{\max}$, the effects of local geometric stress concentrations are omitted. The strain range $\Delta\epsilon_{\max}$ is defined as equal to $2S_{\text{alt}}/E$, where E equals the modulus of elasticity at the maximum metal temperature experienced during the cycle.

(b) Calculate the modified maximum equivalent strain range, $\Delta\epsilon_{\text{mod}}$ using the procedure specified in any one of (c), (d), or (e).

(c) The modified maximum equivalent strain range, $\Delta\epsilon_{\text{mod}}$ may be calculated as:

$$\Delta\epsilon_{\text{mod}} = \left(\frac{S^*}{\bar{S}} \right) K^2 \Delta\epsilon_{\max} \quad (12)$$

(12)

where (see Fig. T-1432-1)

K

= either the equivalent stress concentration factor, as determined by test or analysis, or, the maximum value of the theoretical elastic stress concentration factor in any direction for the local area under consideration. The equivalent stress concentration factor is defined as the effective (von Mises) primary plus secondary plus peak stress divided by the effective primary plus secondary stress. Note that fatigue strength reduction factors developed from low temperature continuous cycling fatigue tests may not be acceptable for defining K when creep effects are not negligible.

S^*

= the stress indicator determined by entering the stress-strain curve of Fig. T-1432-1 at a strain range of $\Delta\epsilon_{\max}$

$\bar{S}$

= the stress indicator determined by entering the stress-strain curve of Fig. T-1432-1 at a strain range of $K\Delta\epsilon_{\max}$

$\Delta\epsilon_{\max}$

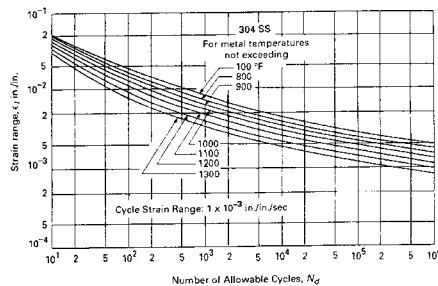
= the maximum equivalent strain range as determined above in (a)

$\Delta\epsilon_{\text{mod}}$

= the modified maximum equivalent strain range that accounts for the effects of local plasticity and creep

Page 123

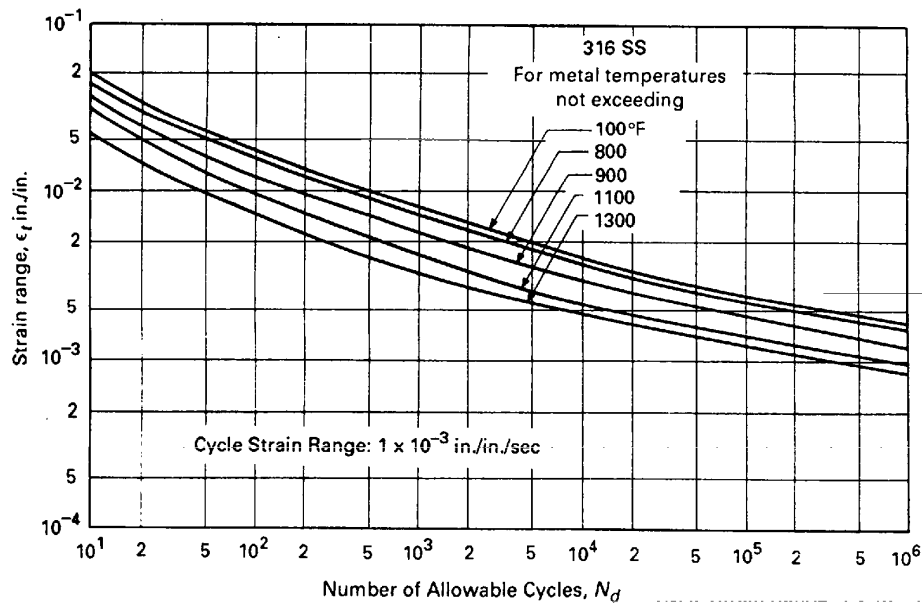
Page 124



N_r Number of Cycles [Note (1)]	ϵ_r Strain Range (in./in.) at Temperature						
	100°F	800°F	900°F	1000°F	1100°F	1200°F	1300°F
10	0.021	0.050	0.0465	0.0425	0.0382	0.0335	0.0297
20	0.036	0.0345	0.0315	0.0284	0.025	0.0217	0.0186
40	0.0263	0.0246	0.0222	0.0197	0.017	0.0146	0.0123
10^3	0.018	0.0164	0.0146	0.0128	0.011	0.0093	0.0077
2×10^3	0.0142	0.0125	0.011	0.0096	0.0082	0.0069	0.0057
4×10^3	0.0113	0.00965	0.00845	0.00735	0.0063	0.00525	0.00443
10^4	0.00845	0.00725	0.0063	0.0055	0.0047	0.00385	0.00333
2×10^4	0.0067	0.0059	0.0051	0.0045	0.0038	0.00315	0.00276
4×10^4	0.00545	0.00485	0.0042	0.00373	0.0032	0.00263	0.0023
10^5	0.0043	0.00385	0.00335	0.00298	0.0026	0.00215	0.00185
2×10^5	0.0037	0.0033	0.0029	0.00256	0.00226	0.00187	0.00158
4×10^5	0.0032	0.00287	0.00254	0.00224	0.00197	0.00162	0.00138
10^6	0.00272	0.00247	0.00213	0.00188	0.00164	0.00140	0.00117
2×10^6	0.0024	0.00215	0.0019	0.00167	0.00145	0.00123	0.00105
4×10^6	0.00215	0.00192	0.0017	0.0015	0.0013	0.0011	0.00094
10^7	0.0019	0.00169	0.00149	0.0013	0.00112	0.00098	0.00084

NOTE:
(1) Cyclic Strain rate: 1×10^{-3} in./in./sec.

FIG. T-1420-1A DESIGN FATIGUE STRAIN RANGE, ϵ_r , FOR 304 SS

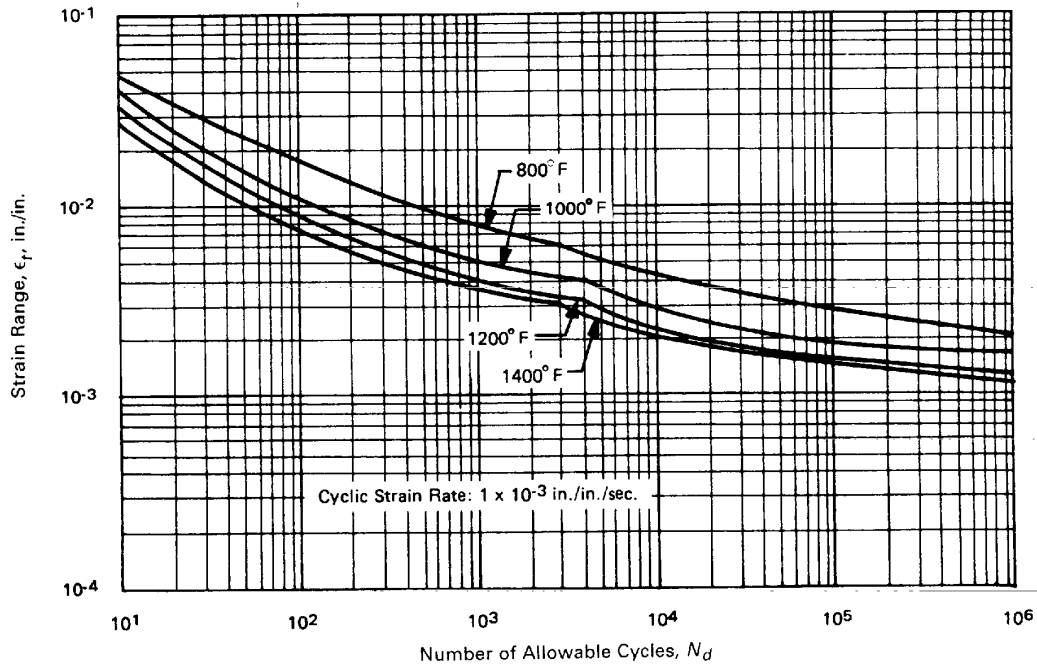


N_d Number of Cycles [Note (1)]	ϵ_r Strain Range (in./in.) at Temperature				
	100°F	800°F	900°F	1000-1200°F	1300°F
10^1	0.0507	0.0438	0.0378	0.0318	0.0214
2×10^1	0.0357	0.0318	0.0251	0.0208	0.0149
4×10^1	0.026	0.0233	0.0181	0.0148	0.0105
10^2	0.0177	0.0159	0.0123	0.00974	0.00711
2×10^2	0.0139	0.0125	0.00961	0.00744	0.00551
4×10^2	0.0110	0.00956	0.00761	0.00574	0.00431
10^3	0.00818	0.00716	0.00571	0.00424	0.00328
2×10^3	0.00643	0.00581	0.00466	0.00339	0.00268
4×10^3	0.00518	0.00476	0.00381	0.00279	0.00226
10^4	0.00403	0.00376	0.00301	0.00221	0.00186
2×10^4	0.00343	0.00316	0.00256	0.00186	0.00162
4×10^4	0.00293	0.00273	0.00221	0.00161	0.00144
10^5	0.00245	0.00226	0.00182	0.00136	0.00121
2×10^5	0.00213	0.00196	0.00159	0.00121	0.00108
4×10^5	0.00188	0.00173	0.00139	0.00109	0.000954
10^6	0.00163	0.00151	0.00118	0.000963	0.000834

NOTE:

(1) Cyclic strain rate: 1×10^{-3} in./in./sec.FIG. T-1420-1B DESIGN FATIGUE STRAIN RANGE, ϵ_r , FOR 316 SS

FIG. T-1420-1B DESIGN FATIGUE STRAIN RANGE, ϵ_p , FOR 316 SS

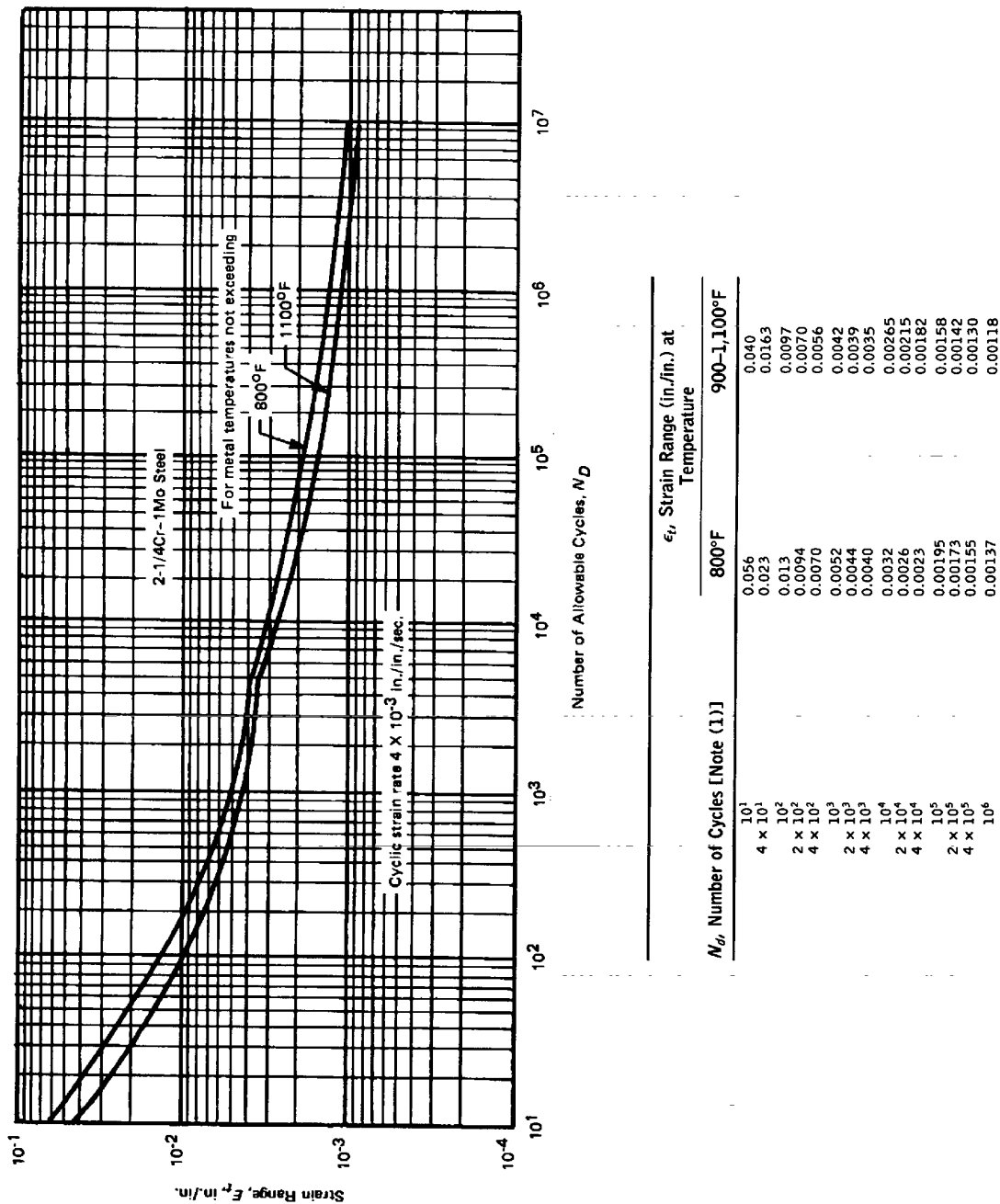


N_d Number of Cycles	ϵ_p Strain Range (in./in.) at Temperature			
	800°F	1000°F	1200°F	1400°F
10^1	0.0500	0.0424	0.03414	0.02841
2×10^1	0.0362	0.02735	0.02199	0.01829
4×10^1	0.0027	0.01849	0.01483	0.01233
10^2	0.0184	0.01164	0.00932	0.00774
2×10^2	0.0142	0.00849	0.00678	0.00562
4×10^2	0.0113	0.00660	0.00533	0.00469
10^3	0.00841	0.00515	0.00417	0.00388
2×10^3	0.00685	0.00454	0.00366	0.00349
3×10^3	0.00644	0.00433	0.00347	0.00309
4×10^3	0.00572	0.00409	0.00327	0.00270
10^4	0.00452	0.00293	0.00234	0.00212
2×10^4	0.00392	0.00243	0.00197	0.00183
4×10^4	0.00343	0.00212	0.00175	0.00164
10^5	0.00288	0.00194	0.00155	0.00149
2×10^5	0.00254	0.00186	0.00147	0.00140
4×10^5	0.00229	0.00178	0.00140	0.00132
10^6	0.00200	0.00169	0.00131	0.00122

NOTE:

(1) Cyclic strain rate: 1×10^{-3} in./in./sec.

FIG. T-1420-1C DESIGN FATIGUE STRAIN RANGE, ϵ_{tr} , FOR Ni-Fe-Cr ALLOY 800H



NOTE:

(1) Cycle strain rate: 4×10^{-3} in./in./sec.

FIG. T-1420-1D DESIGN FATIGUE STRAIN RANGE, ϵ_p FOR $2\frac{1}{4}$ Cr-1Mo STEEL

FIG. T-1420-1D DESIGN FATIGUE STRAIN RANGE, ϵ_p FOR $2\frac{1}{4}$ Cr-1Mo STEEL

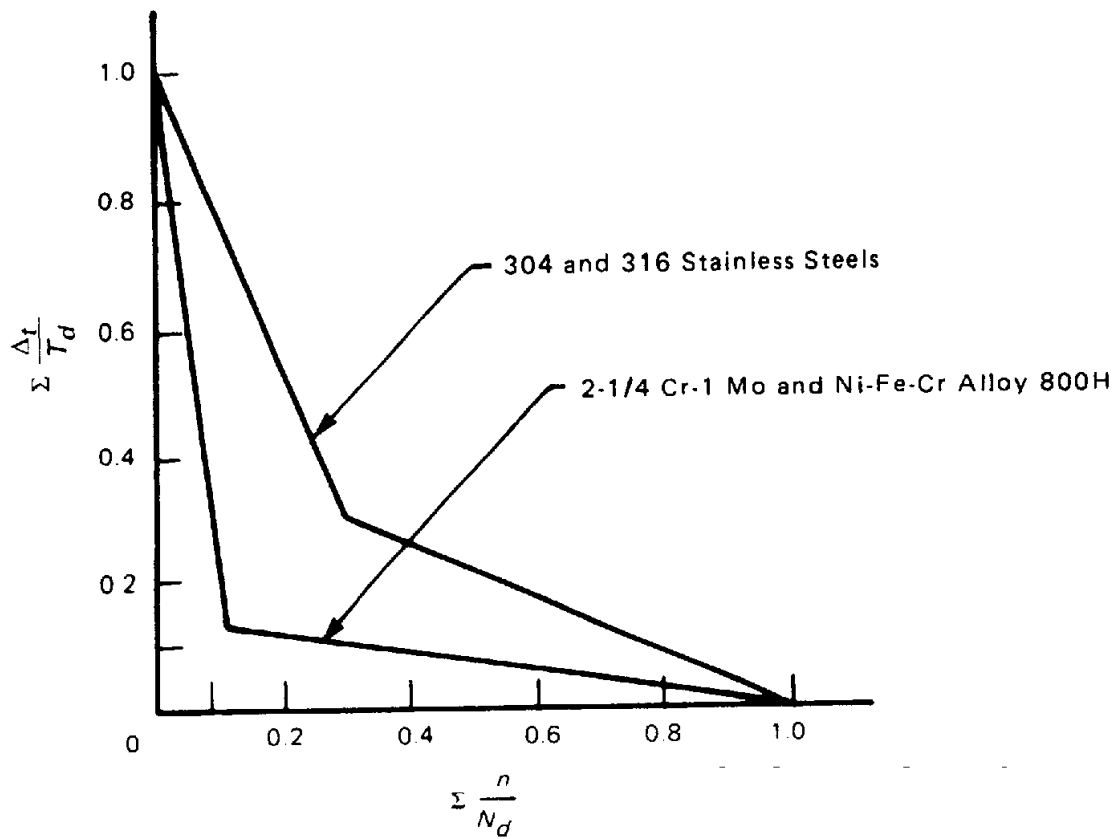


FIG. T-1420-2 CREEP-FATIGUE DAMAGE ENVELOPE

FIG. T-1420-2 CREEP-FATIGUE DAMAGE ENVELOPE

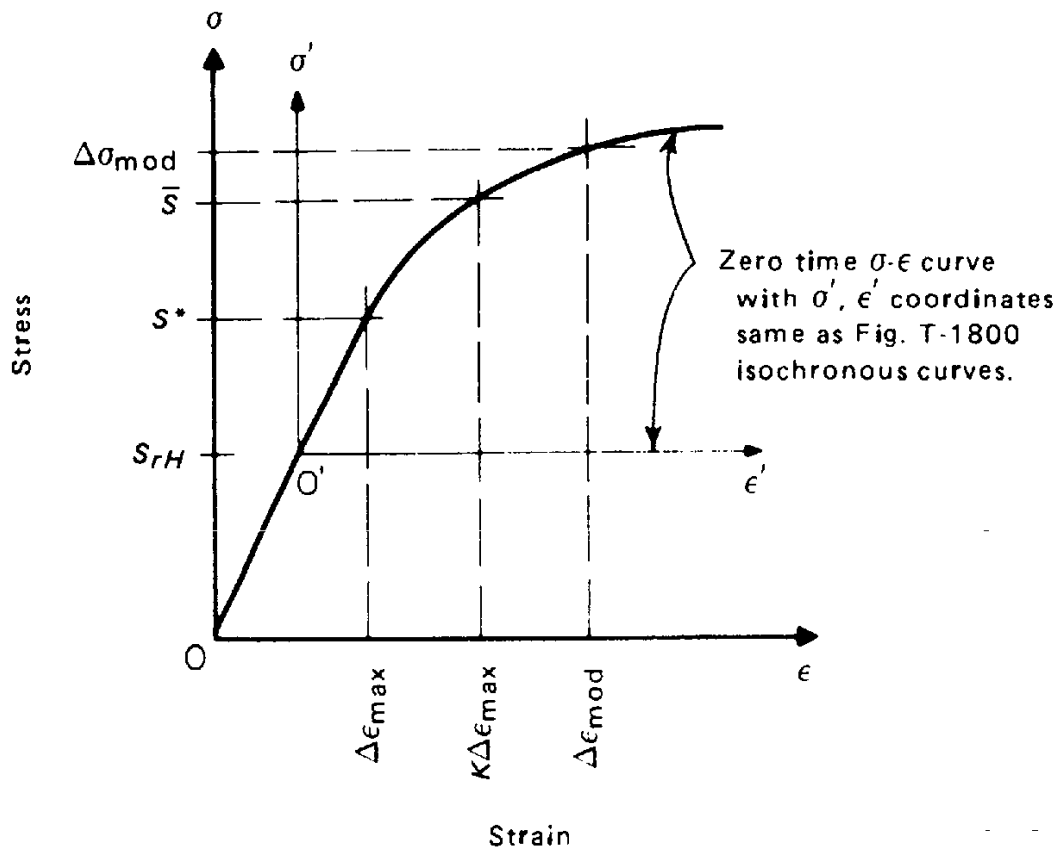


FIG. T-1432-1 STRESS-STRAIN RELATIONSHIP

FIG. T-1432-1 STRESS-STRAIN RELATIONSHIP

The composite stress-strain curve used for this analysis is shown in Fig. T-1432-1, and it is constructed by adding the elastic stress-strain curve for the stress range, S_{rH} , to the appropriate time-independent isochronous stress-strain curve (σ', ϵ') from Figs. T-1800. The appropriate curve of Figs. T-1800 corresponds to the maximum metal temperature occurring during the cycle.

O	= origin of the composite isochronous stress-strain curve (Fig. T-1432-1) used in this analysis
O'	= origin of the time-independent isochronous stress-strain curve of Figs. T-1800
S_{rH}	= a relaxation strength defined in T-1324
ϵ'	= strain abscissa of the time-independent isochronous stress-strain curve of Figs. T-1800
σ'	= stress ordinate of the time-independent isochronous stress-strain curve of Figs. T-1800

(d) Equation (12) results in a conservative determination of the modified maximum equivalent strain range, $\Delta\epsilon_{\text{mod}}$ relative to the maximum equivalent strain range, $\Delta\epsilon_{\text{max}}$. A more accurate and less conservative determination of the modified maximum equivalent strain range, $\Delta\epsilon_{\text{mod}}$ may then be obtained by use of Eq. (13):

$$\Delta\epsilon_{\text{mod}} = \frac{K^2 S^* \Delta\epsilon_{\text{max}}}{\Delta\sigma_{\text{mod}}} \quad (13)$$

(13) where (see Fig. T-1432-1) $\Delta\epsilon_{\text{mod}}$, $\Delta\epsilon_{\text{max}}$, K , and S^* are as defined in (c) above, and $\Delta\sigma_{\text{mod}}$ = the range of effective stress that corresponds to the strain range, $\Delta\epsilon_{\text{mod}}$ in the composite stress-strain curve of Fig. T-1432-1. The unknowns of Eq. (13), i.e., $\Delta\sigma_{\text{mod}}$ and $\Delta\epsilon_{\text{mod}}$ can be solved graphically or analytically by curve fitting the appropriate composite stress-strain curve. Note that the appropriate composite stress-strain curve is constructed as described above in (c).

(e) The most conservative estimate of the modified maximum equivalent strain range, $\Delta\epsilon_{\text{mod}}$ may be obtained as:

$$\Delta\epsilon_{\text{mod}} = K_e K \Delta\epsilon_{\text{max}} \quad (14)$$

(14) where $\Delta\epsilon_{\text{mod}}$, K , and $\Delta\epsilon_{\text{max}}$ are defined in (c) above, and

$$\begin{aligned} K_e &= 1 \text{ if } K\Delta\epsilon_{\text{max}} \leq 3\bar{S}_m/E \\ K_e &= K\Delta\epsilon_{\text{max}}E/3\bar{S}_m \text{ for } K\Delta\epsilon_{\text{max}} > 3\bar{S}_m/E \end{aligned}$$

(f) Determine the multiaxial plasticity and Poisson ratio adjustment factor, K_v , defined in Eq. (15):

$$K_v = 1.0 + f(K_v' - 1.0), \text{ but not less than } 1.0 \quad (15)$$

(15)

where

K_v'

= plastic Poisson ratio adjustment factor determined by entering Fig. T-1432-3 at the ratio of $K_e K \Delta \epsilon_{\max} E / 3 \bar{S}_M$ with the terms as defined in Eq. (14)

f

= factor determined by entering Fig. T-1432-2 at the Triaxiality Factor, T.F., for the stress state at each of the two extremes of the stress cycle. The larger magnitude of f shall be used in Eq. (15).

(g) Determine the creep strain increment $\Delta \epsilon_c$ for the stress cycle due to load controlled stresses by using a stress intensity equal to 1.25 times the effective creep stress $\sigma_c = Z \bullet S_y$ as defined in T-1332. The rules of T-1321, T-1331, and T-1332 apply to determining $\Delta \epsilon_c$ except that the stress cycle time, including hold time between transients, shall be used instead of the entire service life. The restriction on Q_R in T-1323 relative to Table T-1323 does not apply to determining $\Delta \epsilon_c$. Enter the isochronous stress-strain curve (Figs. T-1800) for the maximum metal temperature during the stress cycle time-temperature block with the 1.25 σ_c stress held constant throughout each temperature-time block of the stress cycle. The $\Delta \epsilon_c$ equals the sum of the creep strain increment accumulated in one stress cycle time. Alternatively, the creep strain accumulated during the entire service life divided by the number of stress cycles during the entire service life may be used for the creep strain increment $\Delta \epsilon_c$. Based on satisfaction of T-1320 and the T-1431(a) rules, the $\Delta \epsilon_c$ value used need not exceed 1% divided by the total number of stress cycles:

$$\sum_{j=1}^P (n)_j$$

(h) The total strain range, ϵ_p , that is used to enter one of the design fatigue curves of Figs. T-1420-1, is calculated as:

$$\epsilon_l = K_v \Delta \epsilon_{\text{mod}} + K \Delta \epsilon_c \quad (16)$$

(16)

where

K

= local geometric concentration factor determined above in

K_v

(c), (d), or (e)

= the multiaxial plasticity and Poisson ratio adjustment factor determined above in (f)

$\Delta\epsilon_c$

= the creep strain increment as determined above in (g)

$\Delta\epsilon_{mod}$

= the modified maximum equivalent strain range as determined above in any one of (c), (d), or (e)

ϵ_t

= the total strain range that is used to enter one of the design fatigue curves of Figs. T-1420-1 to determine the allowable number of cycles, N_d

T-1433 Creep Damage Evaluation

The creep damage term of Eq. (10) is to be evaluated using either the general procedure defined in (a) below or the alternate procedure defined in (b) below. As

Page 129

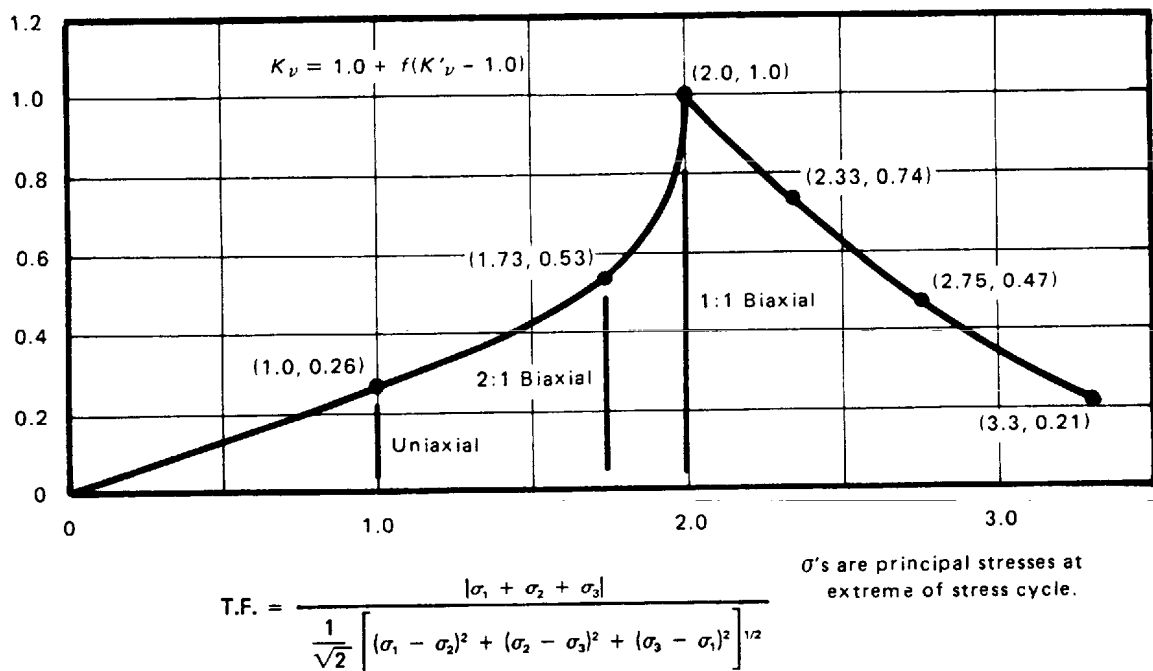


FIG. T-1432-2 INELASTIC MULTIAXIAL ADJUSTMENTS

FIG. T-1432-2 INELASTIC MULTIAXIAL ADJUSTMENTS

Page 130

noted in (b), the alternate procedure cannot be used for any portion of the service life if the total strain range, ϵ_t [as determined in T-1432(h)], exceeds $3\bar{S}_m/E$ for any of the specified cycle types, j .

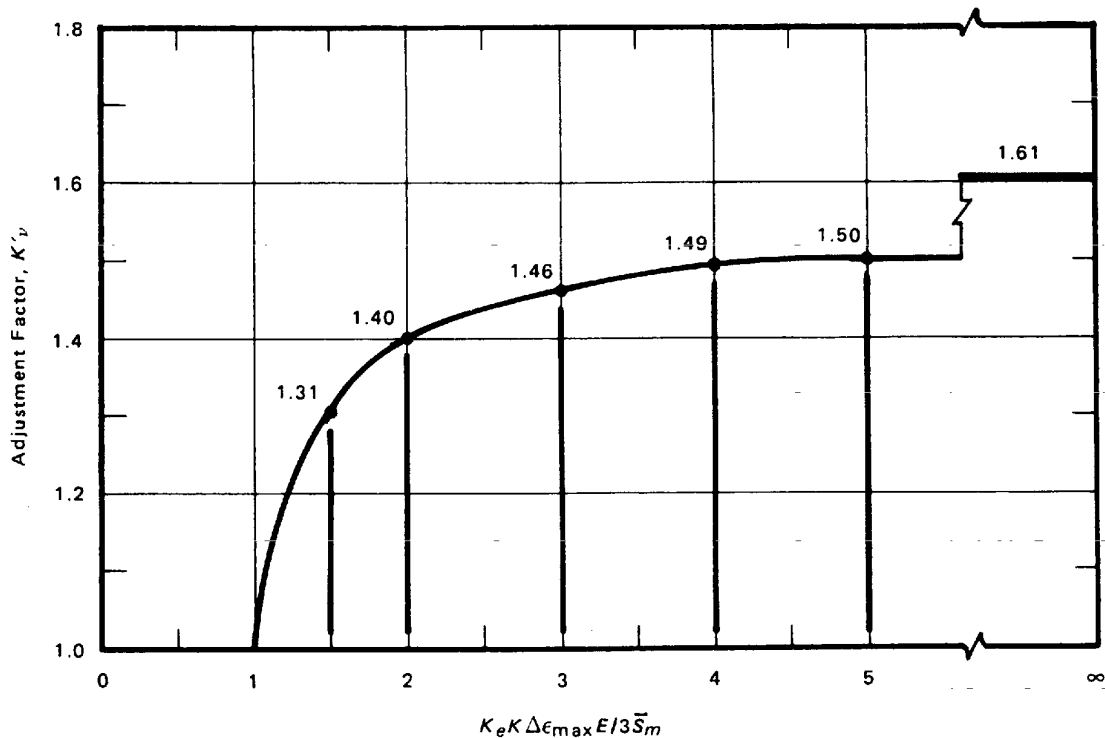


FIG. T-1432-3 ADJUSTMENT FOR INELASTIC BIAXIAL POISSON'S RATIO

FIG. T-1432-3 ADJUSTMENT FOR INELASTIC BIAXIAL POISSON'S RATIO

(a) A general procedure for evaluating the creep damage term of Eq. (10) is provided in Steps 1 through 10 below. Steps 3 through 7 are to be repeated for each cycle type j that was evaluated in T-1432. Recall that j extends from 1 to P as defined in T-1411.

Step 1: Considering the entire specified service life, define the total number of hours expended at temperatures above 800°F (700°F for 2 $\frac{1}{4}$ Cr-1Mo) as t_H

Step 2: Define the hold temperature, T_{HT} , to be equal to the local metal temperature that occurs during sustained normal operation.

Step 3: For each cycle type j , define the average cycle time, $\bar{t}_j$, as:

$$\bar{t}_j = t_H / n_j$$

where

n_j	= specified number of applied repetitions of cycle type j
t_H	= total number of hours at elevated temperatures (for the entire service life) as defined in Step 1 above
$\bar{t}_j$	= average cycle time for cycle type j

Step 4: Select the time-independent isochronous stress-strain curve from Figs. T-1800 that corresponds to the hold-time

temperature T_{HT} . Enter that stress-strain curve at a strain level equal to the strain range ϵ_p , where ϵ_t is that value calculated in T-1432(h) for cycle type j . Establish the corresponding stress level, S_j . Note that the same isochronous stress-strain curve is used for all cycle types, since T_{HT} is independent of cycle definition.

Step 5: Account for stress relaxation during the average cycle time $\bar{t}_j$. This stress relaxation evaluation is to be performed at a constant temperature equal to T_{HT} . The initial stress is S_j for cycle type j . The stress relaxation history may be determined by:

(1) an adjusted uniaxial relaxation analysis where the multiaxial stress state is accounted for by using the following equation (depicted in Fig. T-1433-1(b)):

$$S_r = S_j - 0.8G (S_j - \bar{S}_r)$$

where

G

= the smallest value of the multiaxiality factor as determined for the stress state at each of the two extremes of the stress cycle. The multiaxiality factor is defined as:

$$\frac{[\sigma_1 - 0.5(\sigma_2 + \sigma_3)]}{[\sigma_1 - 0.3(\sigma_2 + \sigma_3)]}$$

where σ_1 , σ_2 , and σ_3 are principal stresses, exclusive of local geometric stress concentration factors, at the extremes of the stress cycle, and are defined by:

$$|\sigma_1| \geq |\sigma_2| \geq |\sigma_3|$$

Values of G greater than 1.0 shall be taken as 1.0.

S_j

= the initial stress level for cycle type j

 S_r

= relaxed stress level at time t adjusted for the multiaxial stress state

 $\bar{S}_r$

= relaxed stress level at time t based on a uniaxial relaxation model

or

(2) by entering the appropriate isochronous stress-strain curves of Figs. T-1800 at a strain level equal to ϵ_t and determining corresponding stress levels at varying times (see Fig. T-1433-1). The appropriate isochronous stress-strain curves correspond to the temperature T_{HT} . This stress relaxation process shall not be permitted to proceed to a stress level less than S_{LB} . This lower bound stress level, S_{LB} , is defined to be equal to 1.25 times the core stress σ_c [see T-1432(g)] intensity that exists during sustained normal operation. Note that the same value of S_{LB} is used for all cycle types. This stress relaxation procedure results in a stress-time history similar to that illustrated in Fig. T-1433-2.

Step 6: The average cycle time, $\bar{t}_j$, includes the time expended during elevated temperature transient conditions in addition to the time at the sustained normal operating conditions. Define that portion of $\bar{t}_j$ that represents time expended during elevated temperature transient conditions, as $(t_{TRAN})_j$. Determine the time point, during the transient conditions, for which the load controlled stresses are at maximum conditions. Define $(S_{TRAN})_j$ to be equal to the load controlled stress intensity at that time point. Indicate both $(t_{TRAN})_j$ and $(S_{TRAN})_j$ on the stress-time history (determined in Step 5)

Page 131

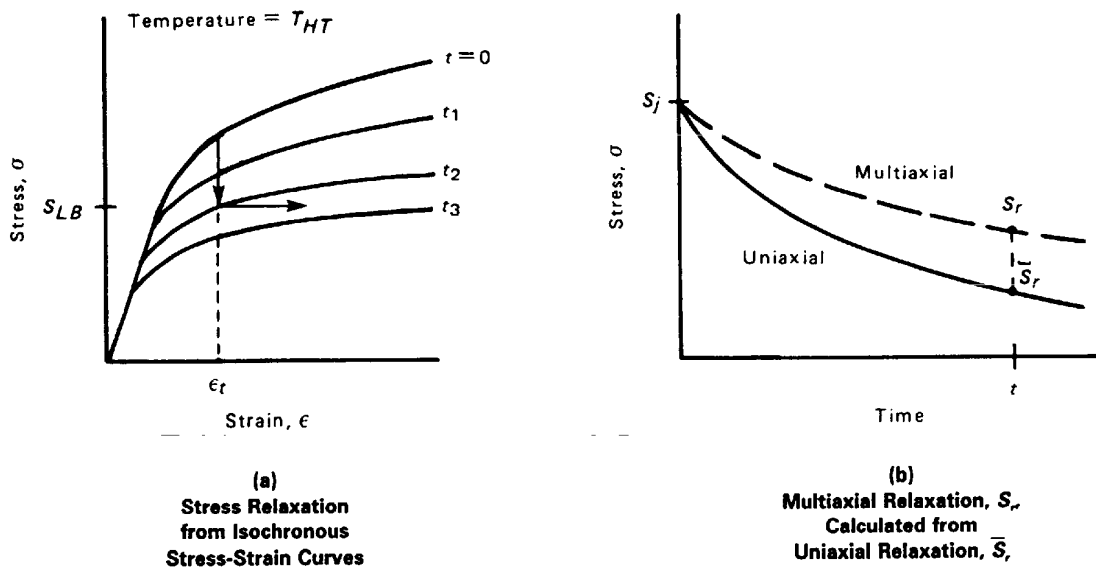


FIG. T-1433-1 METHODS OF DETERMINING RELAXATION

FIG. T-1433-1 METHODS OF DETERMINING RELAXATION

Page 132

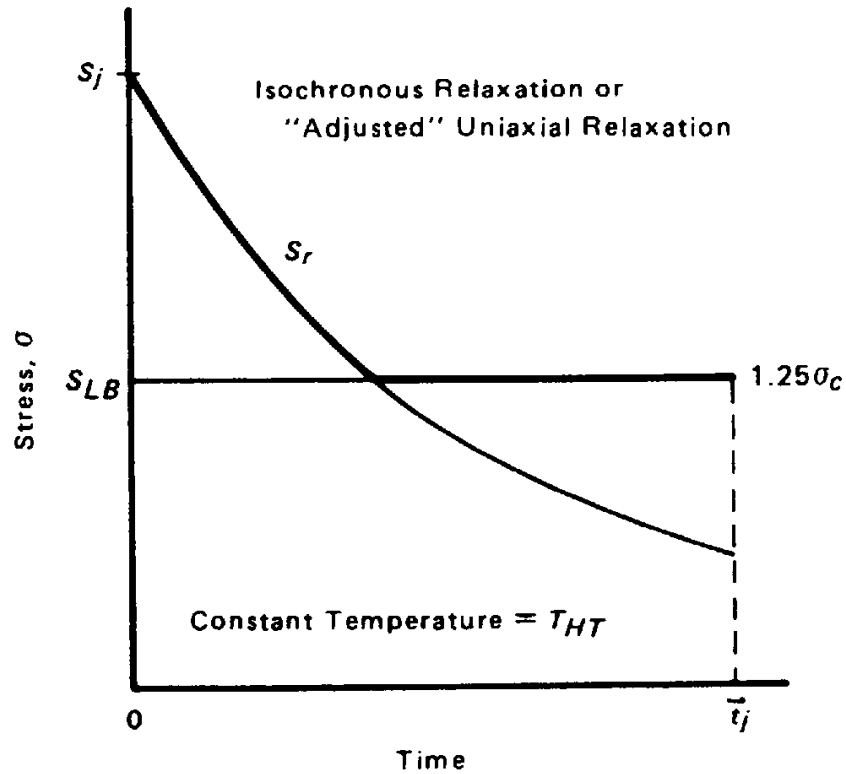


FIG. T-1433-2 STRESS-RELAXATION LIMITS FOR CREEP DAMAGE

FIG. T-1433-2 STRESS-RELAXATION LIMITS FOR CREEP DAMAGE

above) as shown in Fig. T-1433-3(a). If $(S_{\text{TRAN}})_j$ does not exceed the stress-time history within the time duration $(t_{\text{TRAN}})_j$ [as is illustrated in Fig. T-1433-3(a)], then no further modification of the stress-time history is required. If $(S_{\text{TRAN}})_j$ exceeds the stress-time history within the time duration $(t_{\text{TRAN}})_j$, then the stress-time history must be modified by a simple translation in time, as shown in Fig. T-1433-3(b).

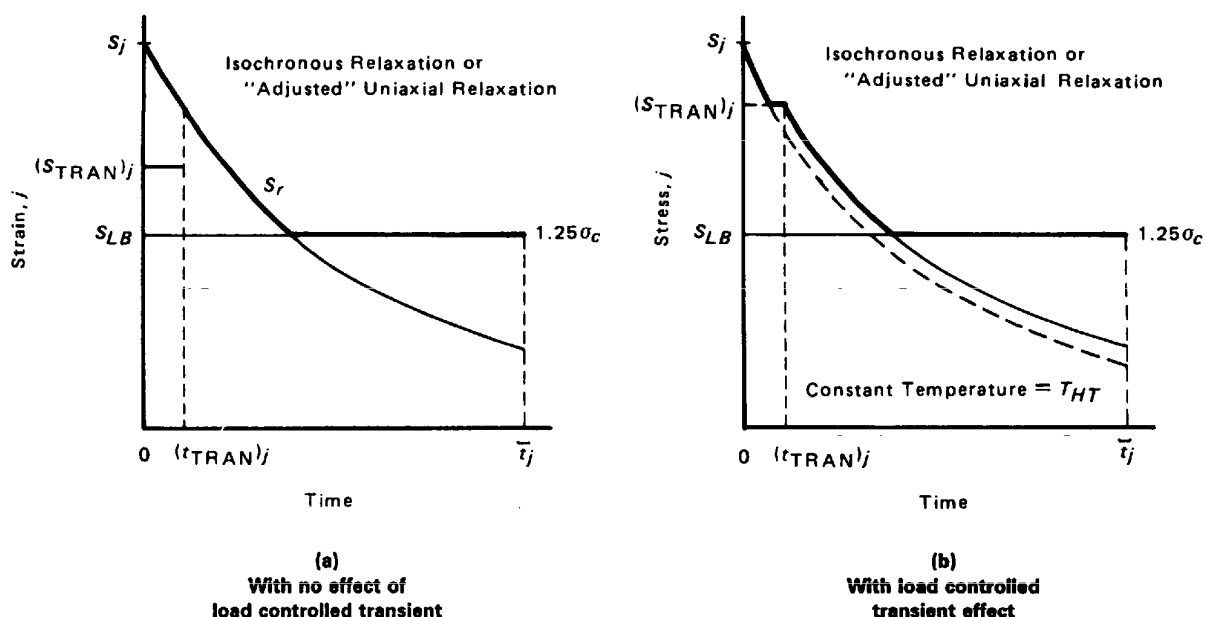


FIG. T-1433-3 STRESS-RELAXATION LIMITS FOR CREEP DAMAGE

FIG. T-1433-3 STRESS-RELAXATION LIMITS FOR CREEP DAMAGE

Step 7: Define the cycle transient temperature, $(T_{\text{TRAN}})_j$, to be equal to the maximum metal temperature that occurs during cycle type j . In no case shall $(T_{\text{TRAN}})_j$ be defined as less than the hold time temperature, T_{HT} . Note that the temperature $(T_{\text{TRAN}})_j$ is not considered in the determination of the stress relaxation history; however, it is considered in the subsequent determination of the creep damage during the time duration $(t_{\text{TRAN}})_j$.

Step 8: The repetition of the above Steps 3 through 7 for $j = 1$ to P will result in P stress/temperature time histories. These stress/temperature time histories are to be superimposed as shown in Fig. T-1433-4.

Step 9: The resulting, composite, stress/temperature time history envelope is divided into q time intervals to facilitate the evaluation of the creep damage term of Eq. (10). These q time intervals are selected to conveniently represent the composite stress/temperature history as a step-wise function of time. During each of these time intervals, $(\Delta t)_k$, the stress, $(S)_k$, and temperature, $(T)_k$, are assumed to be constant and are selected to represent the most damaging stress/temperature combination that could exist during that time interval.

Step 10: For each time interval, $(\Delta t)_k$, the allowable time duration $(T_d)_k$ of Eq. (10) is obtained from the expected minimum stress-to-rupture curve of Figs. I-14.6. The appropriate temperature is $(T)_k$ and the appropriate stress is $(S)_k/K'$, where K' is selected from Table T-1411-1.

(b) Alternatively, the stress/temperature time history can be defined on the basis of a single relaxation cycle for the entire design life. This alternate procedure can be used only if the total strain range ϵ_t [as determined in T-1432(h)] is less than or equal to $3\bar{S}_m/E$ for all specified cycle types, j , considered in T-1432. The

stress-time history for this single relaxation curve is to be constructed using the procedure defined in Steps 1 through 5 in (a) above. For the purposes of this calculation, the average cycle time $\bar{t}_j$ (of Step 5 above) is to be defined as:

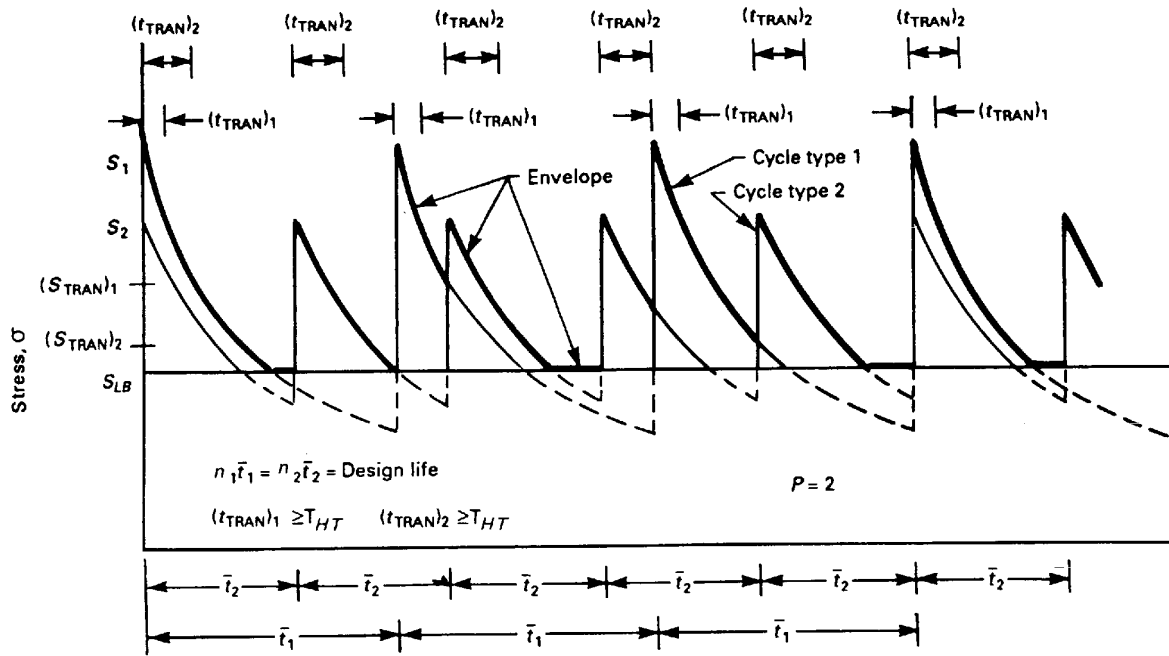


FIG. T-1433-4 ENVELOPE STRESS-TIME HISTORY FOR CREEP DAMAGE ASSESSMENT

FIG. T-1433-4 ENVELOPE STRESS-TIME HISTORY FOR CREEP DAMAGE ASSESSMENT

$$\bar{t}_j = t_H$$

where t_H is as defined in Step 1 above. Similarly, the initial stress, S_j (calculated in Step 4 above), is to be based on the maximum value of ϵ_i that was calculated in T-1432(h). The lower bound stress, S_{LB} , is as defined in Step 5 above. The hold-time temperature, T_{HT} , is as defined in Step 2 above. The resulting stress-time history will be similar to that shown in Fig. T-1433-2.

This single cycle, stress-time history is divided into q time intervals to conveniently represent the history as a step-wise function. During each of these time intervals $(\Delta t)_k$ the stress $(S)_k$ is assumed to be constant and is equal to the value at the start of that interval. The temperature $(T)_k$ is constant for the entire design life and is equal to T_{HT} .

For each time interval $(\Delta t)_k$ the allowable time duration $(T_d)_k$ of Eq. (10) is obtained from the expected minimum stress-to-rupture curve of Figs. I-14.6. The appropriate temperature is $(T)_k$ and the appropriate stress is $(S)_k/K'$, where K' is selected from Table T-1411-1.

T-1434 Calculation of Strain Range for Piping

When simplified elastic rules are used for piping analysis utilizing the stress indices of Table NB-3681(a)-1, the equivalent strain range may be calculated directly from Eqs. (12) or (14) by scalar addition of elastic and inelastic strain. The calculation of temperature distributions for use in the simplified analysis must reflect the actual component geometry.

Piping systems shall be assessed for thermal expansion elastic follow-up and its effects shall be accounted for in the strain range ϵ_i and stress intensity S_k assessments of T-1430. The follow-up analysis shall be disclosed and justified in the Design Report.

T-1435 Alternate Creep-Fatigue Evaluation

Providing the limits of T-1324 are satisfied, the rules of T-1431, T-1432, and T-1433 may be replaced by NB-3222.4, except:

Page 134

(a) The reference to Figs. I-9.0 may be replaced by Figs. T-1420-1, where S_a is one half the product of ϵ_t and Young's Modulus E at the metal temperature of the cycle for the point under consideration.

(b) The S_n value in NB-3228.5 and NB-3653.6 shall be taken as S_p .

(c) The cumulative usage factor U shall not exceed 0.90.

(d) Note the exception of T-1412.

T-1500 BUCKLING AND INSTABILITY

T-1510 GENERAL REQUIREMENTS

(a) The stability limits in NB-3133 of Section III pertain only to specific geometrical configurations under specific loading conditions. For example, column mode buckling is not evaluated by NB-3133 and Appendix VII. These Section III limits include the effects of initial geometrical imperfections permitted by fabrication tolerances on vessel shells. However, Section III limits do not consider the effects of creep due to long term loadings at elevated temperatures and the effects of the other loads or other geometries. The T-1500 rules provide additional limits which are applicable to general configurations and loading conditions that may cause buckling or instability due to time-independent as well as time-dependent creep behavior of the material. These additional limits are applicable to all specified Design and Service Loadings.

(b) For the limits specified in T-1520, distinction is made between load controlled buckling and strain-controlled buckling. Load controlled buckling is characterized by continued application of an applied load in the post-buckling regime, leading to failure, e.g., collapse of a tube under external pressure. Strain controlled buckling is characterized by the immediate reduction of strain induced load upon initiation of buckling, and by the self-limiting nature of the resulting deformations. Even though it is self-limiting, strain controlled buckling must be avoided to guard against failure by fatigue, excessive strain, and interaction with load controlled instability.

(c) For conditions under which strain controlled and load controlled buckling may interact, the Load Factors applicable to load controlled buckling shall be used for the combination of load controlled and strain controlled loads to guard against buckling in the interactive mode.

(d) For conditions where significant elastic follow-up may occur, the Load Factors applicable to load controlled buckling shall also be used for strain controlled buckling.

(e) For load controlled buckling, the effects of initial geometrical imperfections and tolerances shall be considered in the time-independent calculations of T-1521; and the effects of the geometrical imperfections and tolerances, whether initially present or induced by service, shall be considered in the time-dependent calculations of T-1522.

(f) For purely strain controlled buckling, the effects of geometrical imperfections and tolerances, whether initially present or induced by service, need not be considered in the calculation of the instability strain. However, if significant geometrical imperfections are present initially, enhancement due to creep may cause excessive deformation or strain. These effects shall be considered in the application of deformation and strain limits of T-1200 and T-1300.

(g) The expected minimum stress-strain curve for the material at the specified temperatures shall be used. The expected minimum values may be obtained by normalizing the inelastic portion of the appropriate average hot tensile curve of Fig. T-1800 to the tabulated yield strength given in Table I-14.5.

When re-solution annealed Type 300 series austenitic stainless steel is utilized, the tabulated yield strength shall be further reduced by 17%. This reduction is not required if it is demonstrated by test that the room temperature yield strength meets the specified minimum values following re-solution annealing.

(h) The limits of both T-1521 and T-1522 shall be satisfied for the specified Design and Service Loadings.

T-1520

T-1520 BUCKLING LIMITS

T-1521 Time-Independent Buckling

For load controlled buckling, the Load Factor, and for strain controlled buckling, the Strain Factor, shall equal or exceed the values given in Table T-1521-1 for the specified Design and Service Loadings to guard against time-independent (instantaneous) buckling. Alternatively, for cylindrical shells under external pressure or axial compression, with or without stiffeners, and for spherical shells under external pressure, the design limits of Section III, Division 1, NB-3133 may be applied.

T-1522 Time-Dependent Buckling

To protect against load controlled time-dependent creep buckling, it shall be demonstrated that instability will not occur during the specified lifetime for a load

Page 135

**TABLE T-1521-1
TIME-INDEPENDENT BUCKLING FACTORS**

	Load Factor [Note (1)]	Strain Factor [Notes (1), (2)]
Design Loadings	3.0	1.67
Service Loadings	3.0	
Level A	3.0	1.67
Level B	3.0	1.67
Level C	2.5	1.4
Level D	1.5	1.1
Test [Note (3)]	2.25	1.67

NOTES:

(1)

$$\text{Load (Strain) Factor} = \left[\begin{array}{c} \text{Load (strain) which would} \\ \text{cause instant instability at} \\ \text{the design (or actual ser-} \\ \text{vice) temperature} \end{array} \right] \div \left[\begin{array}{c} \text{Design or ex-} \\ \text{pected load} \\ \text{(strain)} \end{array} \right]$$

Changes in configuration induced by service need not be considered in calculating the buckling load.

- (2) For thermally induced strain controlled buckling, the Strain Factor is applied to loads induced by thermal strain. To determine the buckling strain, it may be necessary to artificially induce high strains concurrent with the use of realistic stiffness properties. The use of an *adjusted* thermal expansion coefficient is one technique for enhancing the applied strains without affecting the associated stiffness characteristics.
- (3) These factors apply to hydrostatic, pneumatic, and leak tests. Other types of tests shall be classified according to NH-3113.7.

TABLE T-1521-1 TIME-INDEPENDENT BUCKLING FACTORS

history obtained by multiplying the specified Service Loadings by the factors given in Table T-1522-1. A design factor is not required for purely strain controlled buckling because strain controlled loads are reduced concurrently with resistance of the structure to buckling when creep is significant. Alternatively, for temperatures below the limits of Figs. T-1522-1, T-1522-2, or T-1522-3, the design limits of Section III, Division 1, NB-3133 may be applied without consideration of creep effects. The temperature limits of Figs. T-1522-1 and T-1522-2 are given in terms of design life and are applicable for any radius-to-thickness ratio. The temperature limits of Fig. T-1522-3 are given in terms of radius-to-thickness ratio and are applicable for any design life.

**TABLE T-1522-1
TIME-DEPENDENT LOAD CONTROLLED BUCKLING
FACTORS**

Service Loadings	
Level A	1.5
Level B	1.5
Level C	1.5
Level D	1.25

TABLE T-1522-1 TIME-DEPENDENT LOAD CONTROLLED BUCKLING FACTORS

T-1700 SPECIAL REQUIREMENTS

T-1710 SPECIAL STRAIN REQUIREMENTS AT WELDS

T-1711 Scope

Because of the potential for limited ductility of weld metal at elevated temperatures and the potential for high strain concentrations (both metallurgical and geometric) in the heat affected zone of weldments, the additional analysis requirements of this Subarticle shall be satisfied for all pressure boundary and other primary structural welds subjected under Service Levels A, B, and C Loadings to metal temperatures where creep effects are significant (see NH-3211). The potential for reduced ductility often precludes locating welds in regions of high loading.

T-1712 Material Properties

In calculating strain deformations in a weld region, the parent material properties shall be used up to the centerline of the weld.

T-1713 Strain Limits

Inelastic strains accumulated in the weld region shall not exceed one-half the strain values permitted for the parent material.

T-1714 Analysis of Geometry

The analysis for strains and creep-fatigue interactions at welds shall use stress and strain concentration factors appropriate for the worst surface geometry and shall be included in the Stress Report (NCA-3350). The worst surface geometry for a given weld shall be determined by the methods described in NH-3353.

T-1715 Creep-Fatigue Reduction Factors

In the vicinity of a weld (defined by ± 3 times the thickness to either side of the weld center line), the creep-fatigue evaluation of T-1400 shall utilize reduced values of the allowable number of design cycles N_d and the allowable time duration T_d in Eq. (10). The N_d value shall be one-half the value permitted for the parent material (Figs. T-1420-1). The T_d value shall

Page 136

Page 137

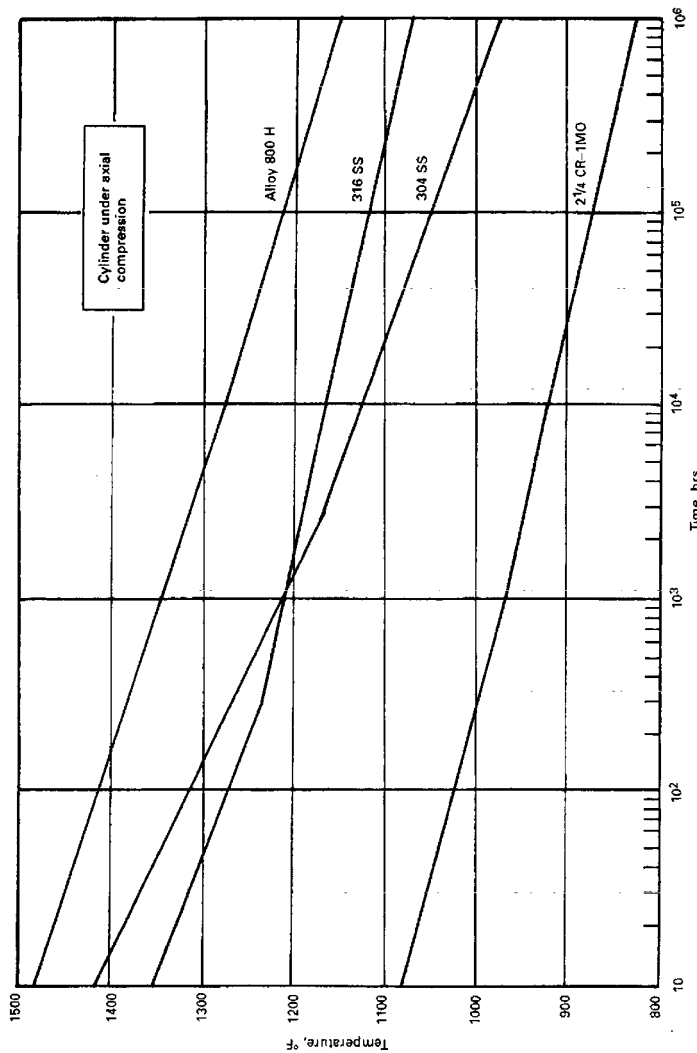


FIG. T-1522-1 TIME-TEMPERATURE LIMITS FOR APPLICATION OF SECTION II EXTERNAL PRESSURE CHARTS

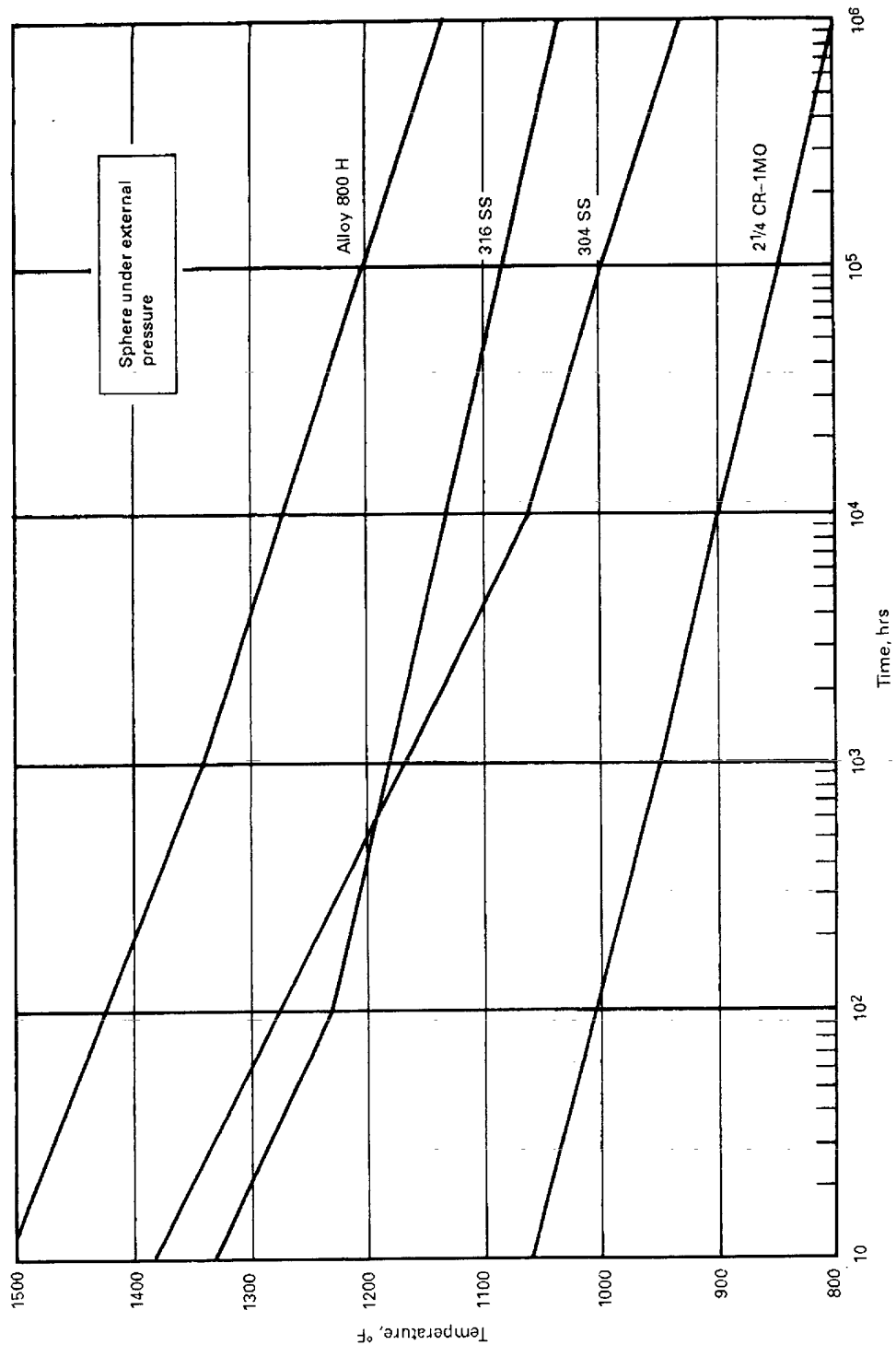


FIG. T-1522-2 TIME-TEMPERATURE LIMITS FOR APPLICATION OF SECTION II EXTERNAL PRESSURE CHARTS

FIG. T-1522-2 TIME-TEMPERATURE LIMITS FOR APPLICATION OF SECTION II EXTERNAL PRESSURE CHARTS

be determined from a stress-to-rupture curve obtained by multiplying the parent material stress-to-rupture values (Tables I-14.6) by the weld strength reduction factors given in Table I-14.10, and defined in NH-3220. The factor K' (Table T-1411-1) must still be applied in this determination of T_d

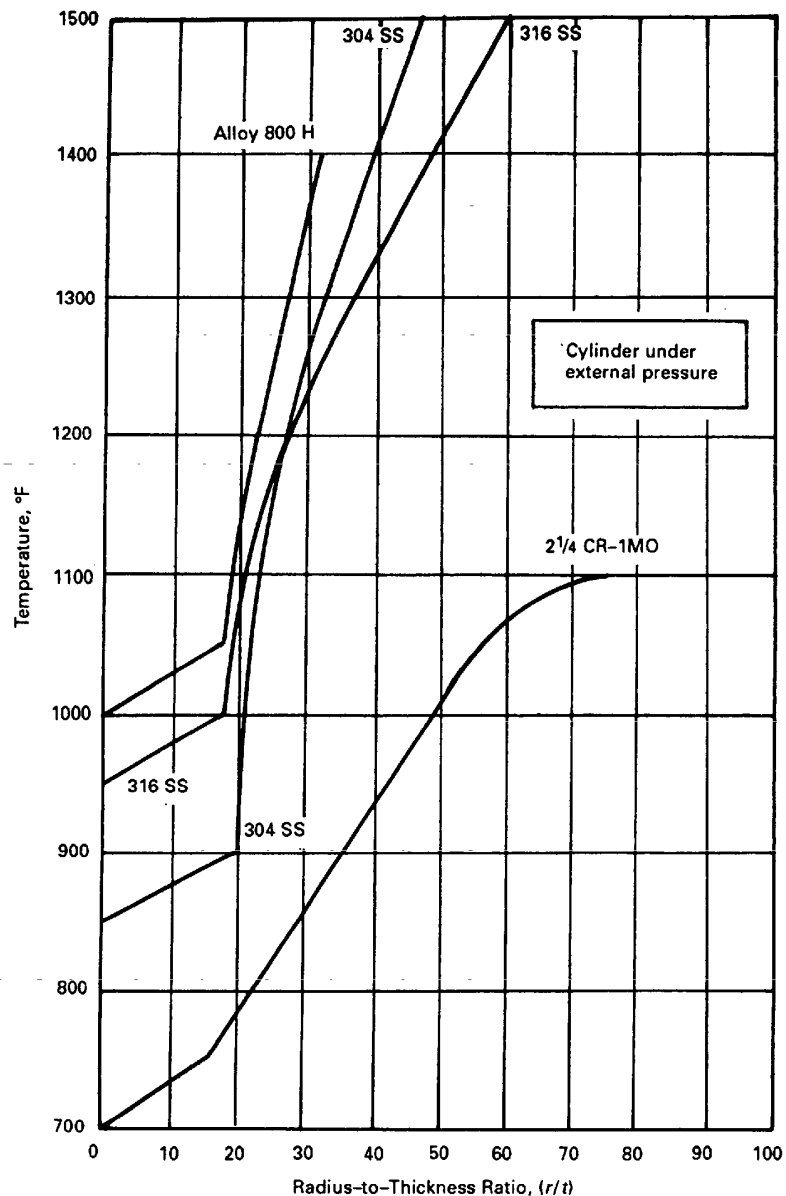


FIG. T-1522-3 TEMPERATURE LIMITS FOR APPLICATION OF SECTION II EXTERNAL PRESSURE CHARTS

T-1720 STRAIN REQUIREMENTS FOR BOLTING

T-1721 Strain Limits

The limits of T-1300 shall apply.

T-1722 Creep-Fatigue Damage Accumulation

The fatigue analysis exemptions in NB-3222.4(d) of Section III shall not apply. Creep and fatigue damage shall be assessed using Eq. (10) of T-1411. The total damage factor, D , shall be set at the appropriate value determined from Fig. T-1420-2. Additional requirements are given in (a) and (b) below.

(a) Unless it can be shown by analysis or tests that a lower fatigue strength reduction factor and/or a lower stress rupture reduction factor is appropriate, the reduction factors shall not be less than 4.0 and 1.8, respectively, for the threaded region.

(b) The geometrical restriction of the thread and fillet radii at the end of the shank as described in NB-3232.3(b)(2) and (3) shall apply.

TABLE T-1820-1

Material	Max. Temp., °F	Temp. Increment, °F
A. 304 SS	1,500	50
B. 316 SS	1,500	50
C. Ni-Fe-Cr, Alloy 800H	1,400	50
D. 2 $\frac{1}{4}$ Cr-1Mo	1,200	50

TABLE T-1820-1

T-1800 ISOCHRONOUS STRESS-STRAIN RELATIONS

T-1810 OBJECTIVE

This Subarticle provides graphs giving isochronous stress-strain curves, each graph being for a specific material at a specific temperature. The graphs are intended to provide the designer with information regarding the total strain caused by stress under elevated temperature conditions, assuming average material properties.

T-1820 MATERIALS AND TEMPERATURE LIMITS

Table T-1820-1 gives the alloys and temperatures covered by the isochronous stress-strain curves of this Subarticle.

Page 140

Page 141

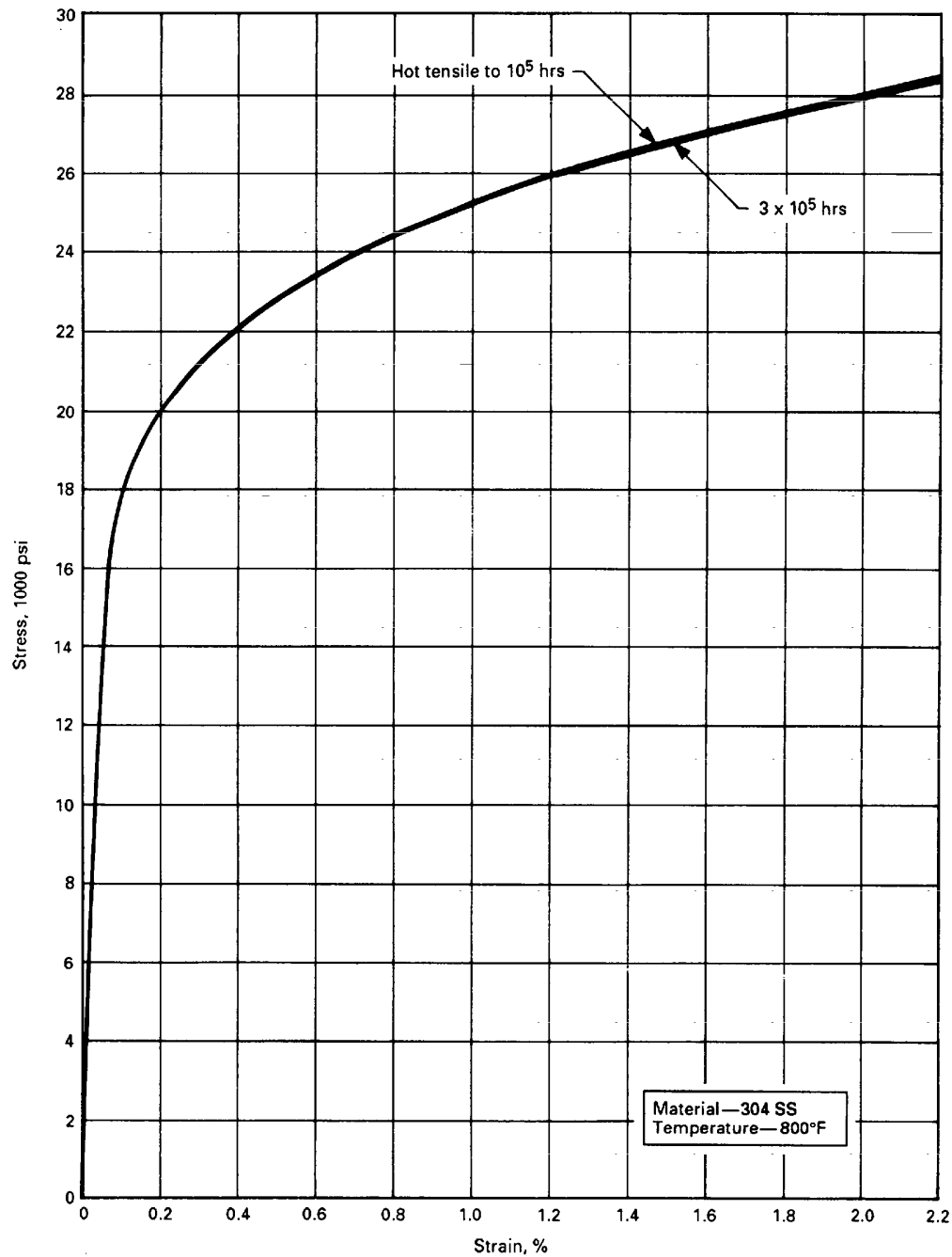


FIG. T-1800-A-1 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

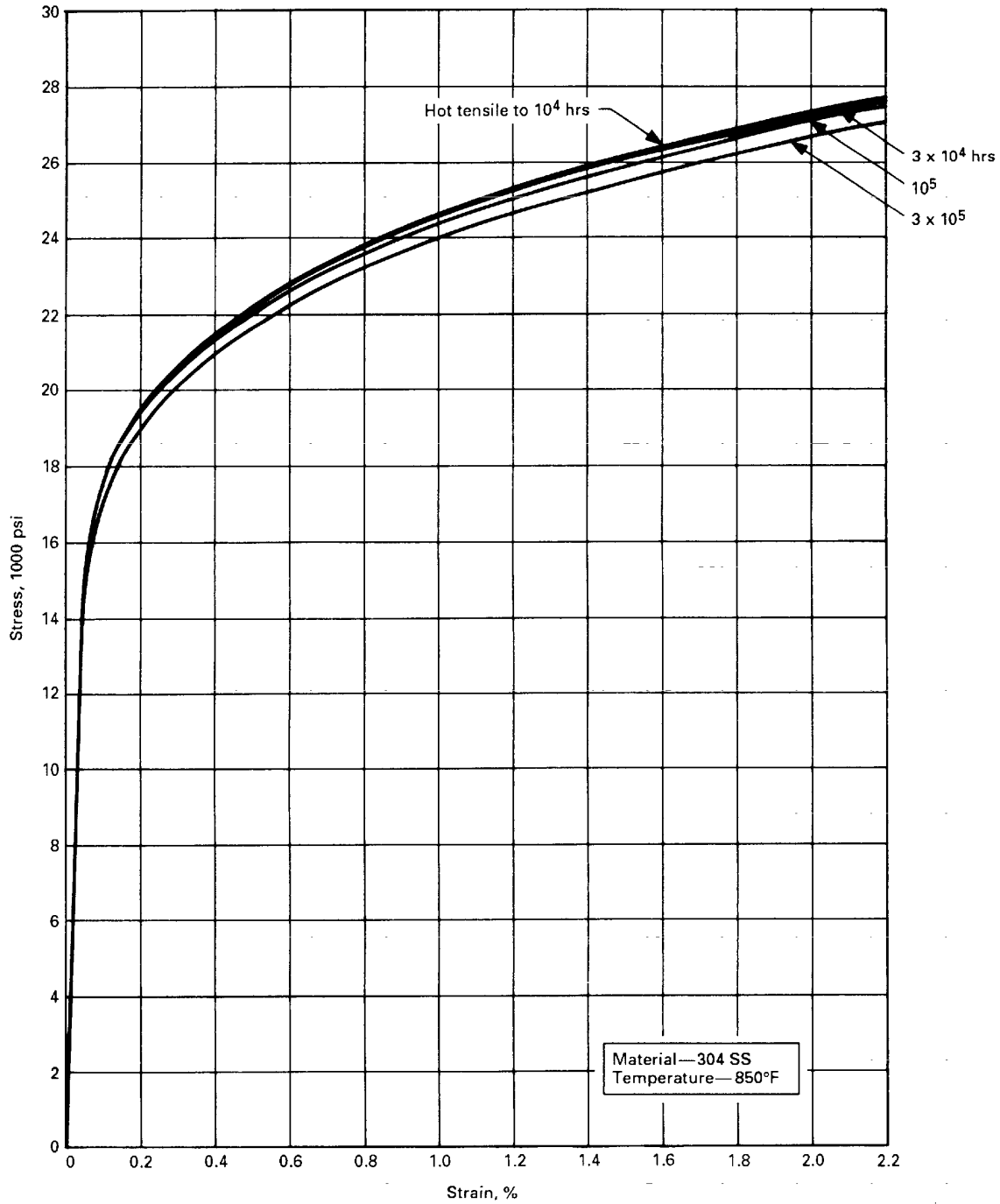


FIG. T-1800-A-2 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

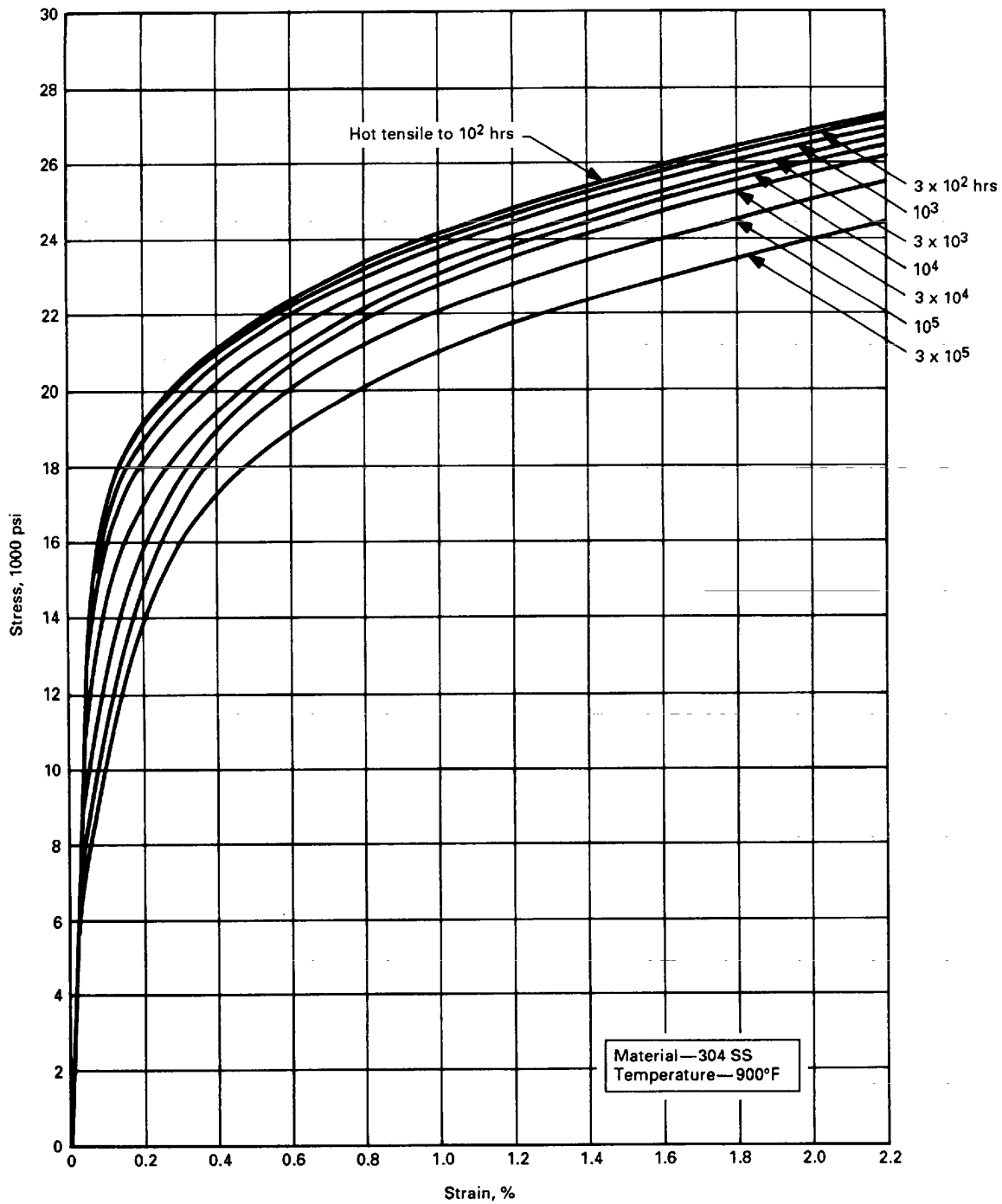


FIG. T-1800-A-3 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

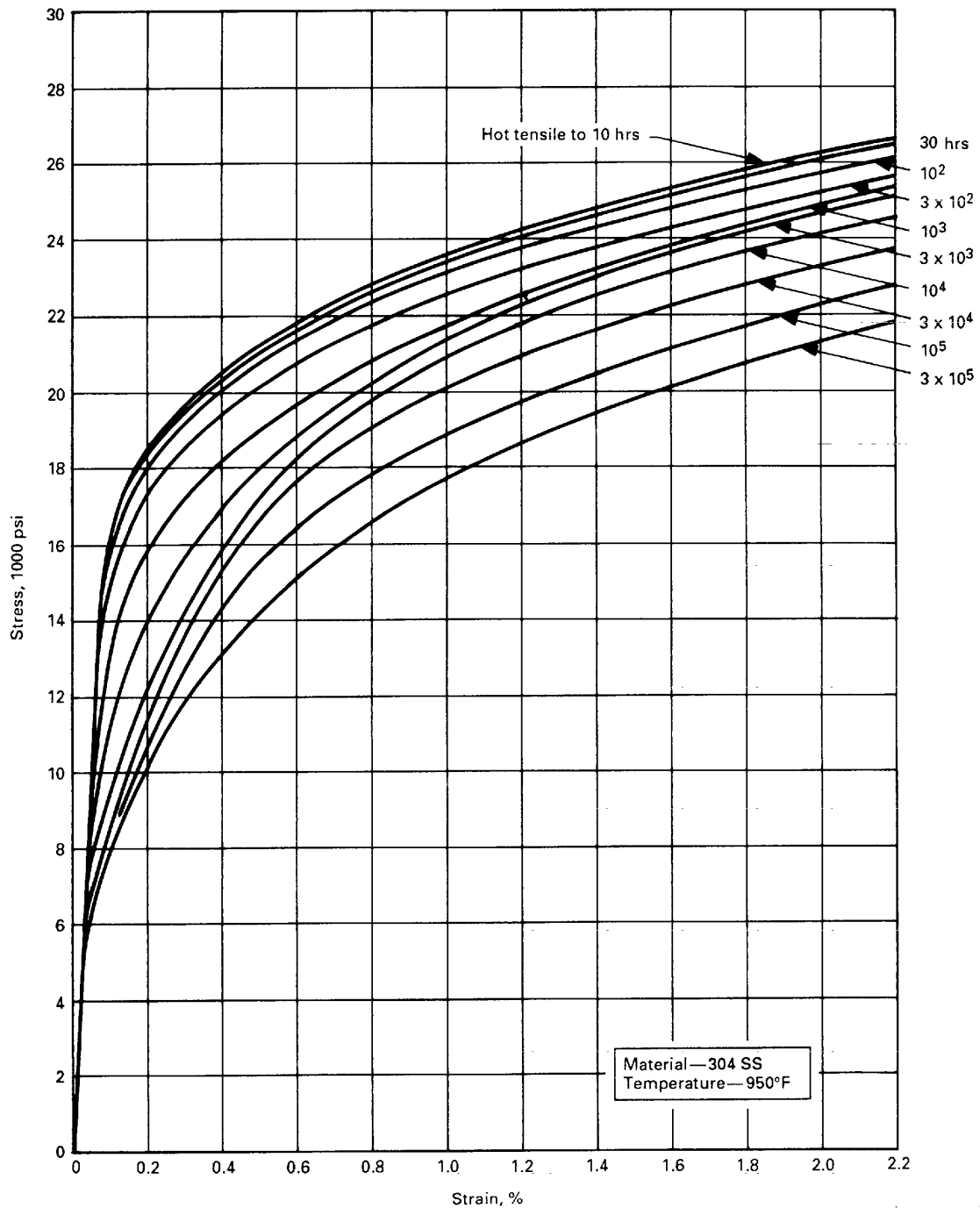


FIG. T-1800-A-4 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

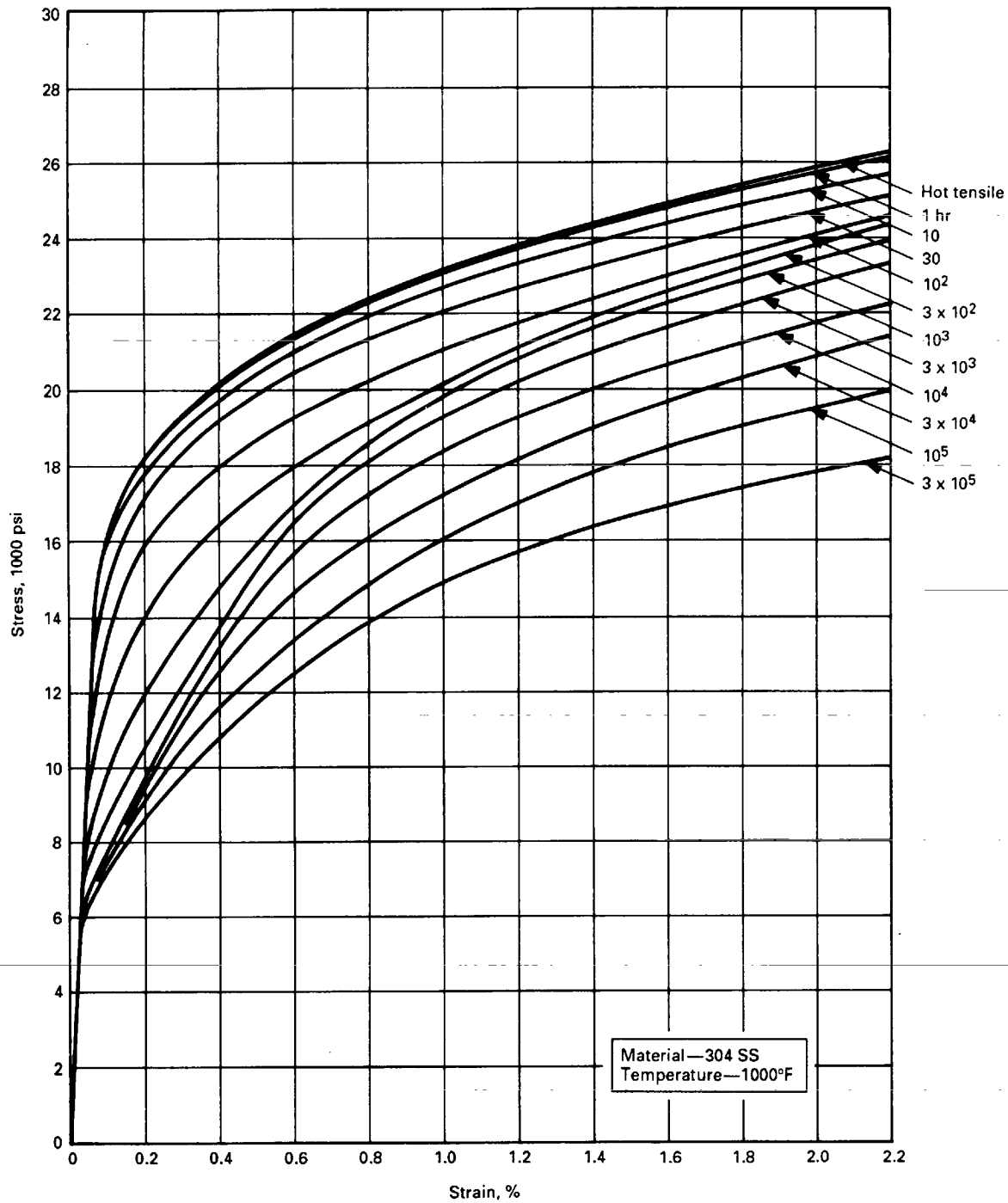


FIG. T-1800-A-5 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

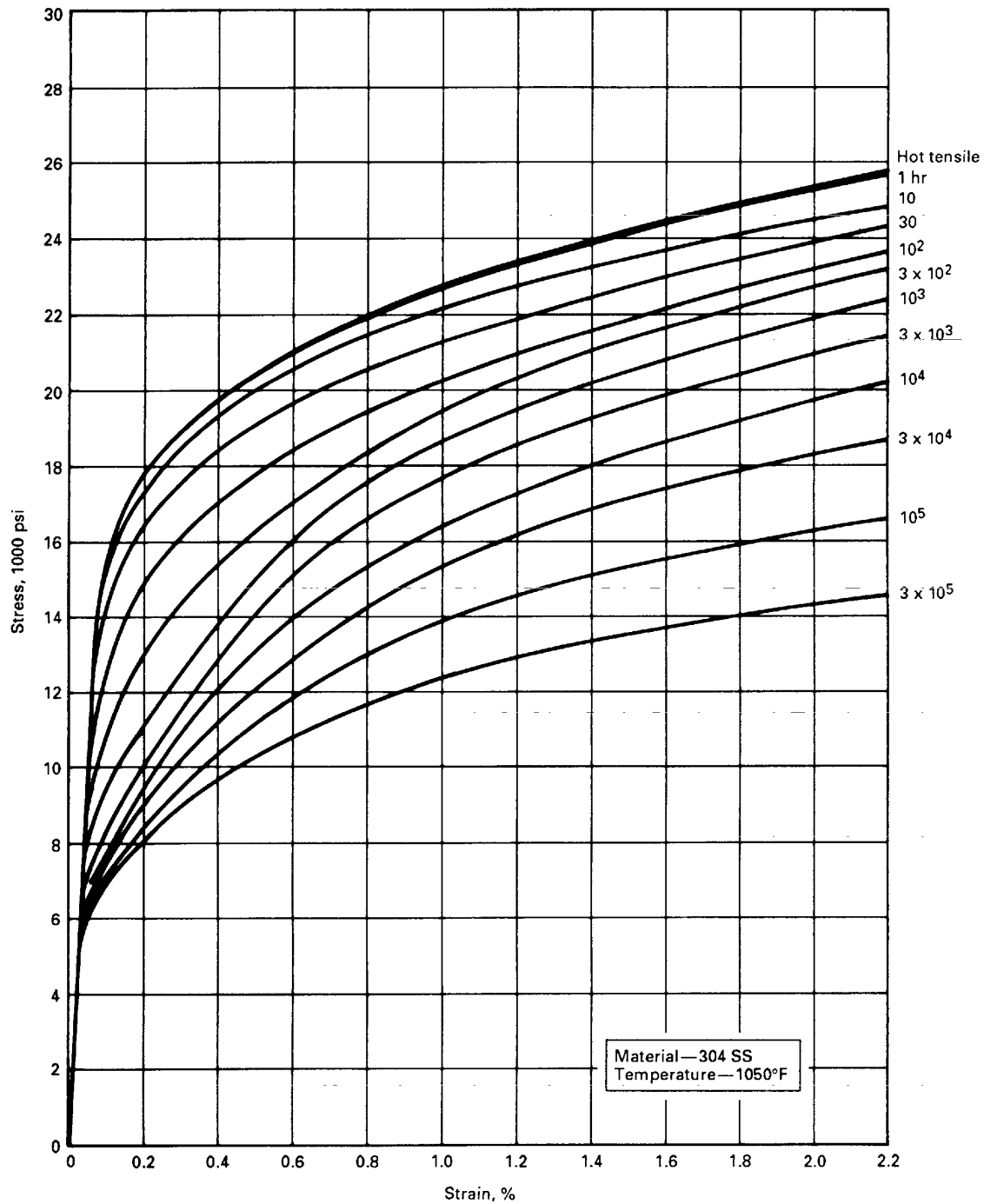


FIG. T-1800-A-6 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

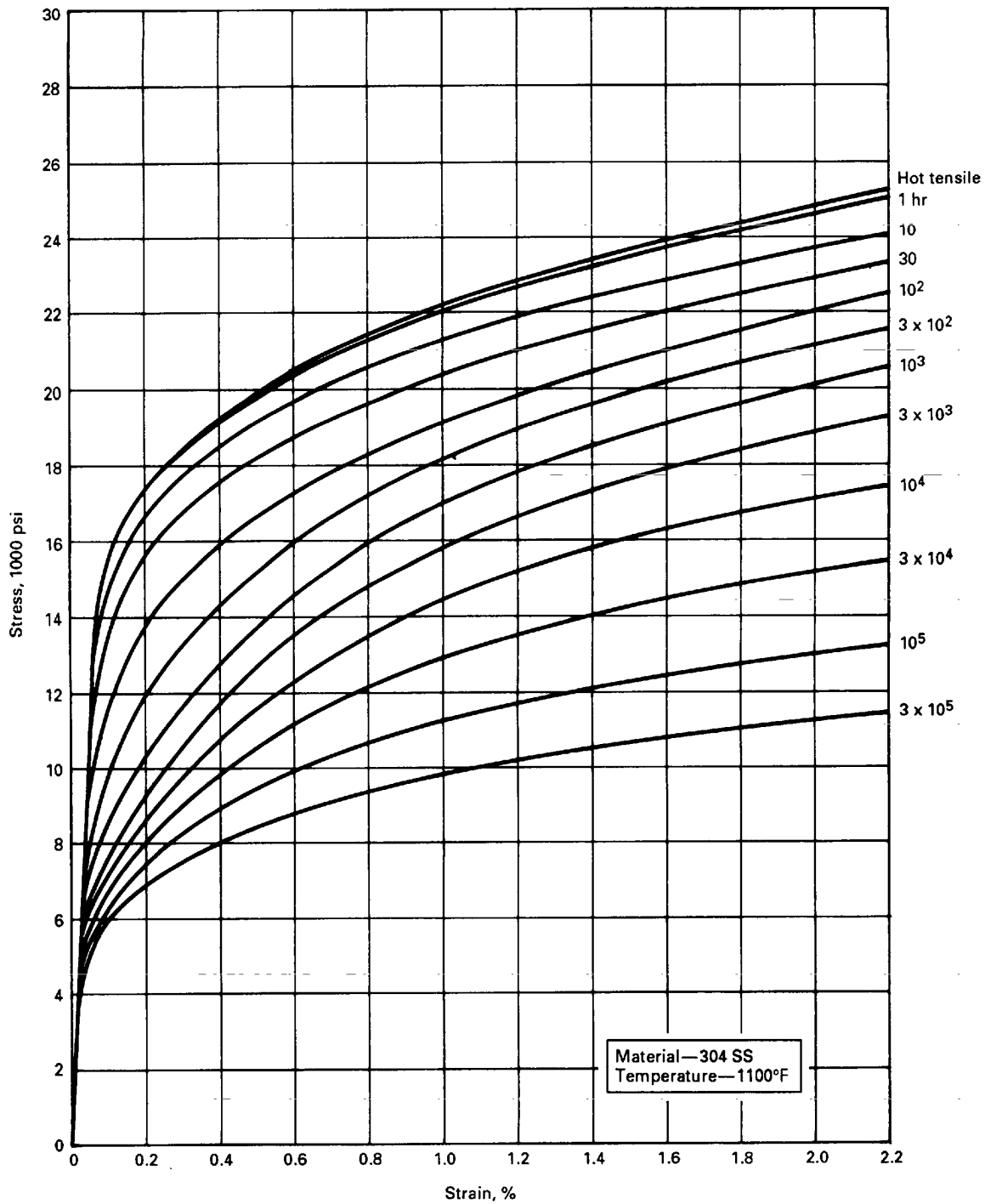


FIG. T-1800-A-7 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

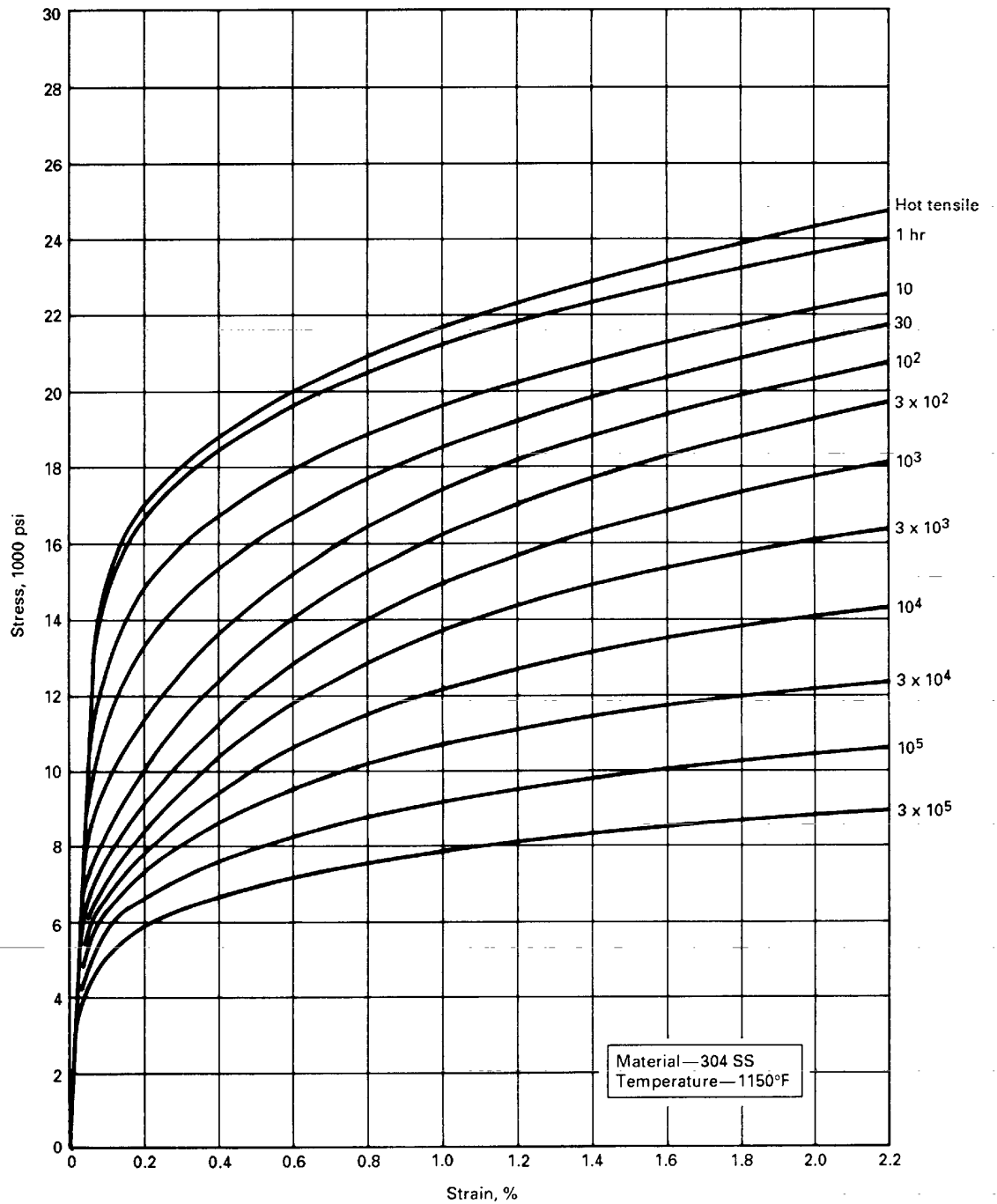


FIG. T-1800-A-8 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

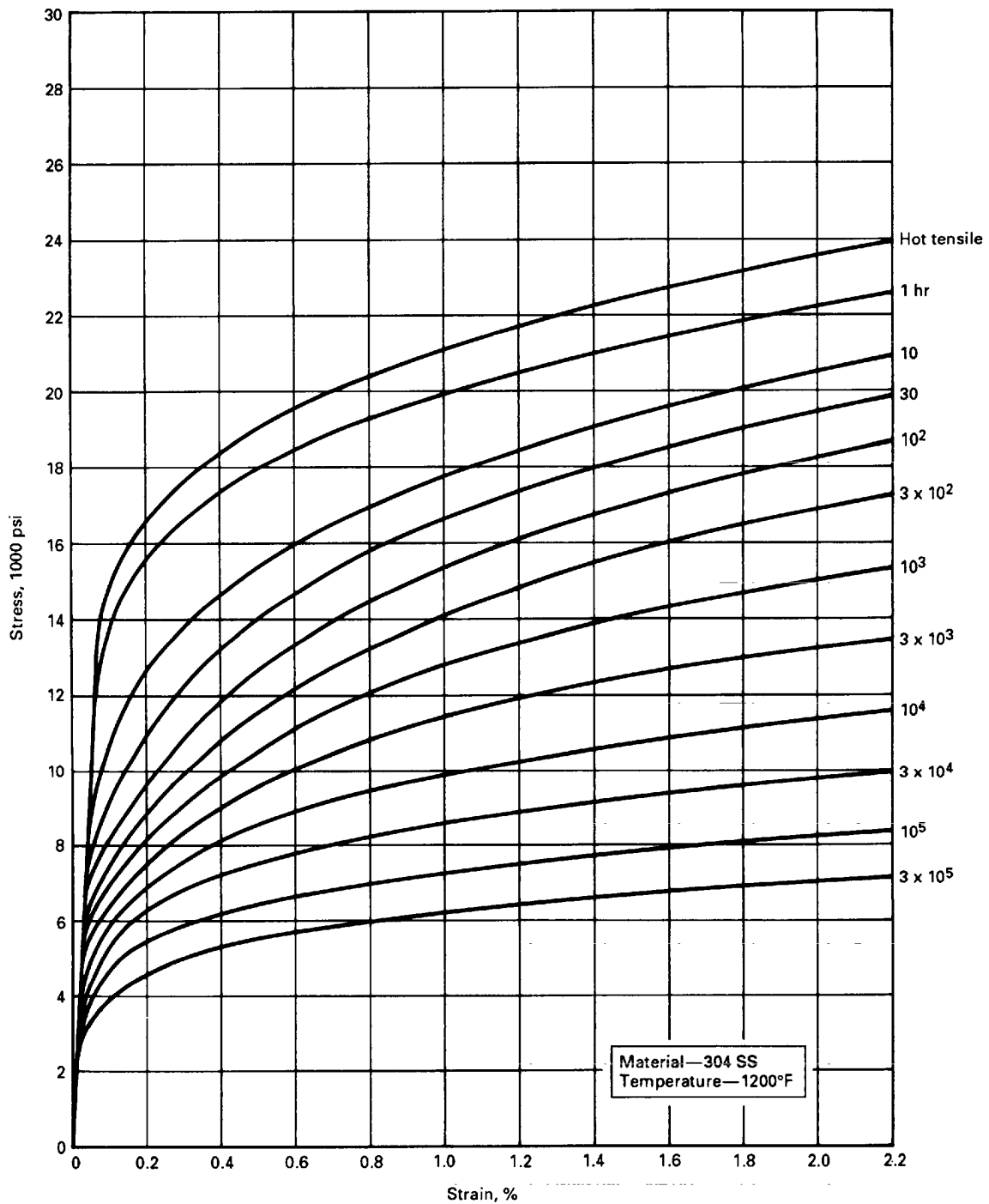


FIG. T-1800-A-9 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

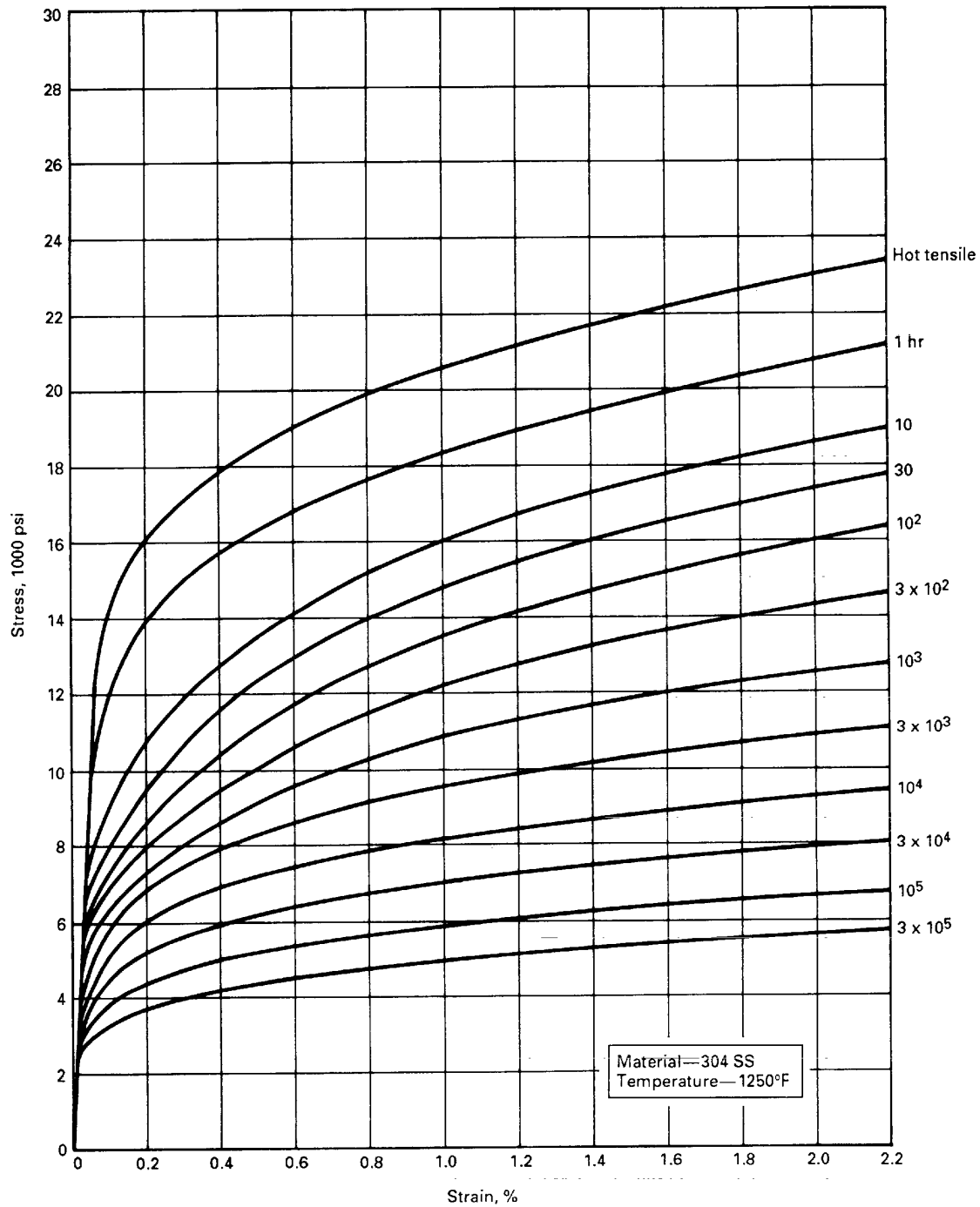


FIG. T-1800-A-10 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

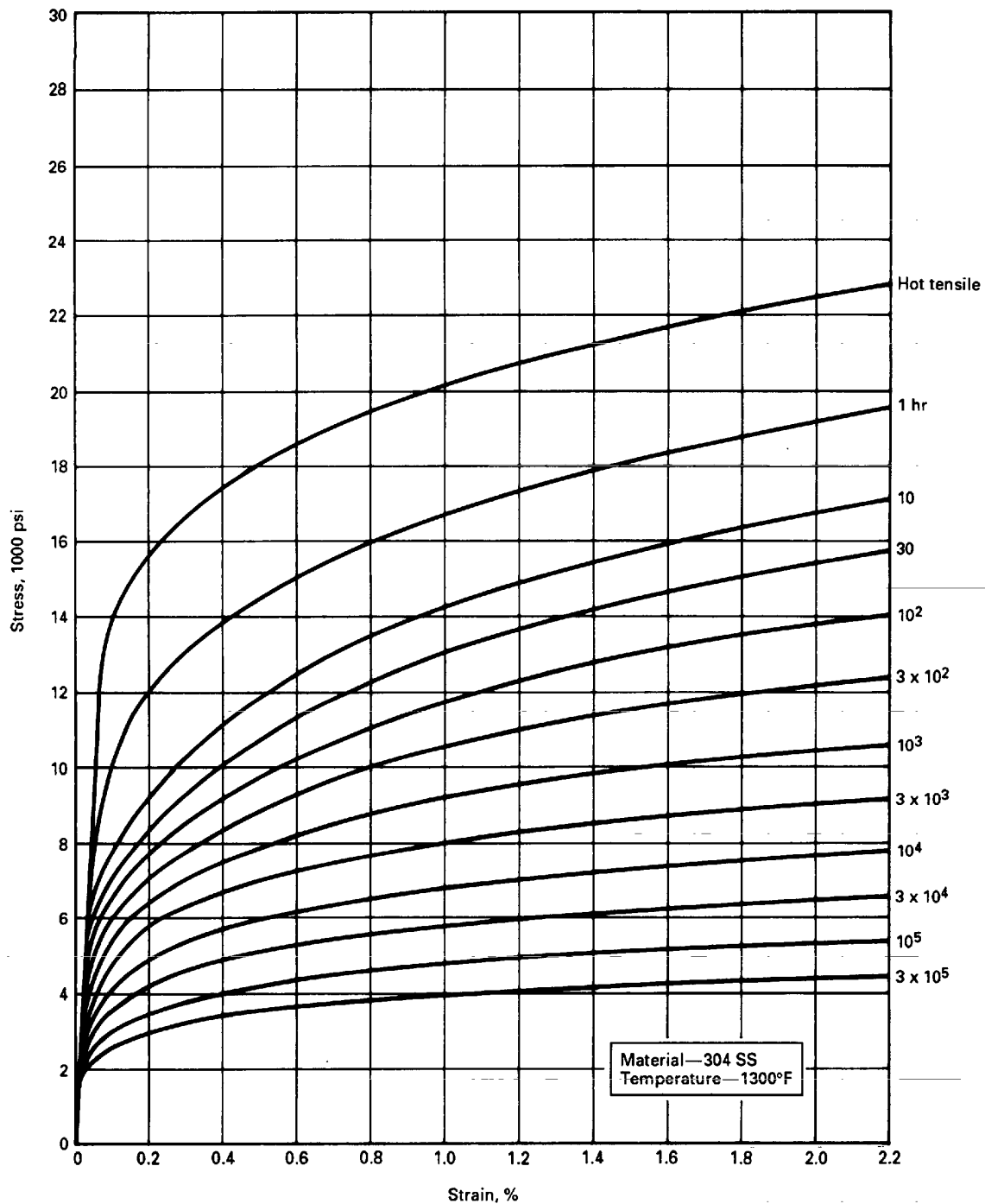


FIG. T-1800-A-11 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

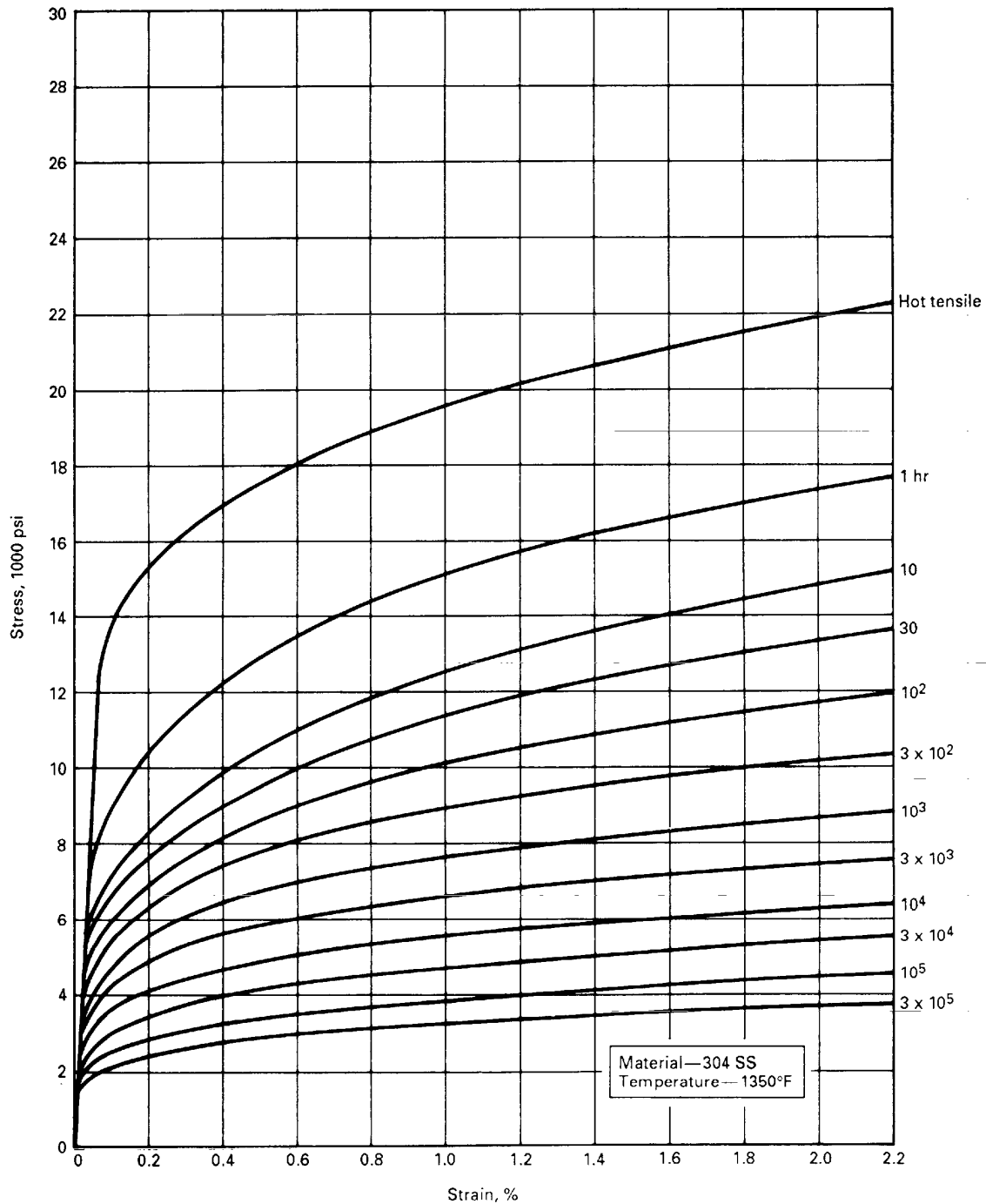


FIG. T-1800-A-12 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

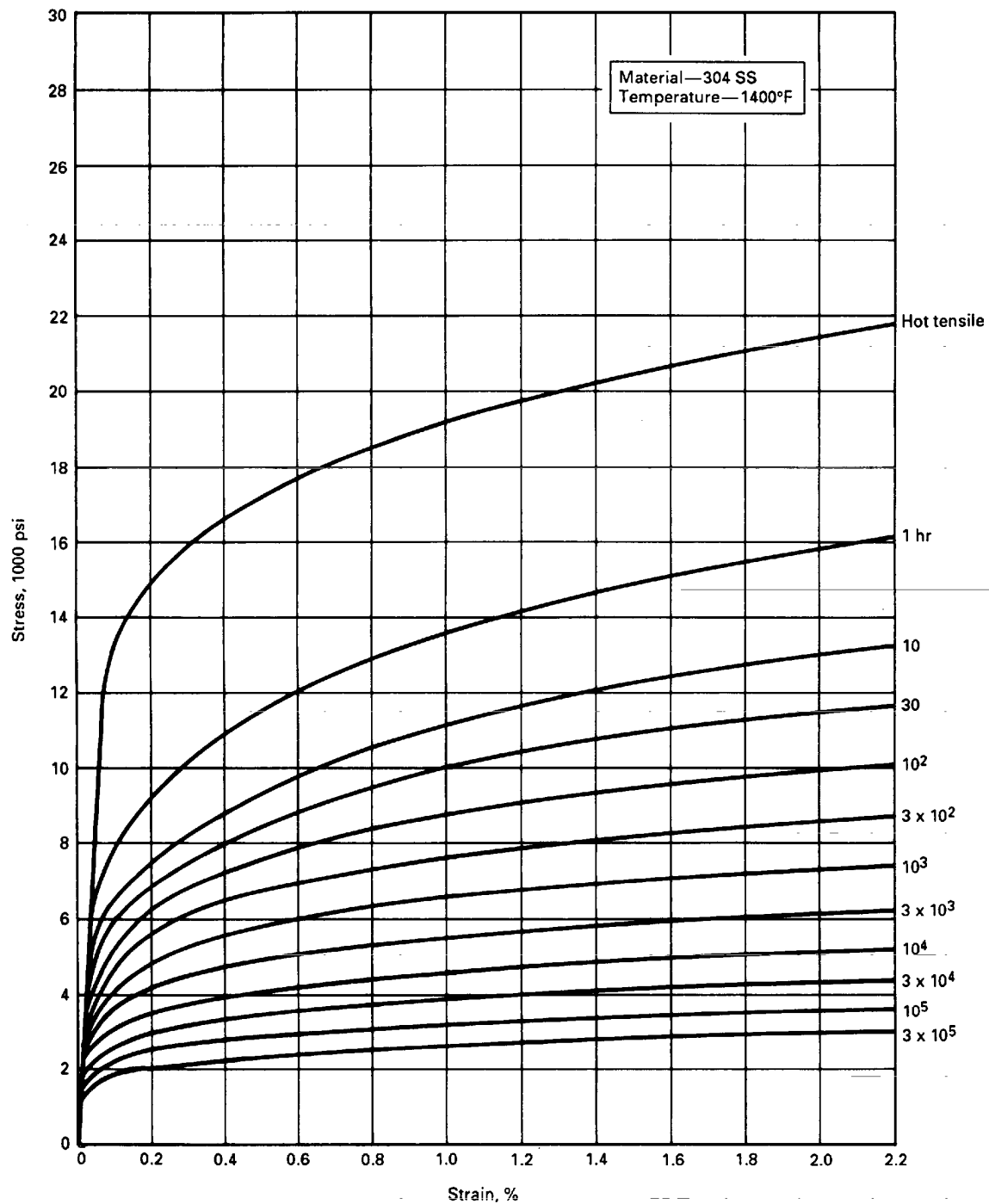


FIG. T-1800-A-13 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

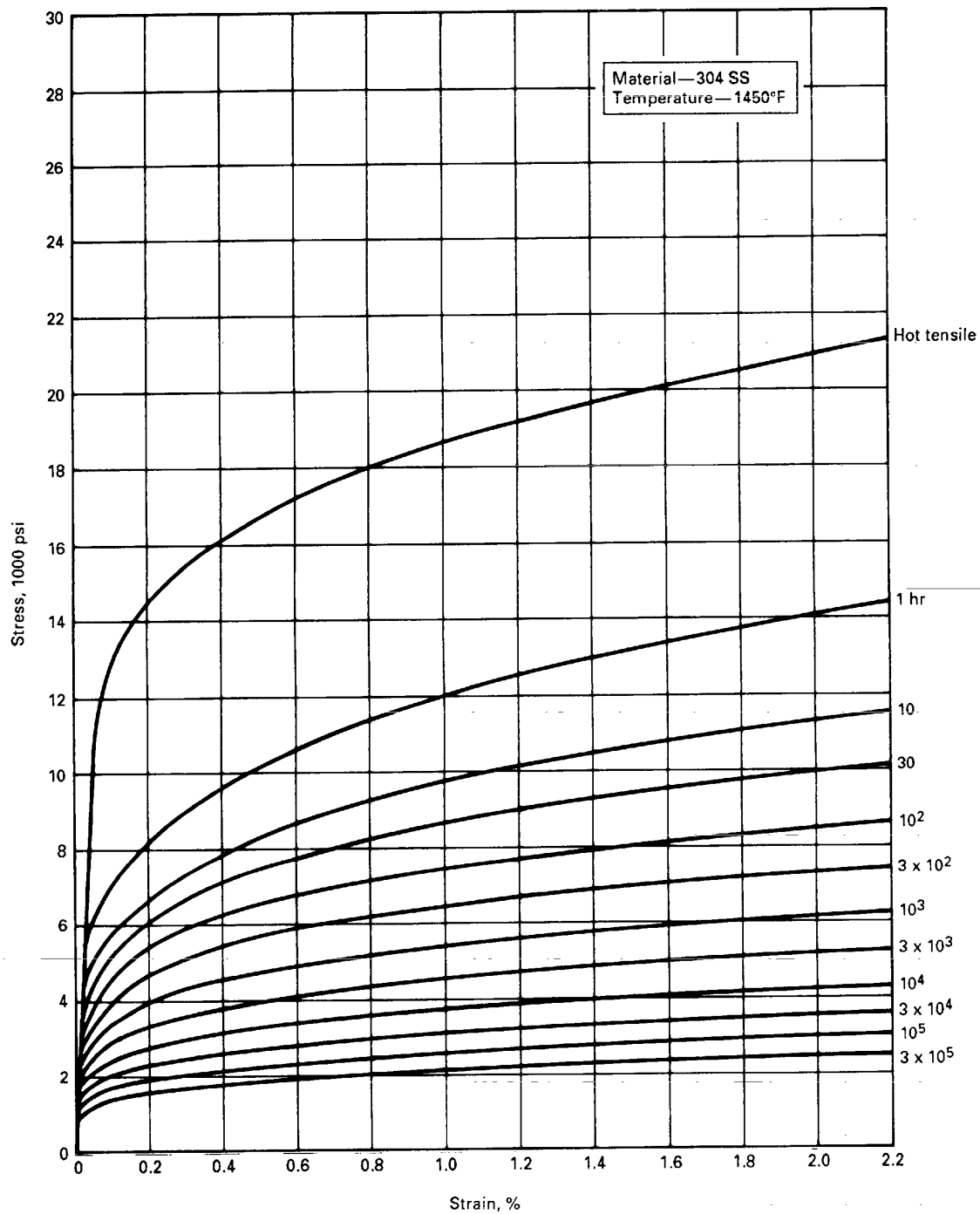


FIG. T-1800-A-14 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

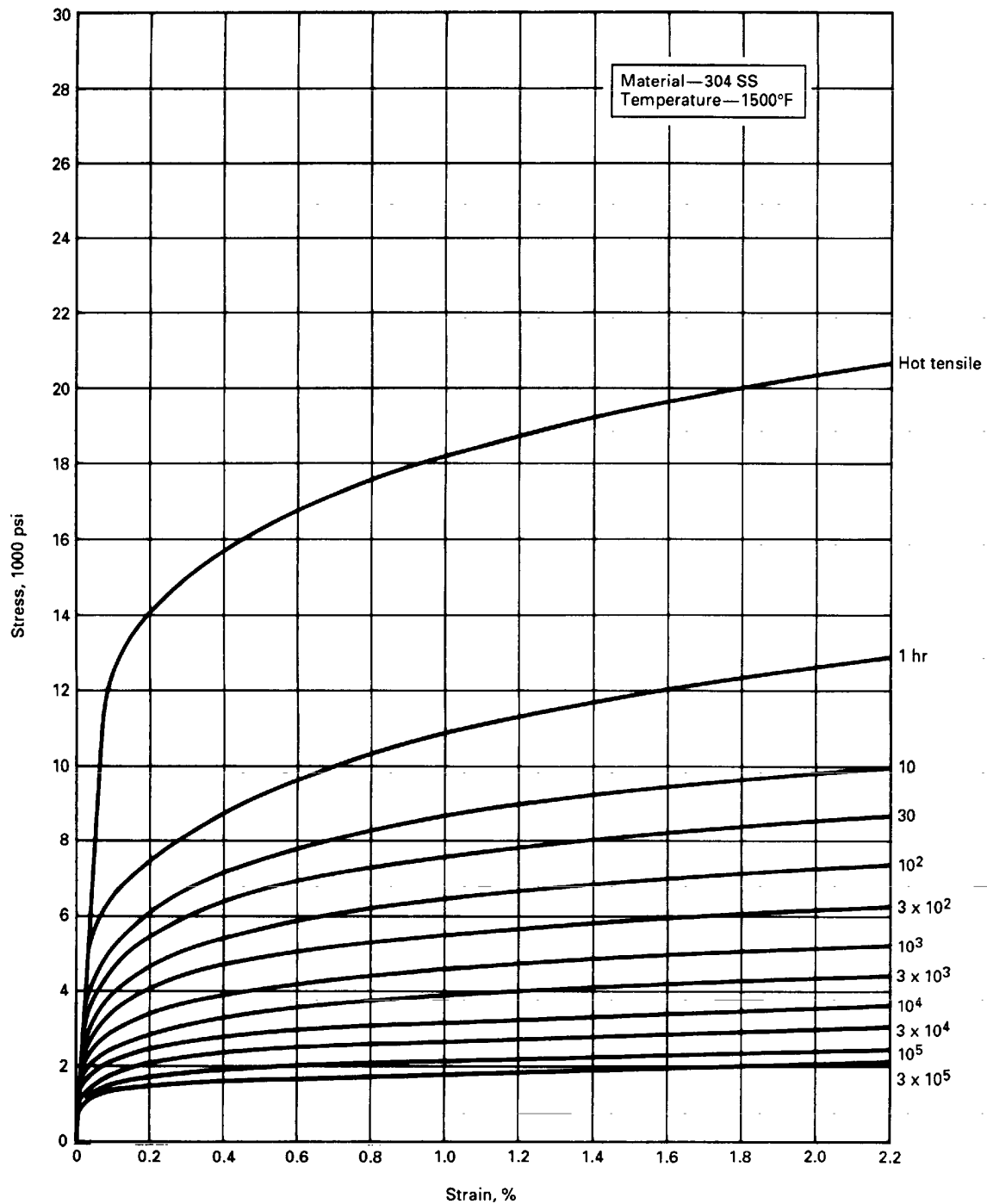


FIG. T-1800-A-15 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

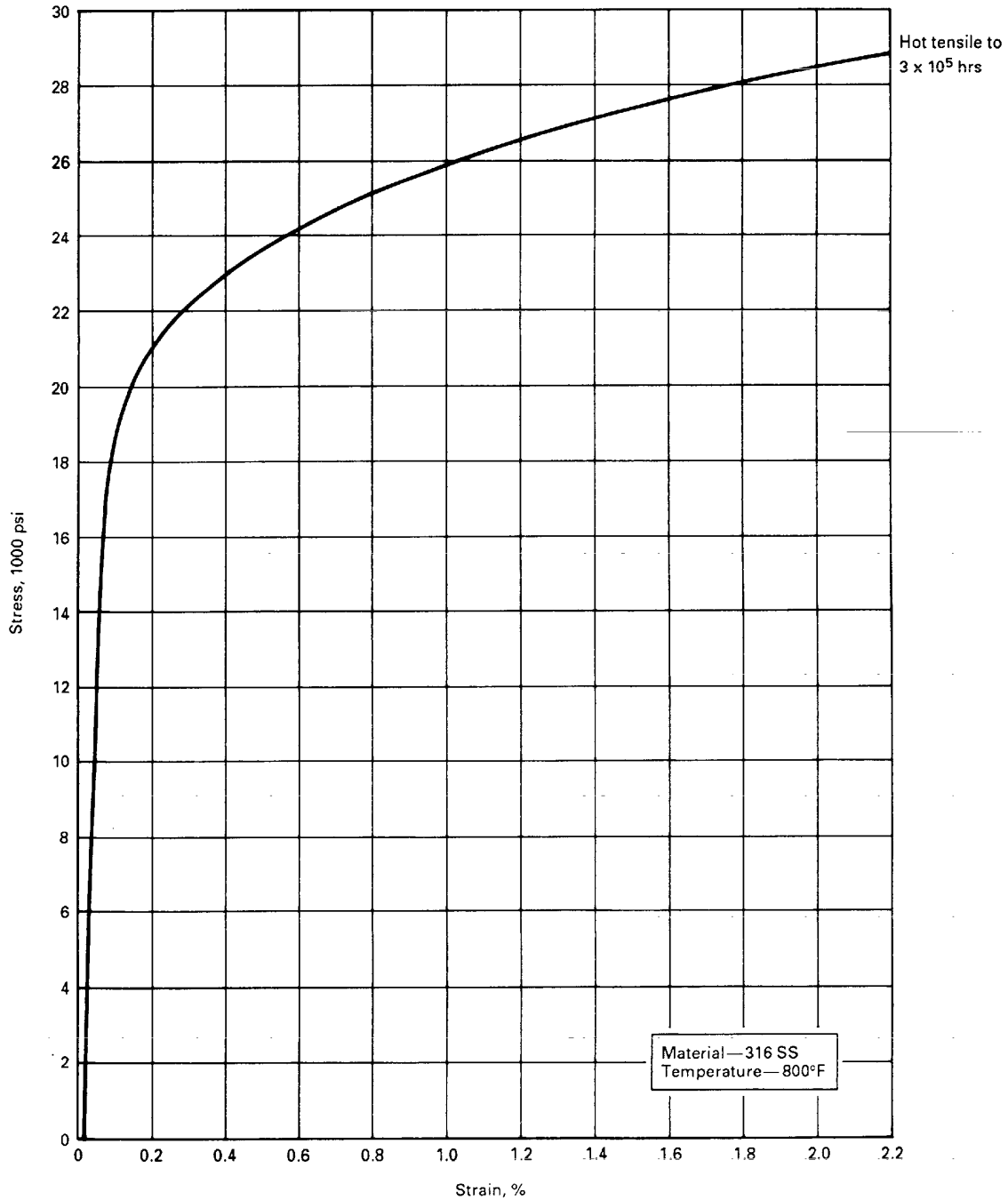


FIG. T-1800-B-1 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

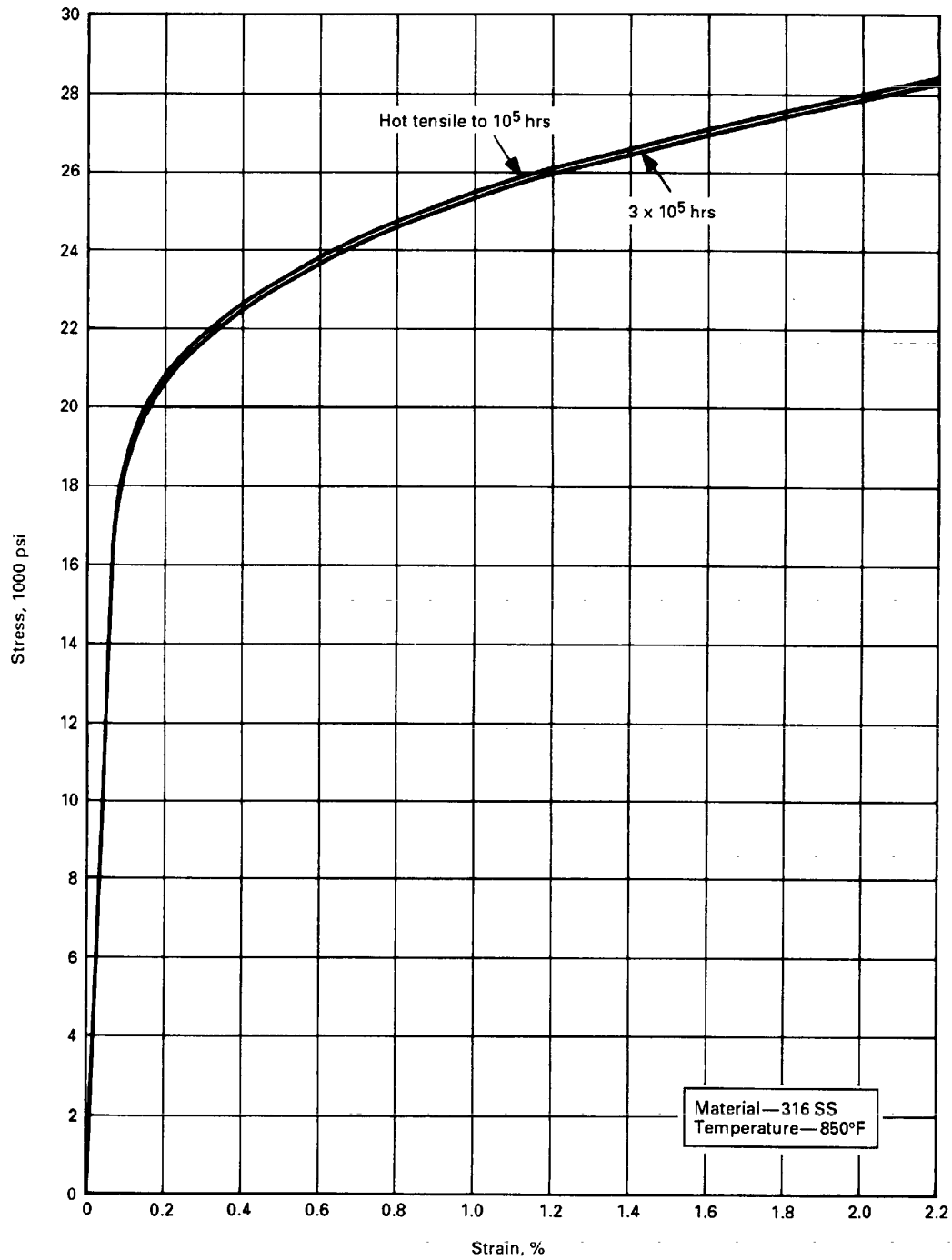


FIG. T-1800-B-2 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

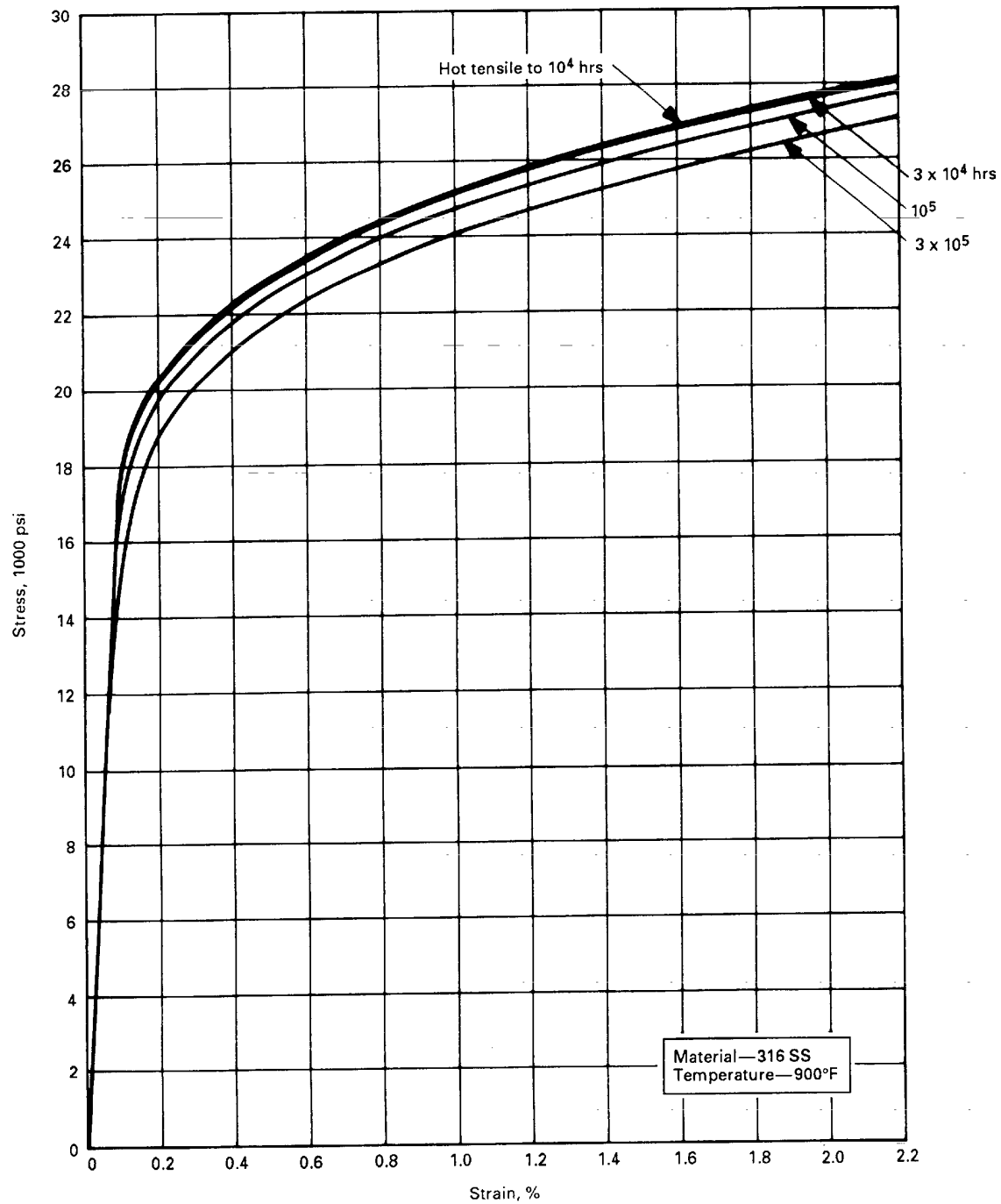


FIG. T-1800-B-3 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

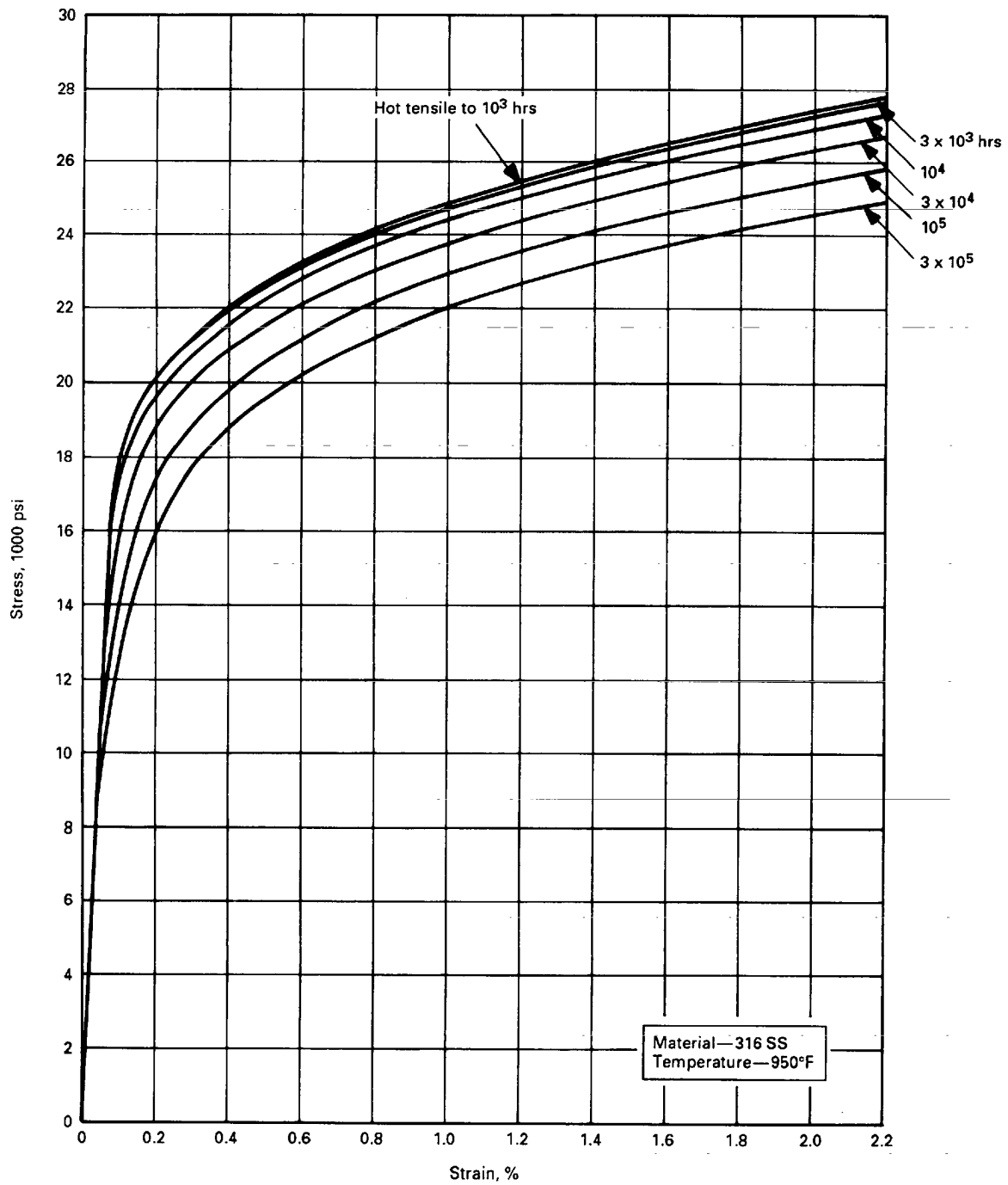


FIG. T-1800-B-4 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

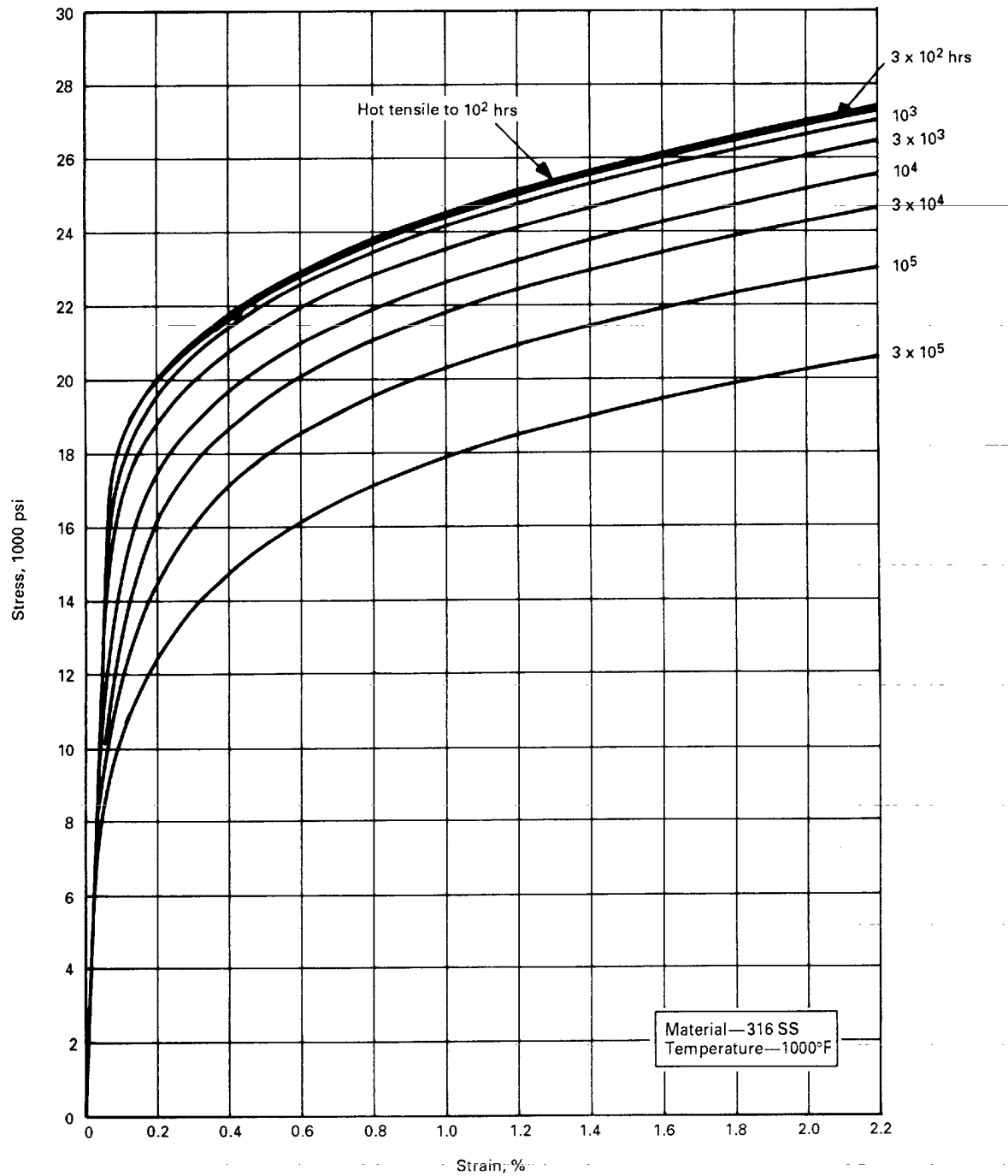


FIG. T-1800-B-5 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

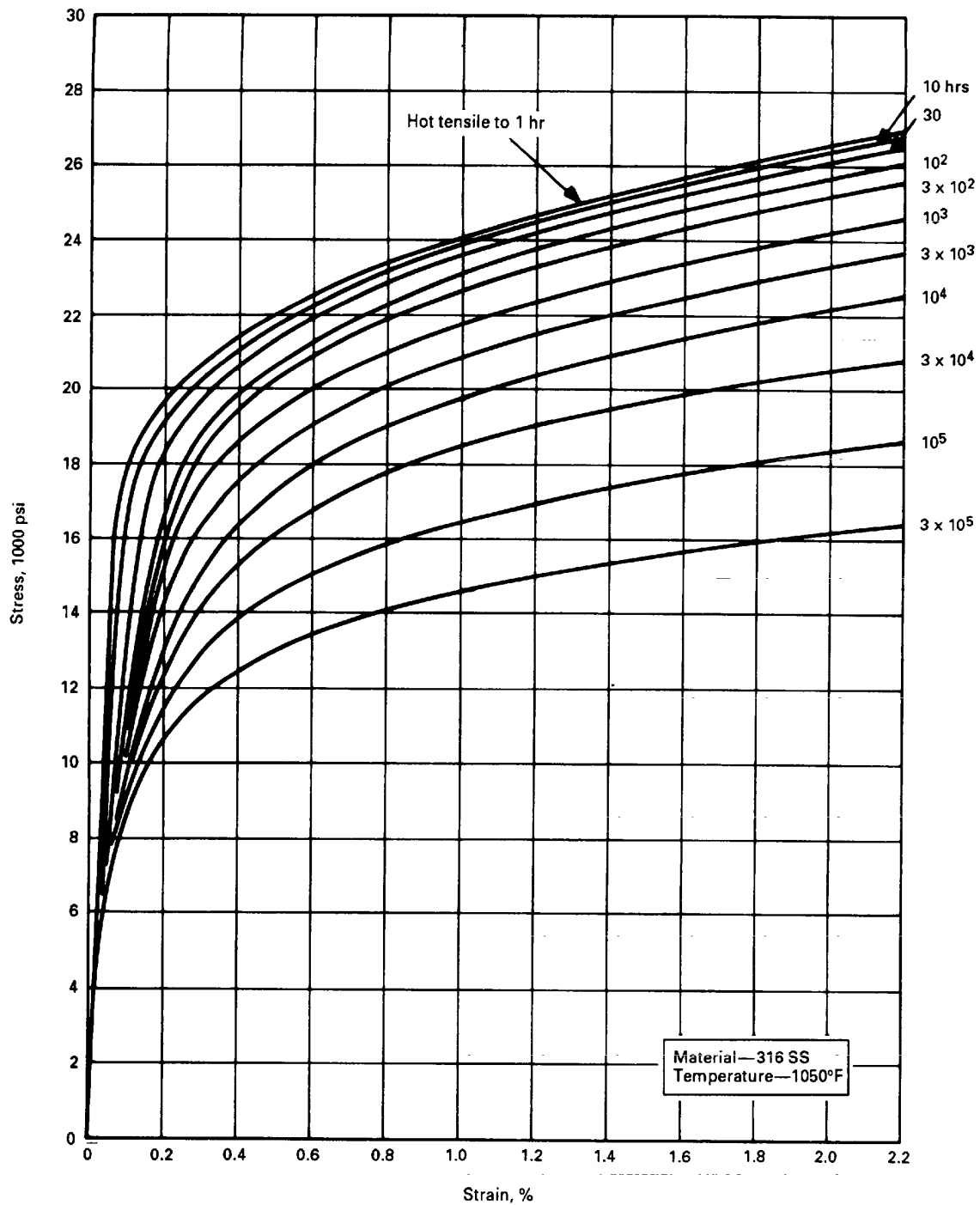


FIG. T-1800-B-6 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

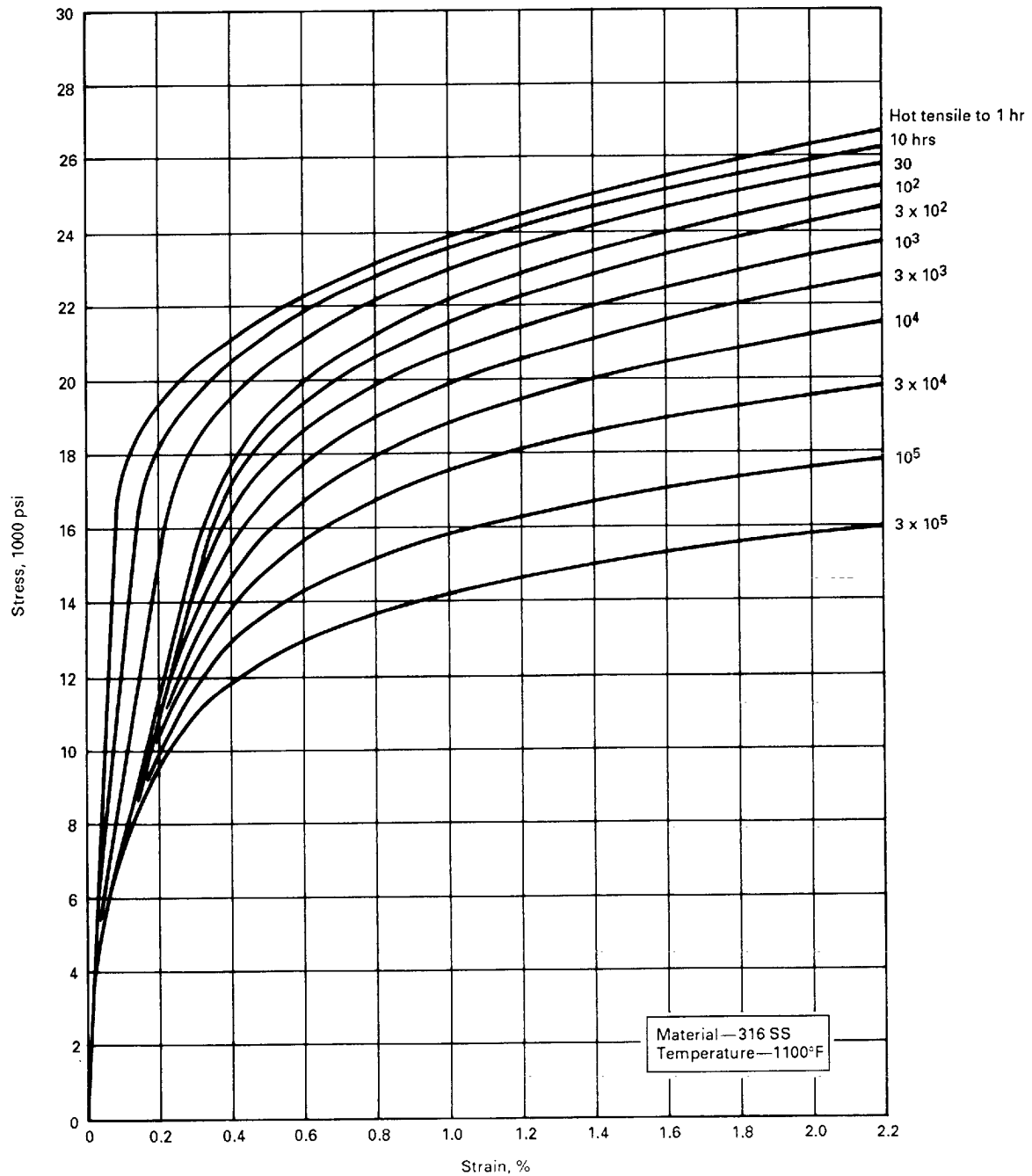


FIG. T-1800-B-7 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

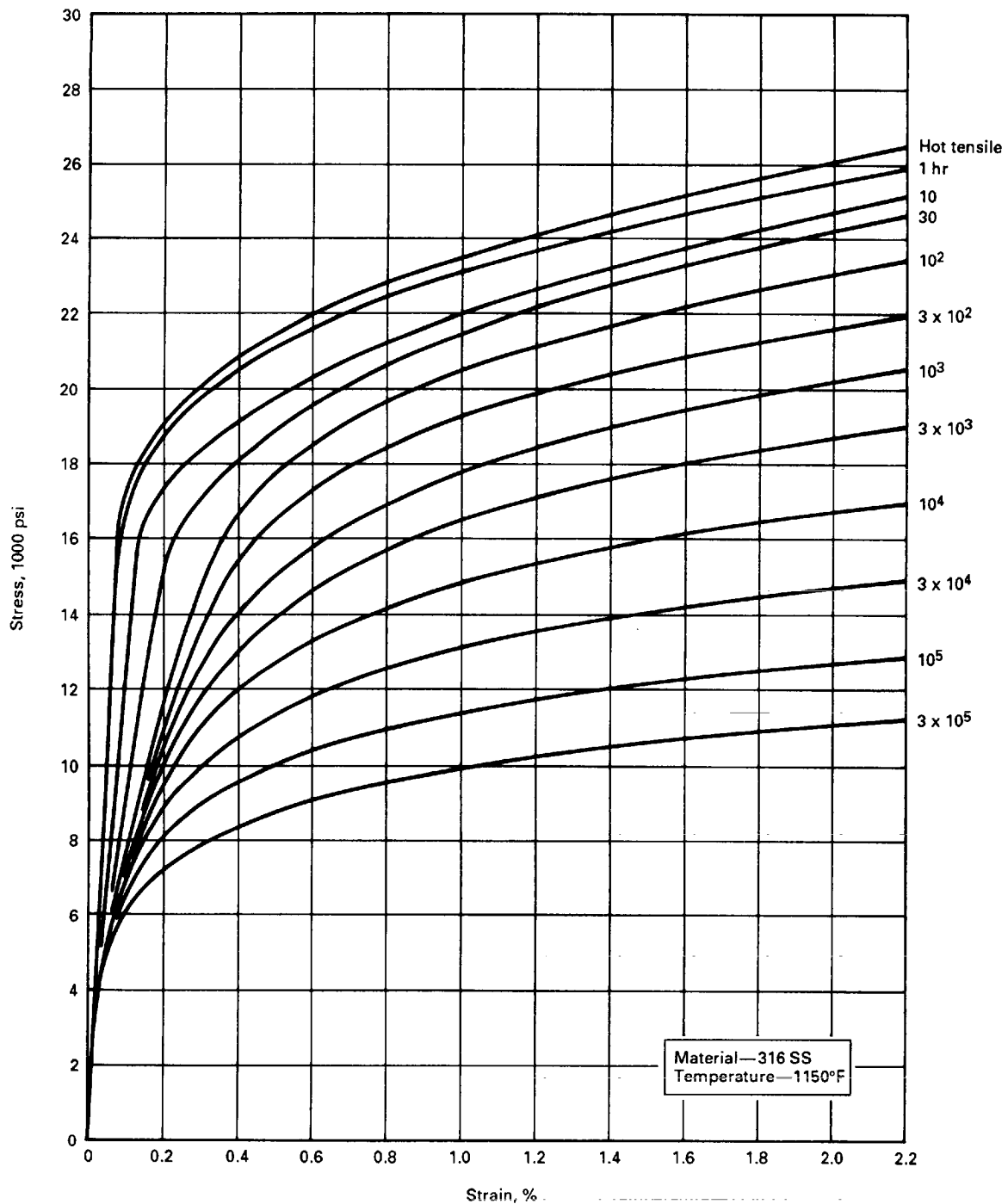


FIG. T-1800-B-8 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

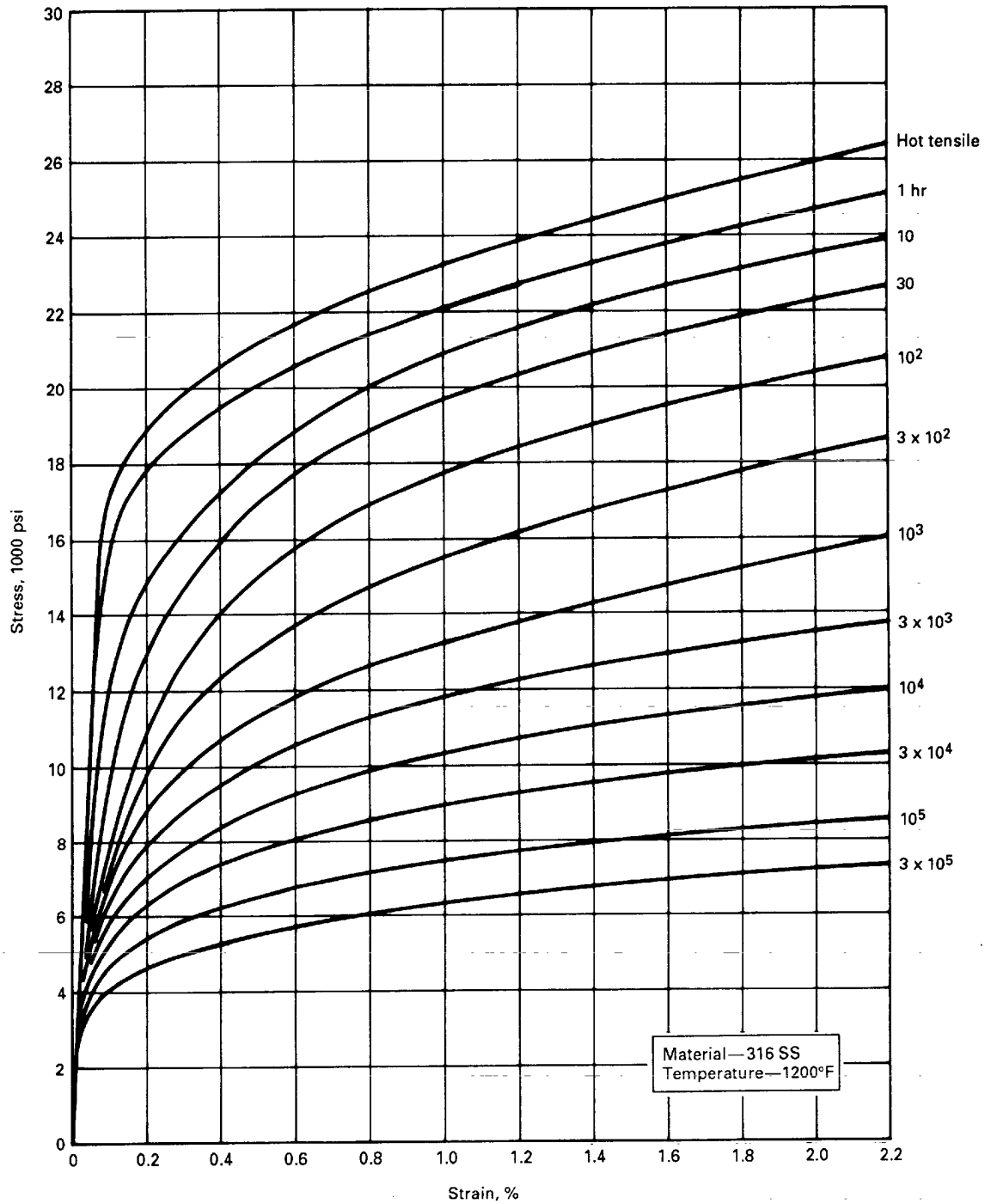


FIG. T-1800-B-9 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

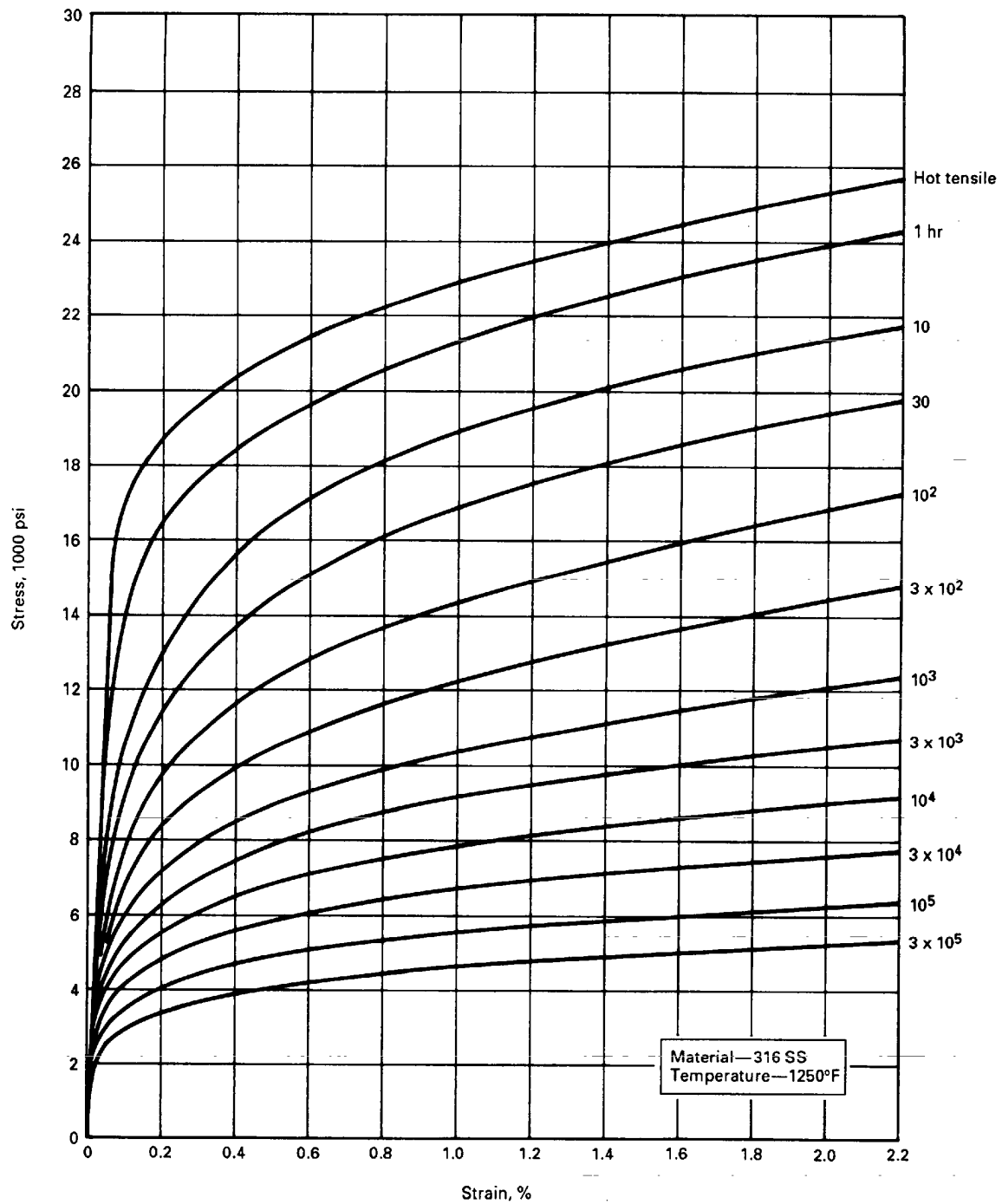


FIG. T-1800-B-10 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

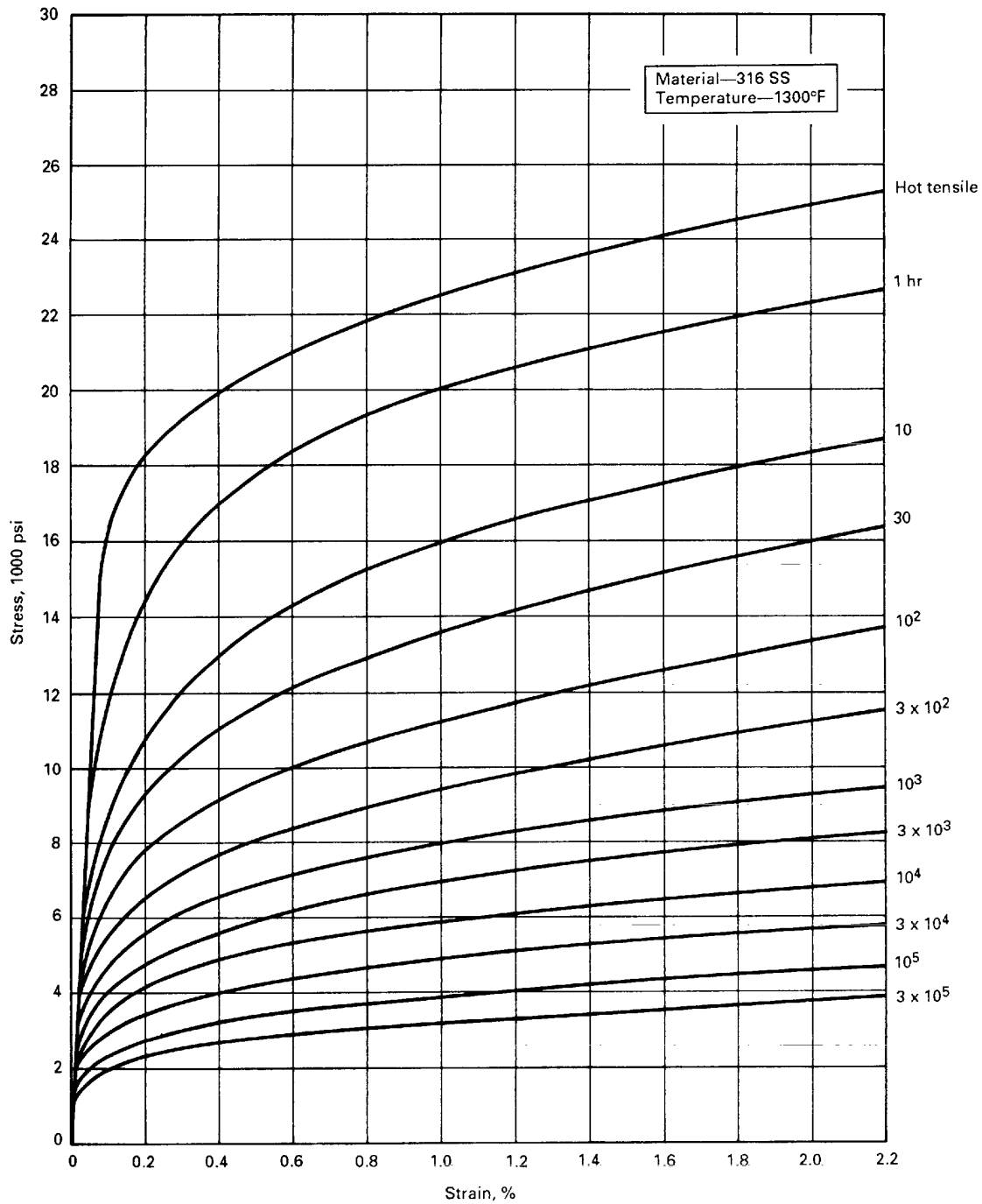


FIG. T-1800-B-11 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

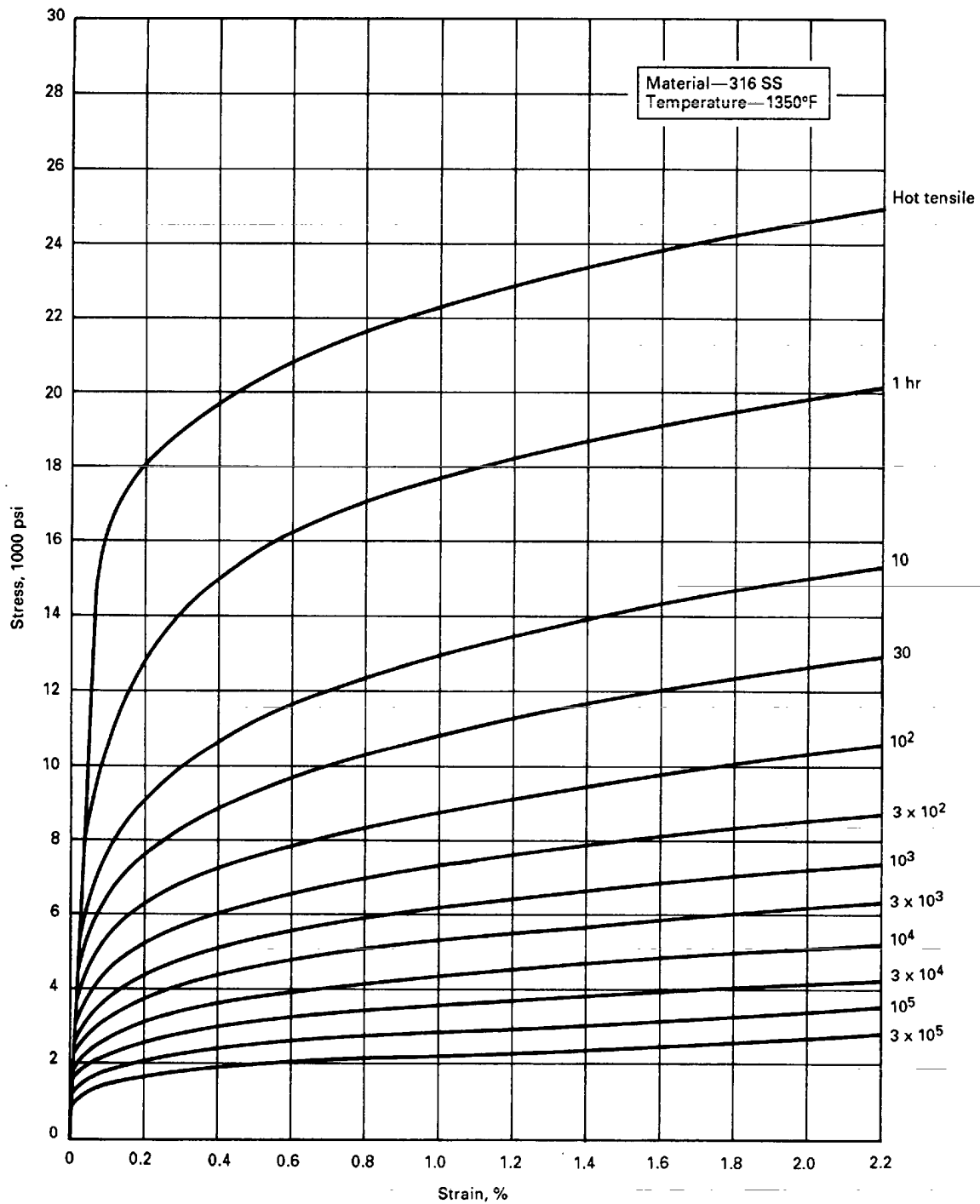


FIG. T-1800-B-12 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

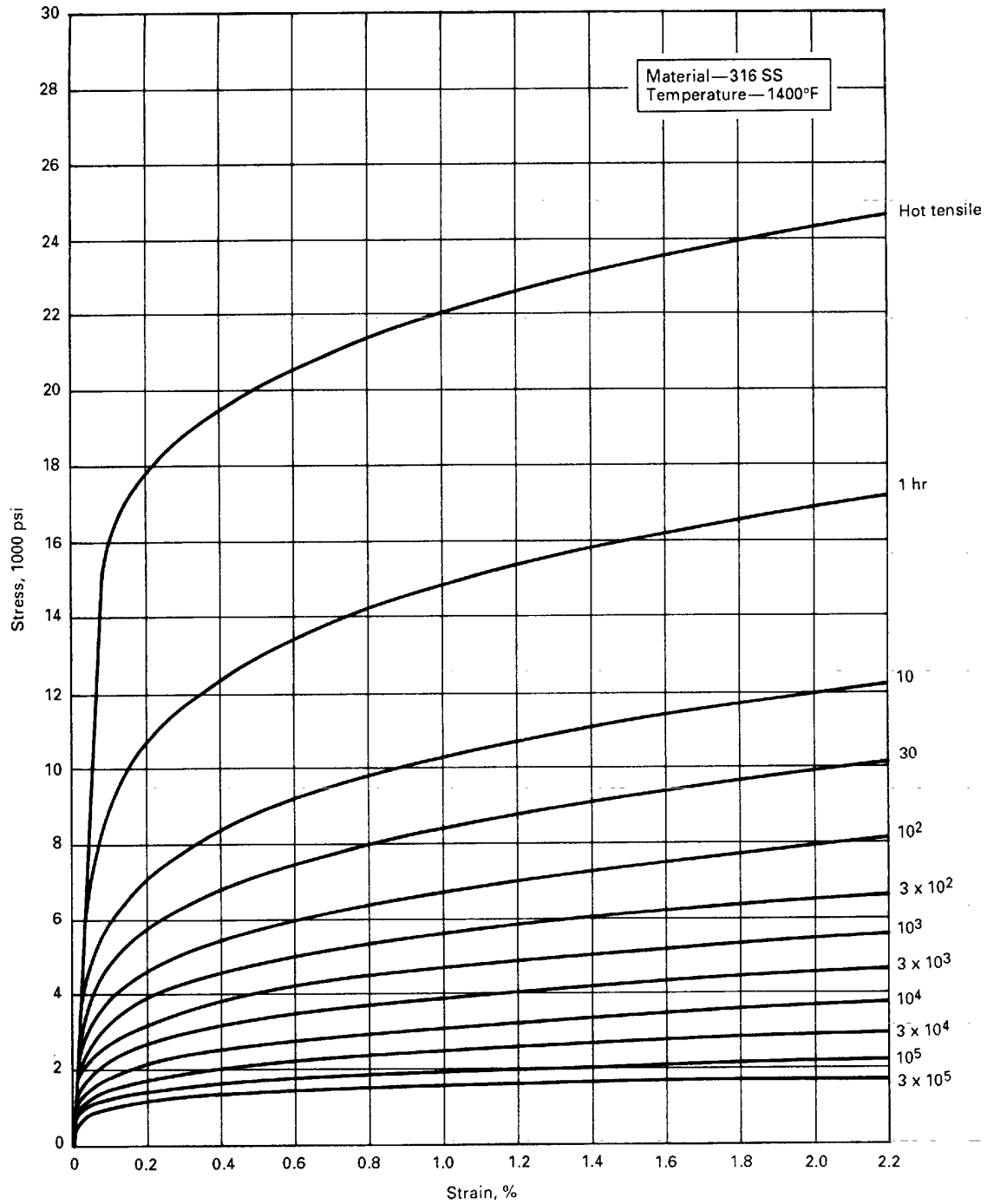


FIG. T-1800-B-13 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

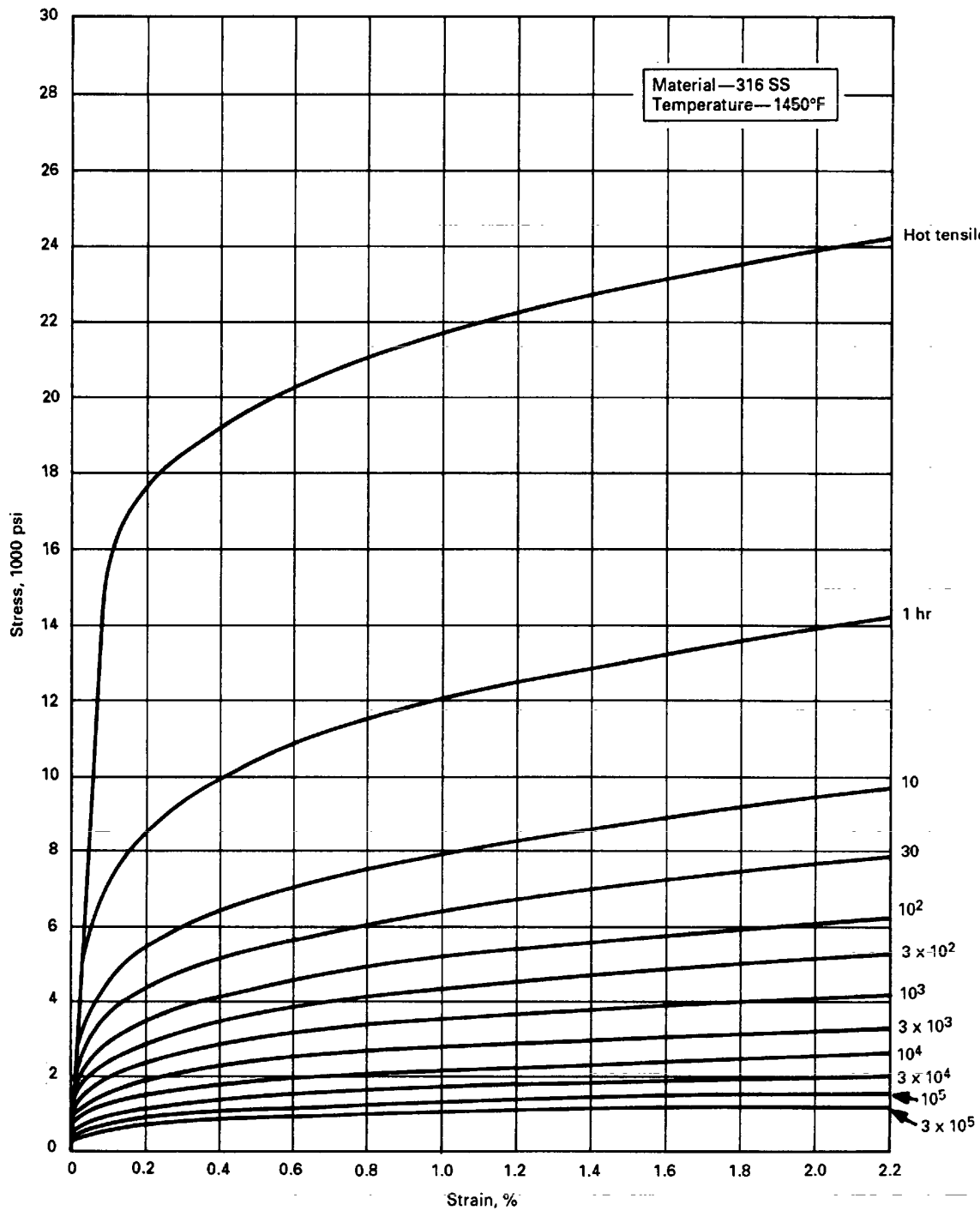


FIG. T-1800-B-14 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

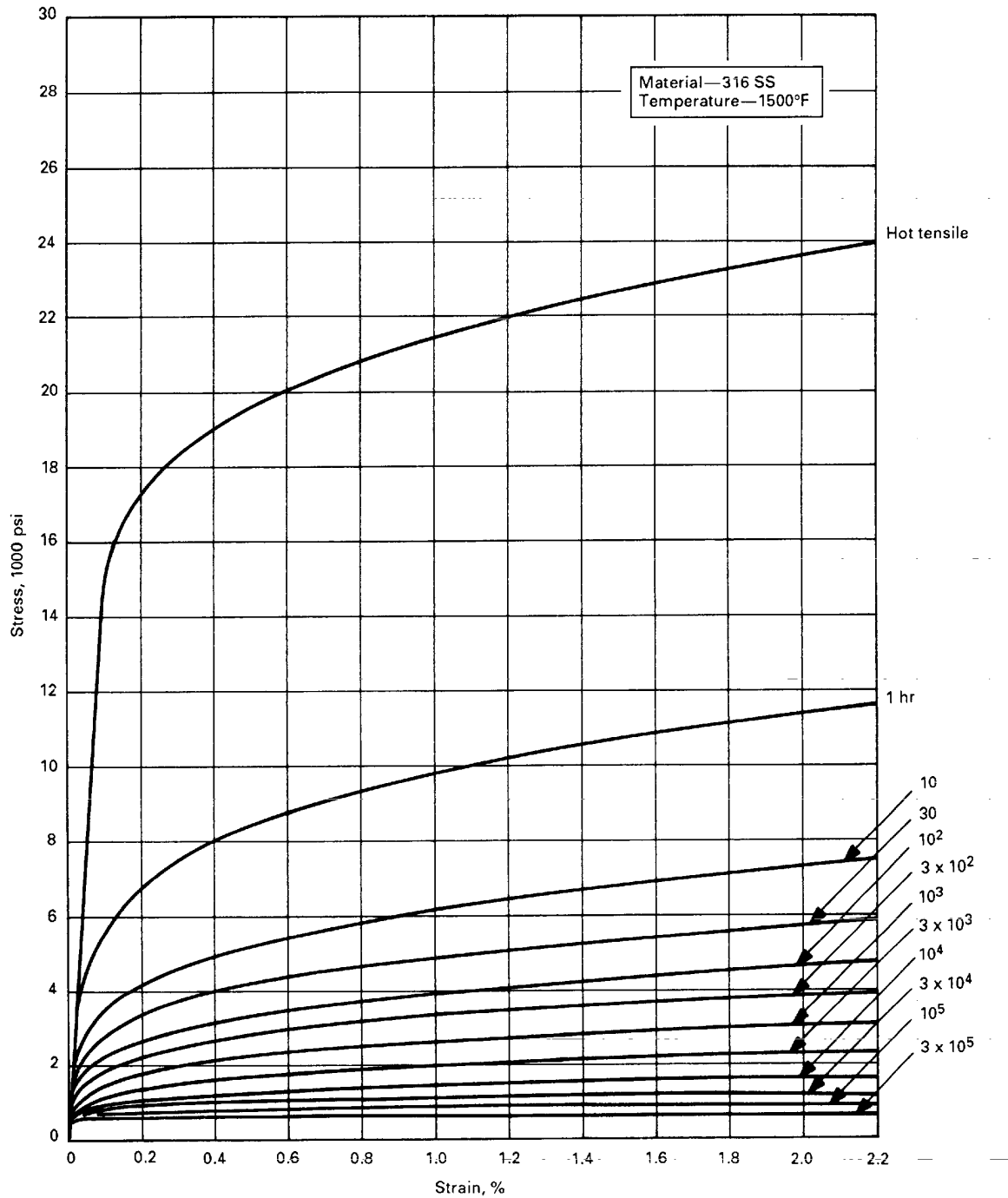


FIG. T-1800-B-15 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

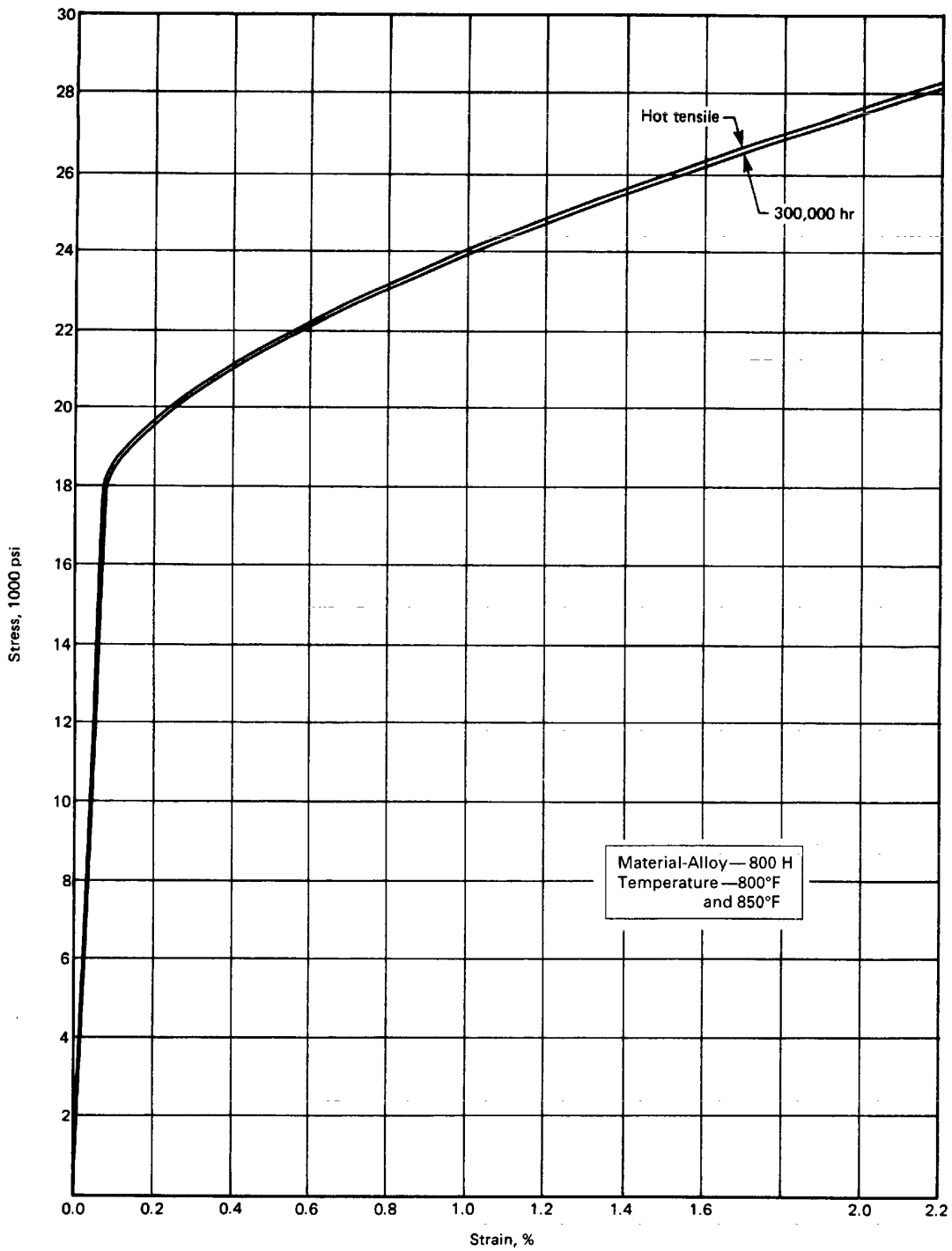


FIG. T-1800-C-1 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

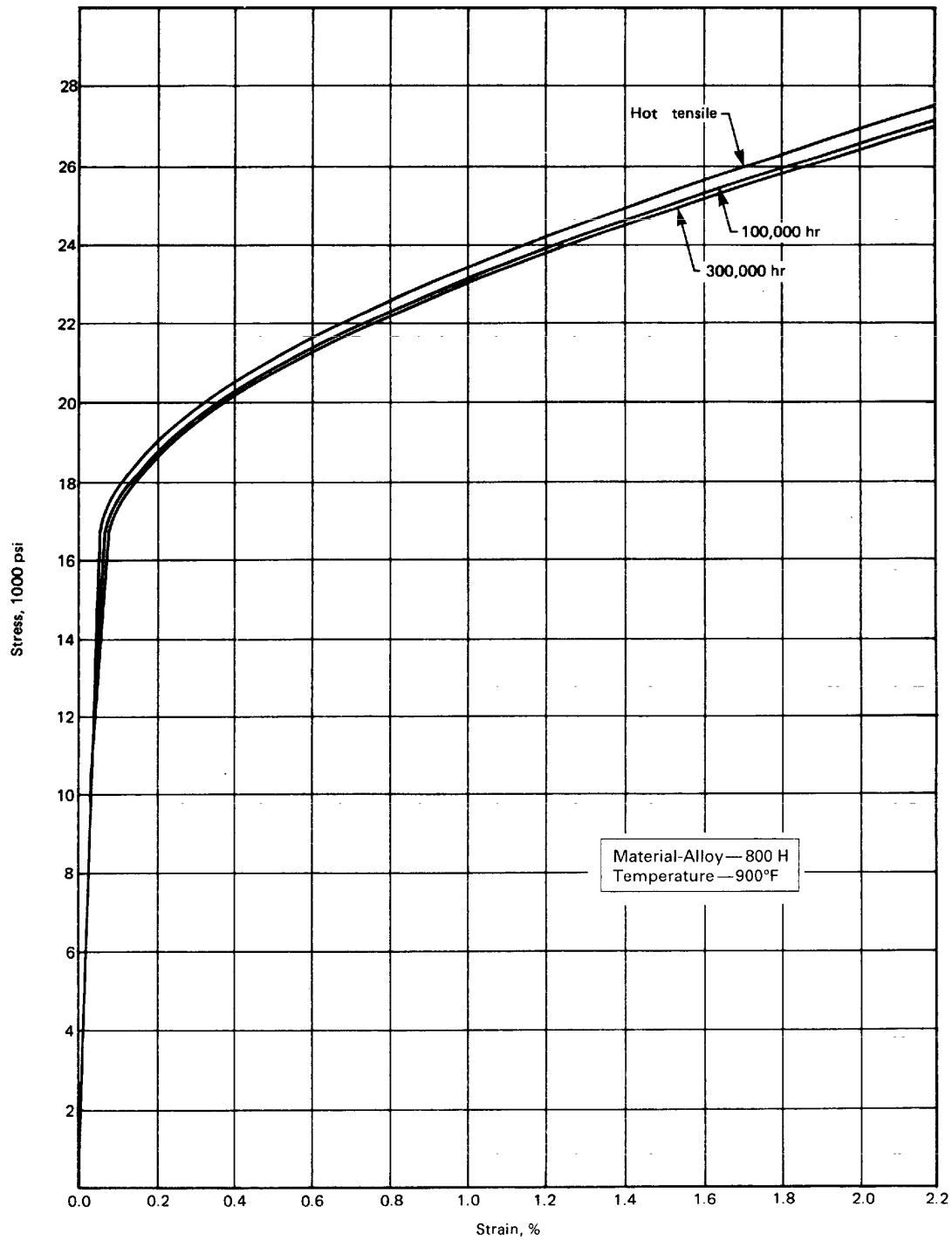


FIG. T-1800-C-2 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

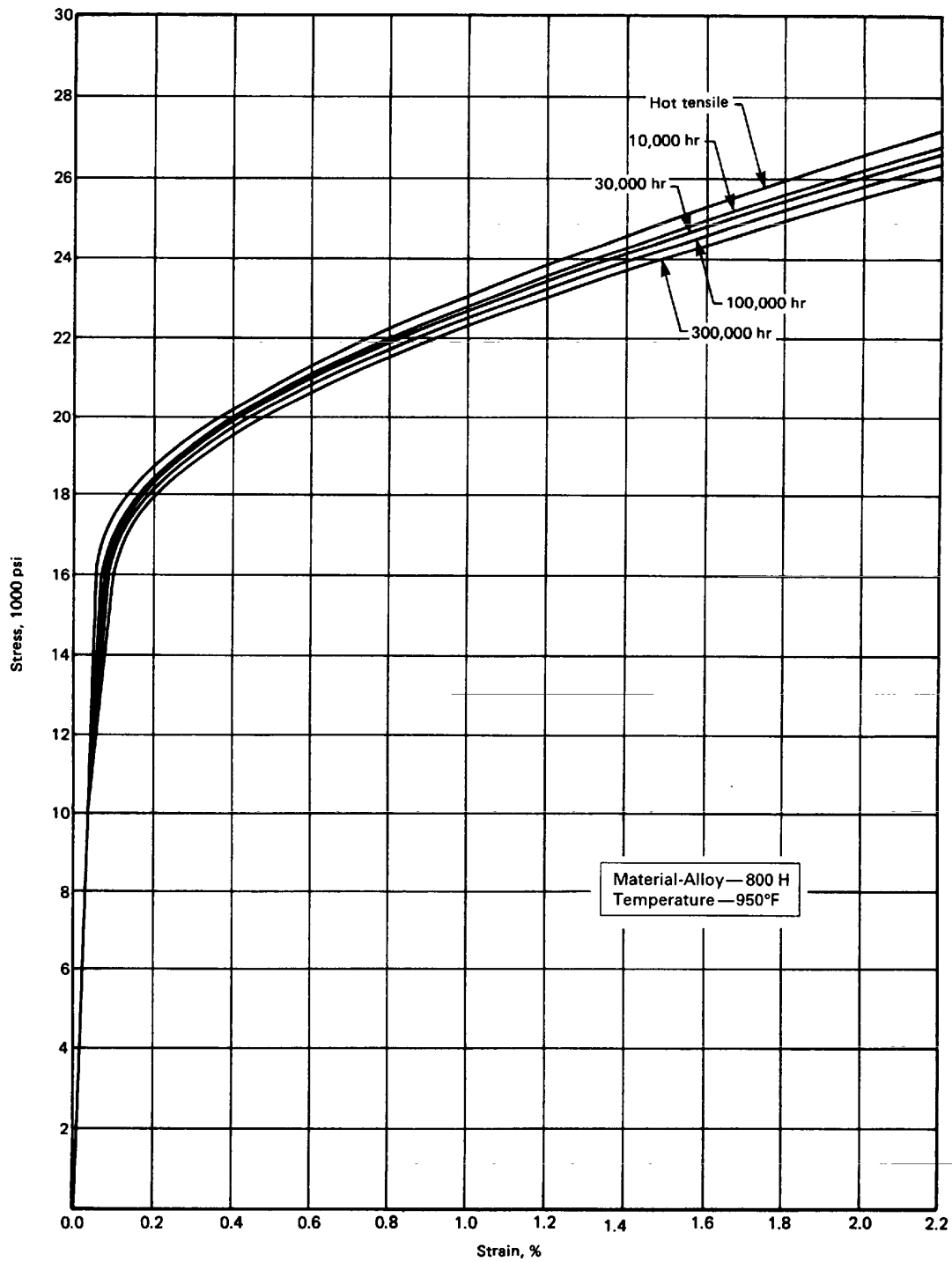


FIG. T-1800-C-3 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

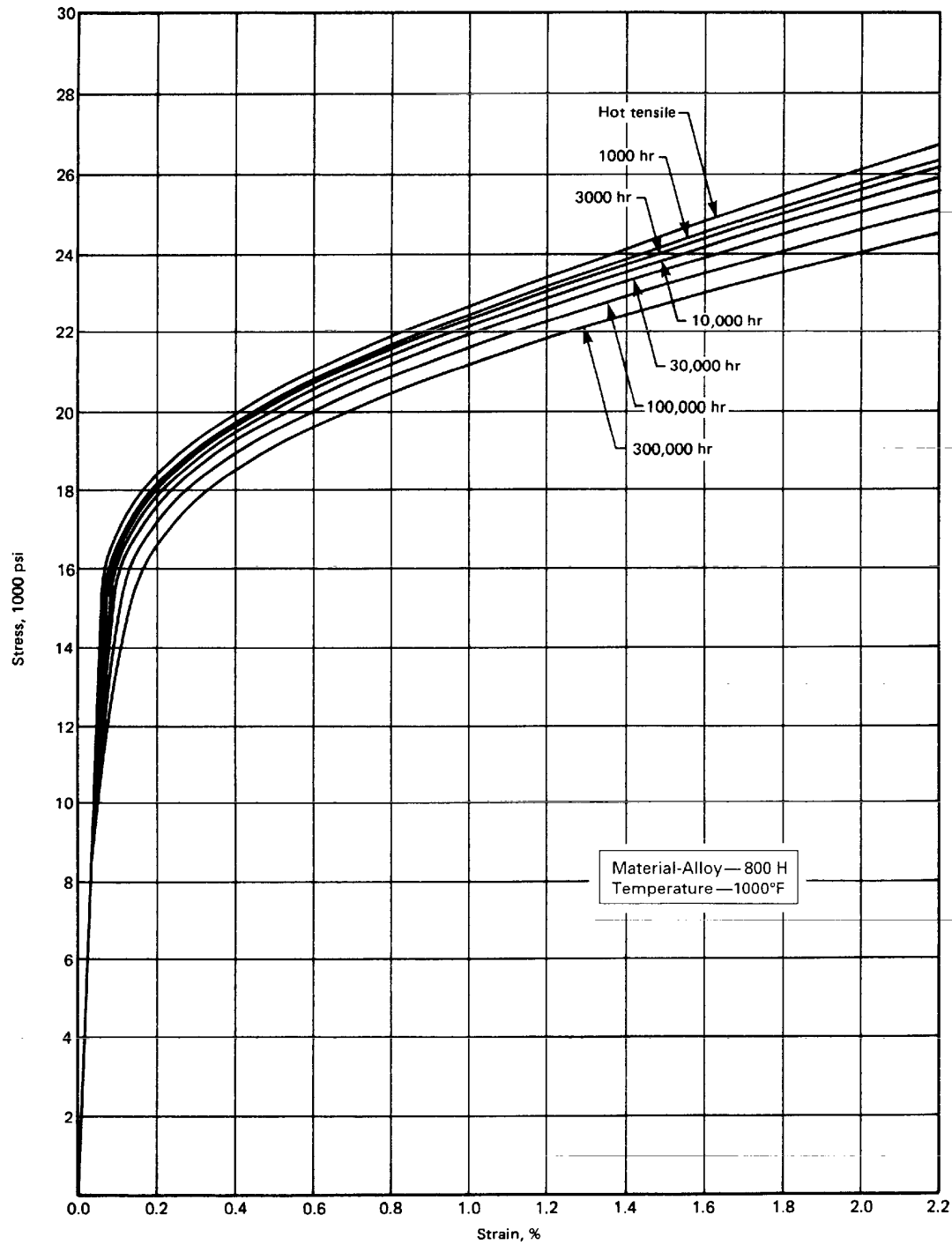


FIG. T-1800-C-4 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

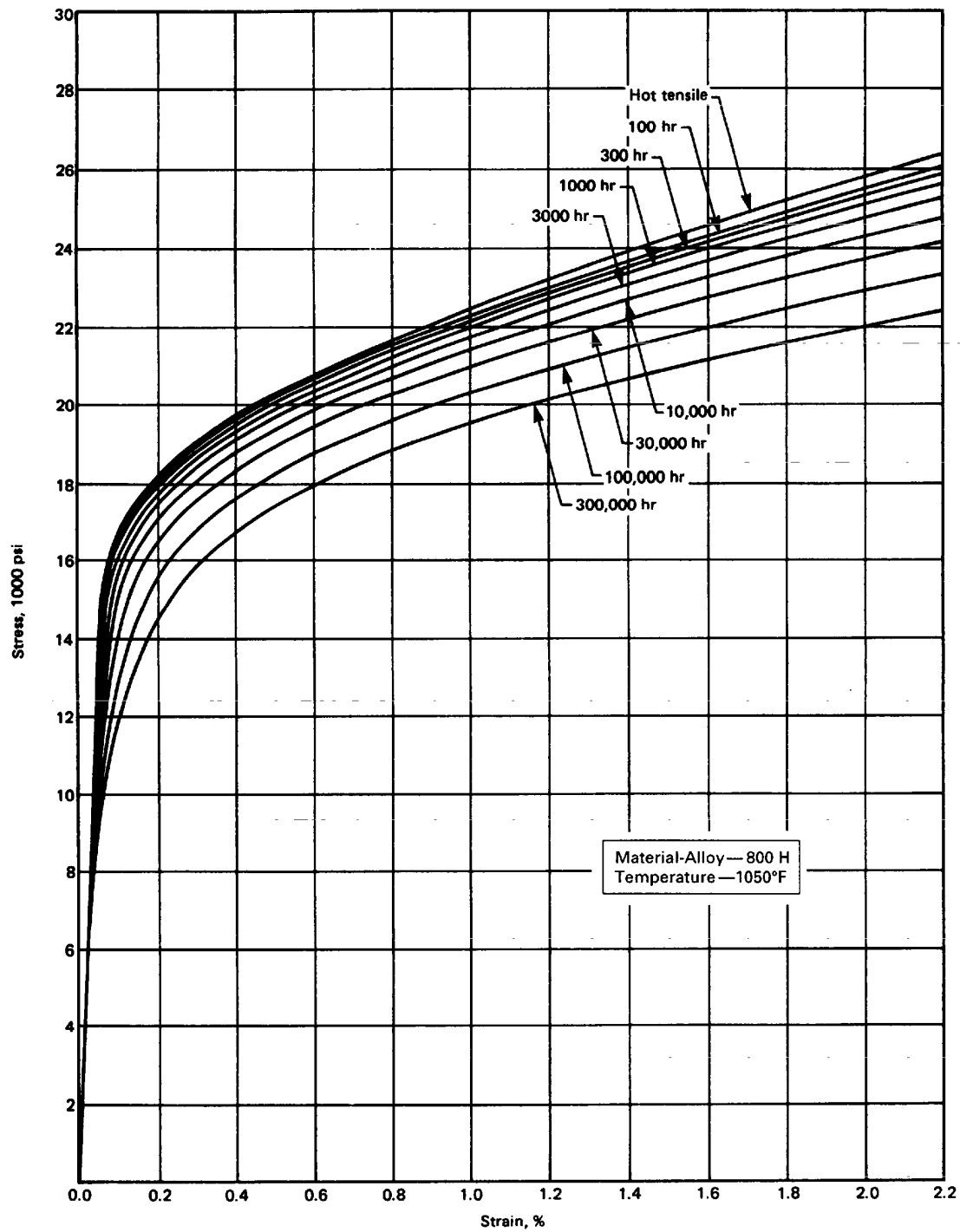


FIG. T-1800-C-5 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

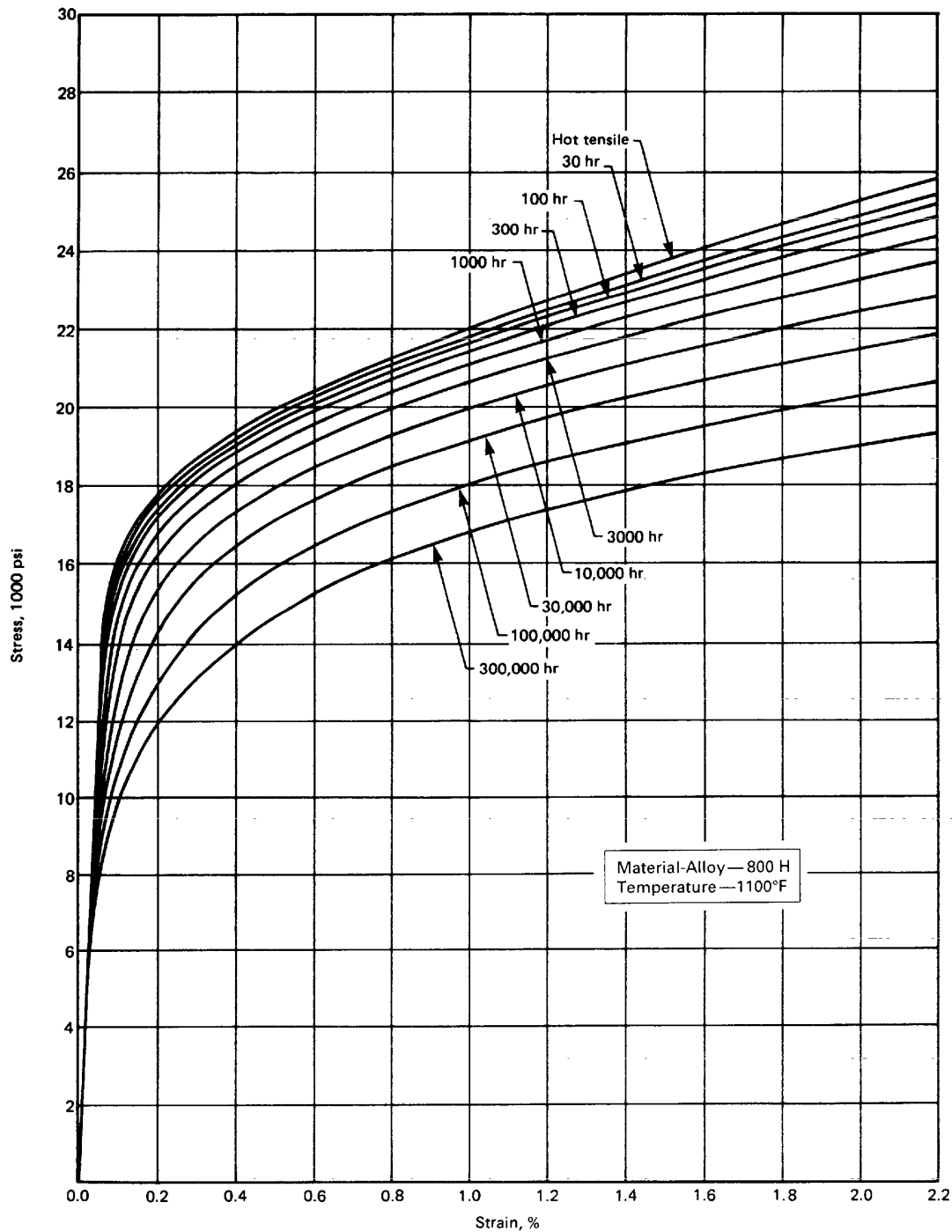


FIG. T-1800-C-6 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

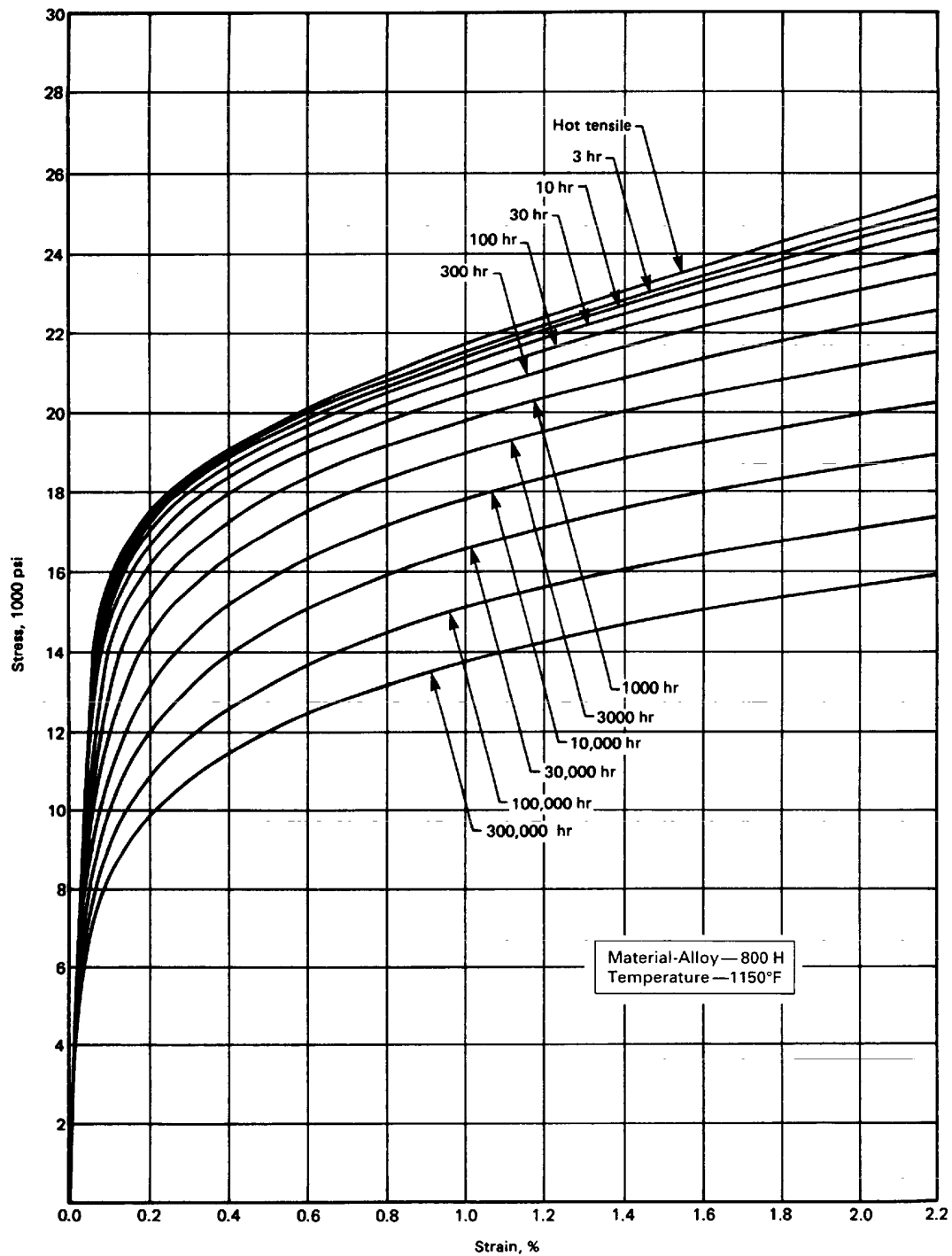


FIG. T-1800-C-7 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

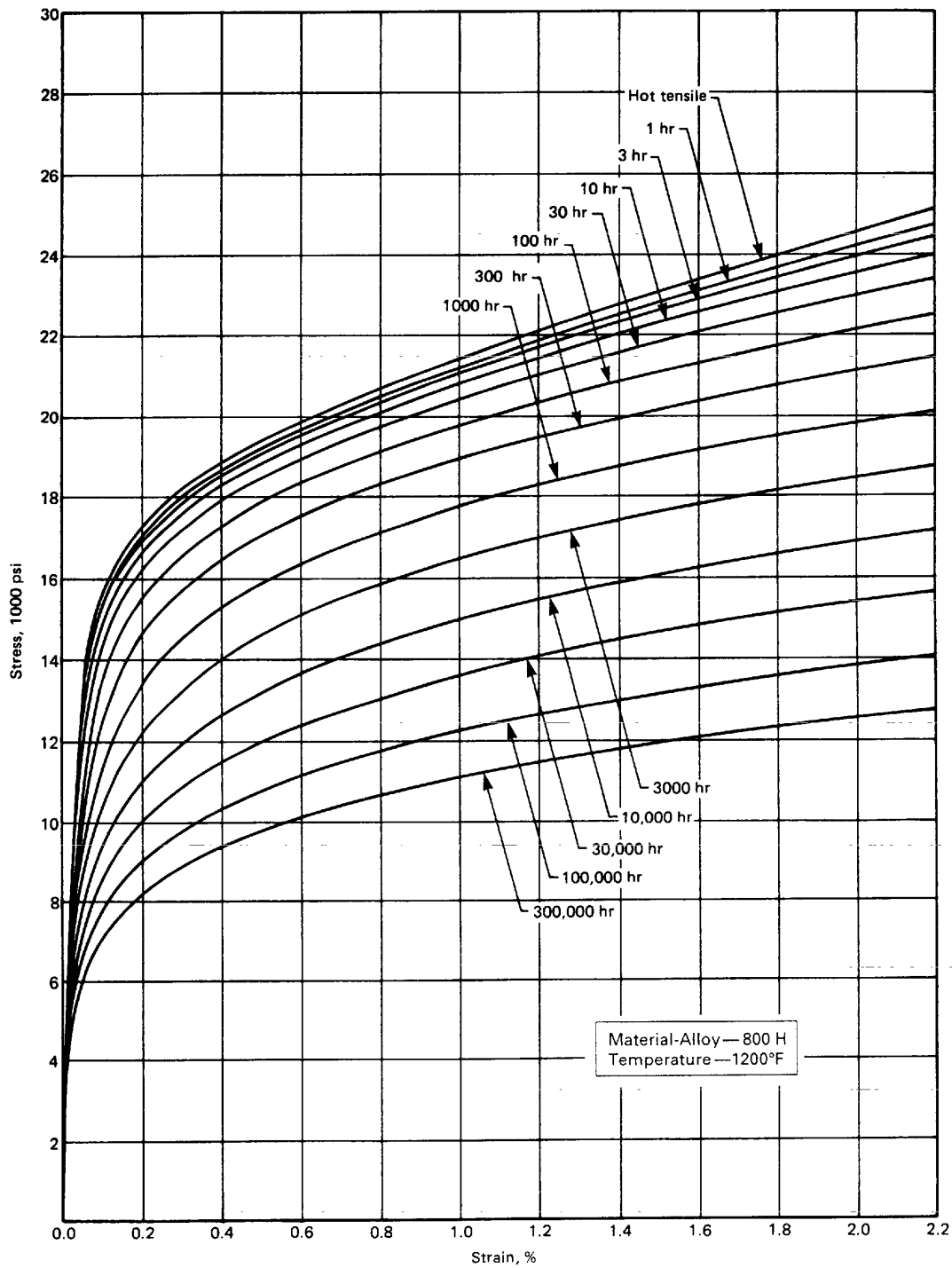


FIG. T-1800-C-8 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

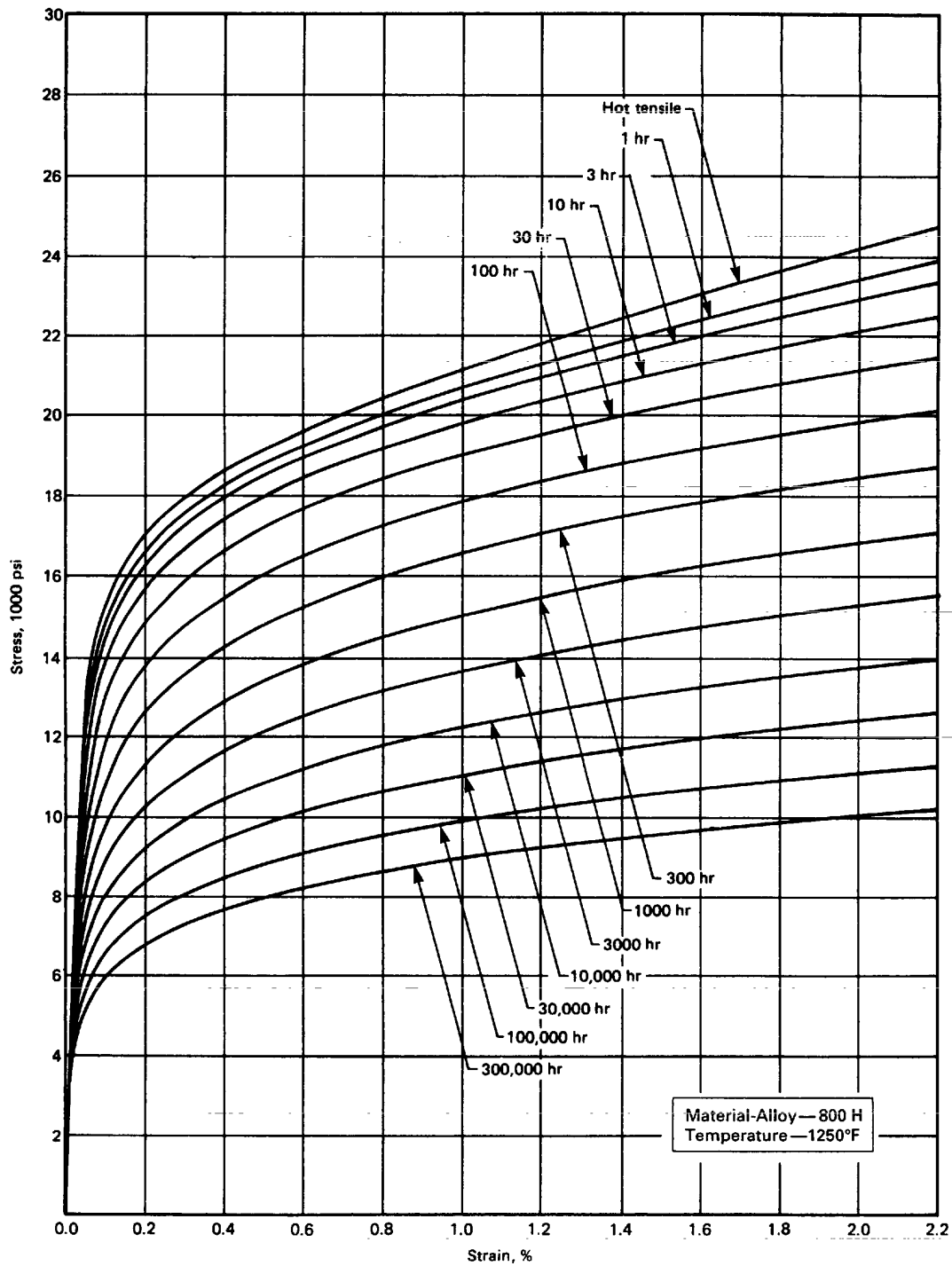


FIG. T-1800-C-9 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

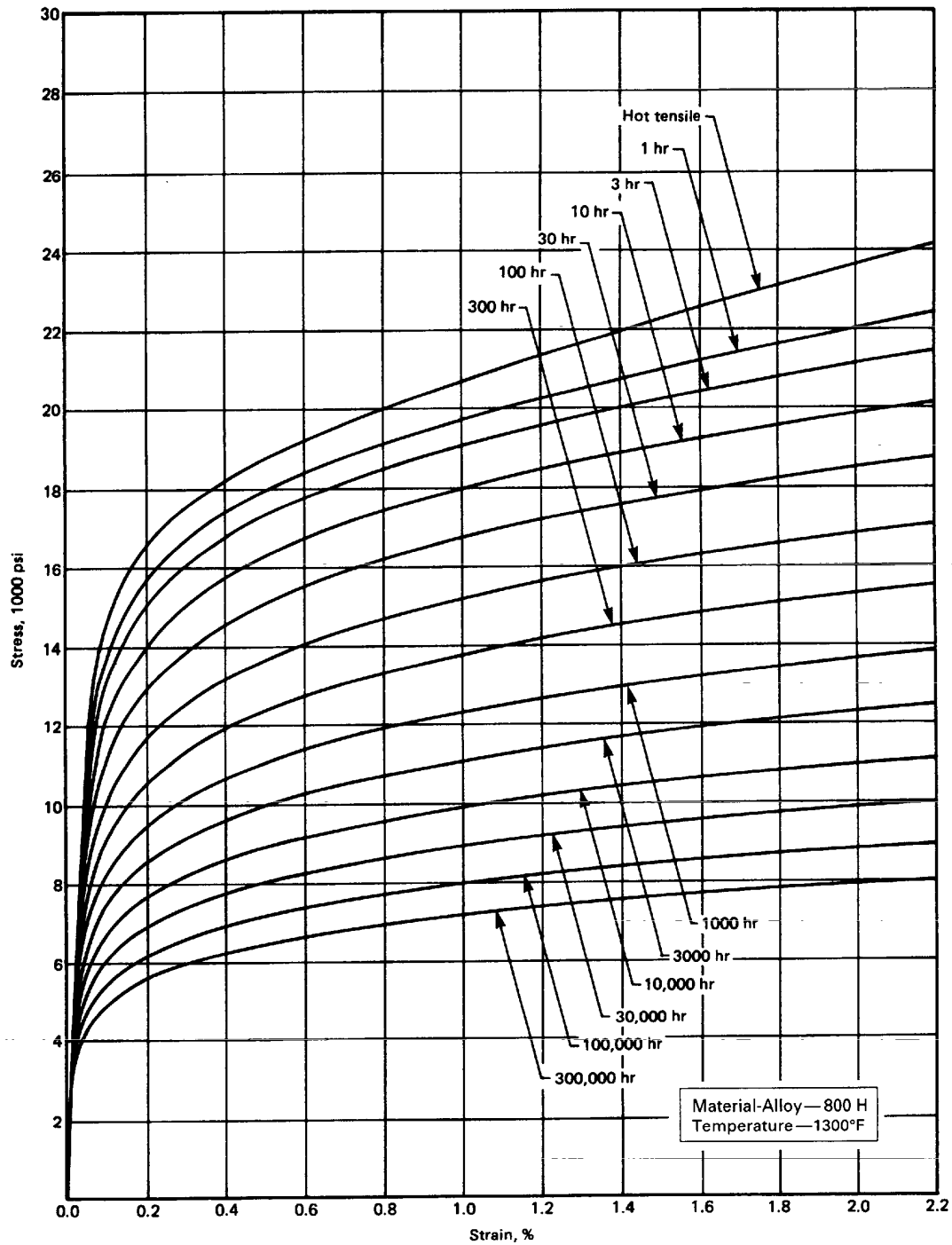


FIG. T-1800-C-10 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

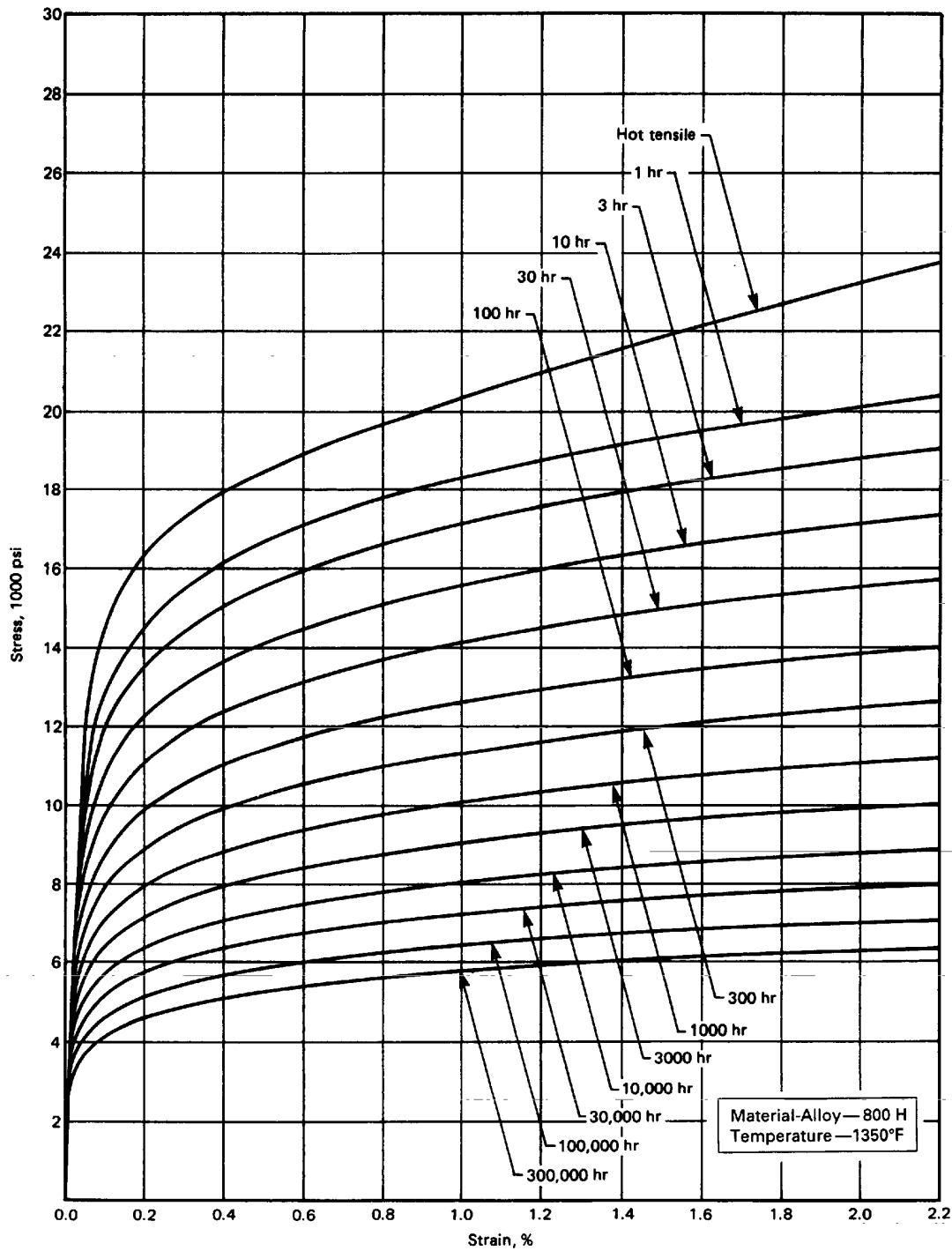


FIG. T-1800-C-11 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

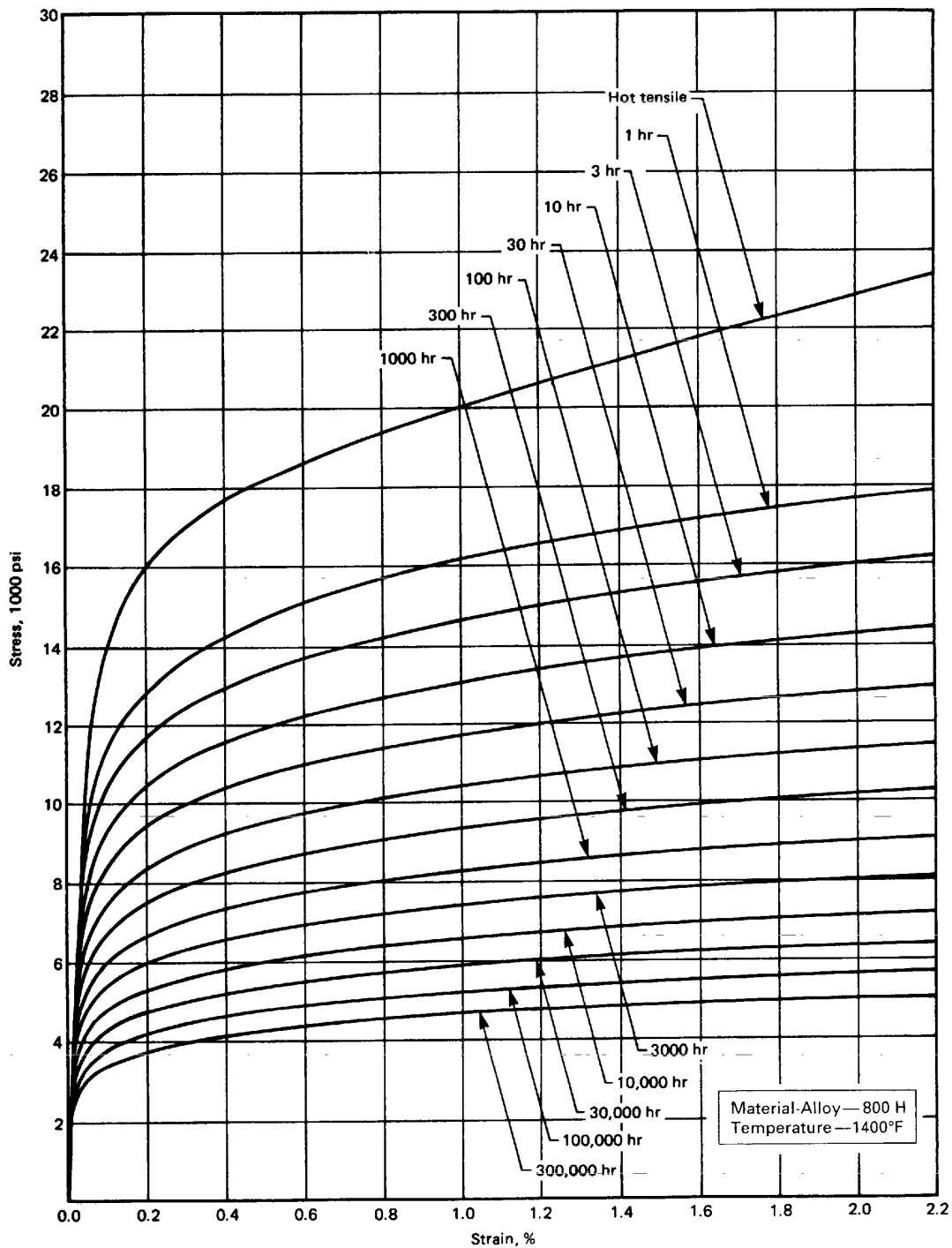


FIG. T-1800-C-12 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

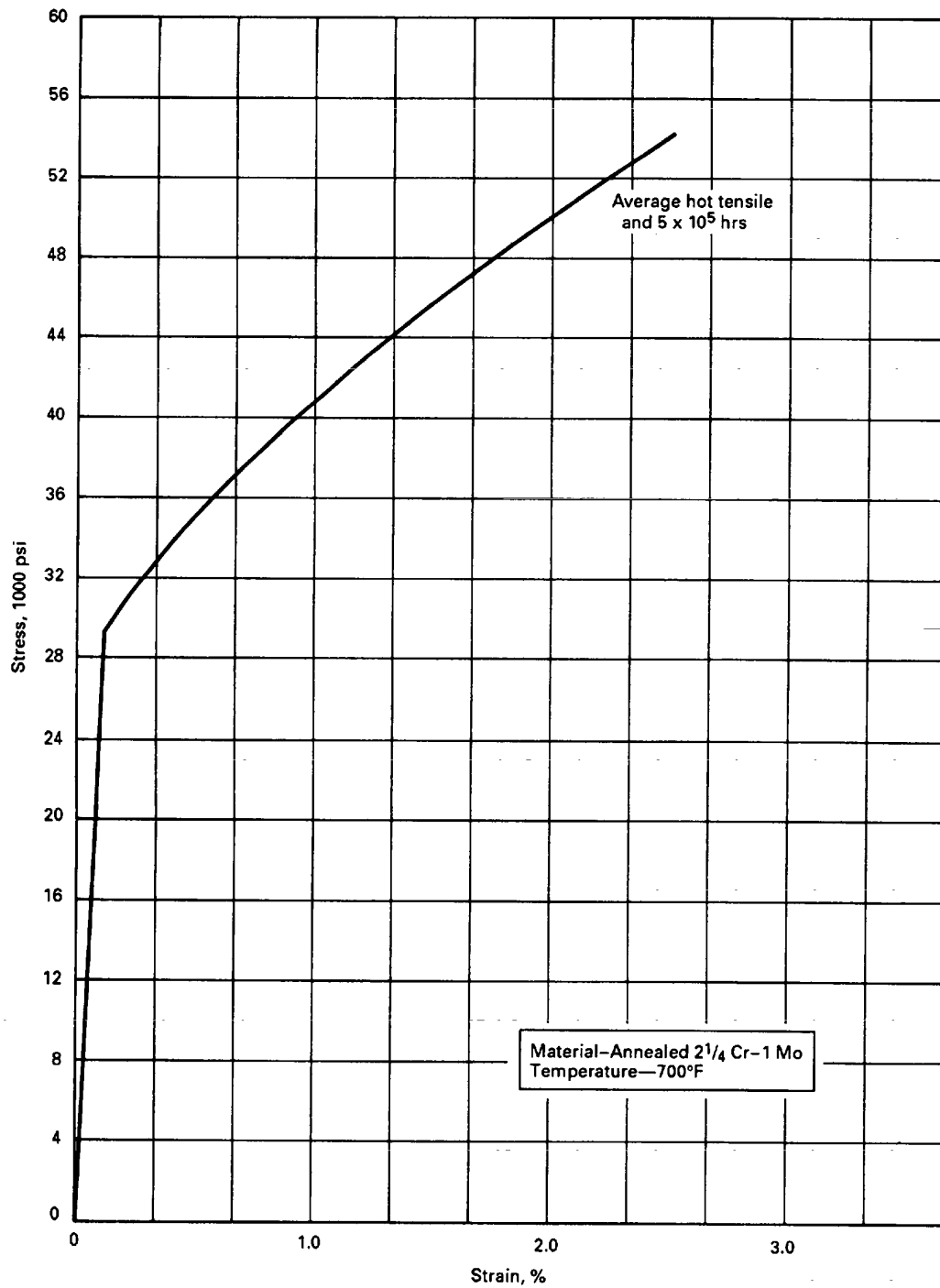


FIG. T-1800-D-1 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

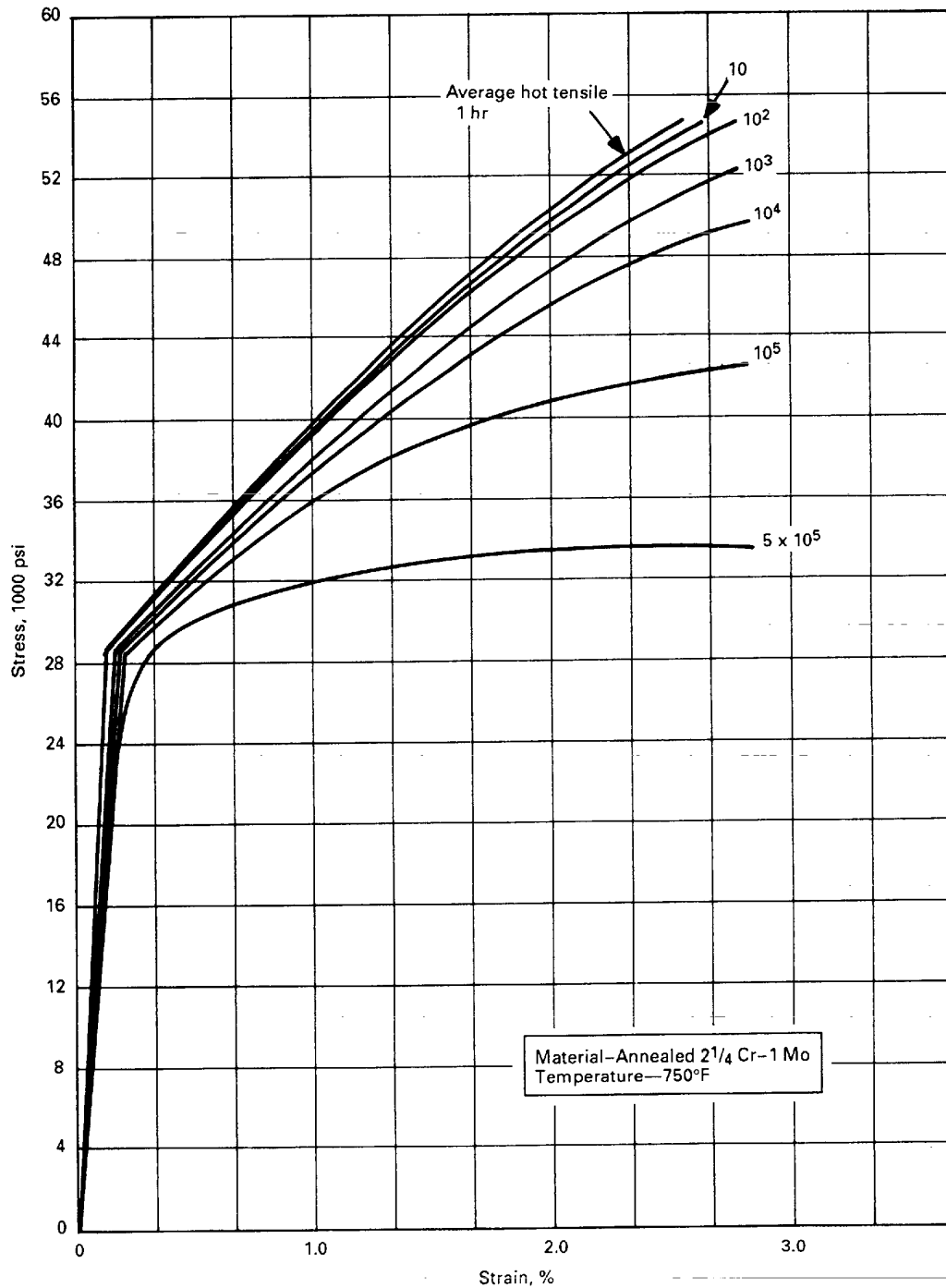


FIG. T-1800-D-2 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

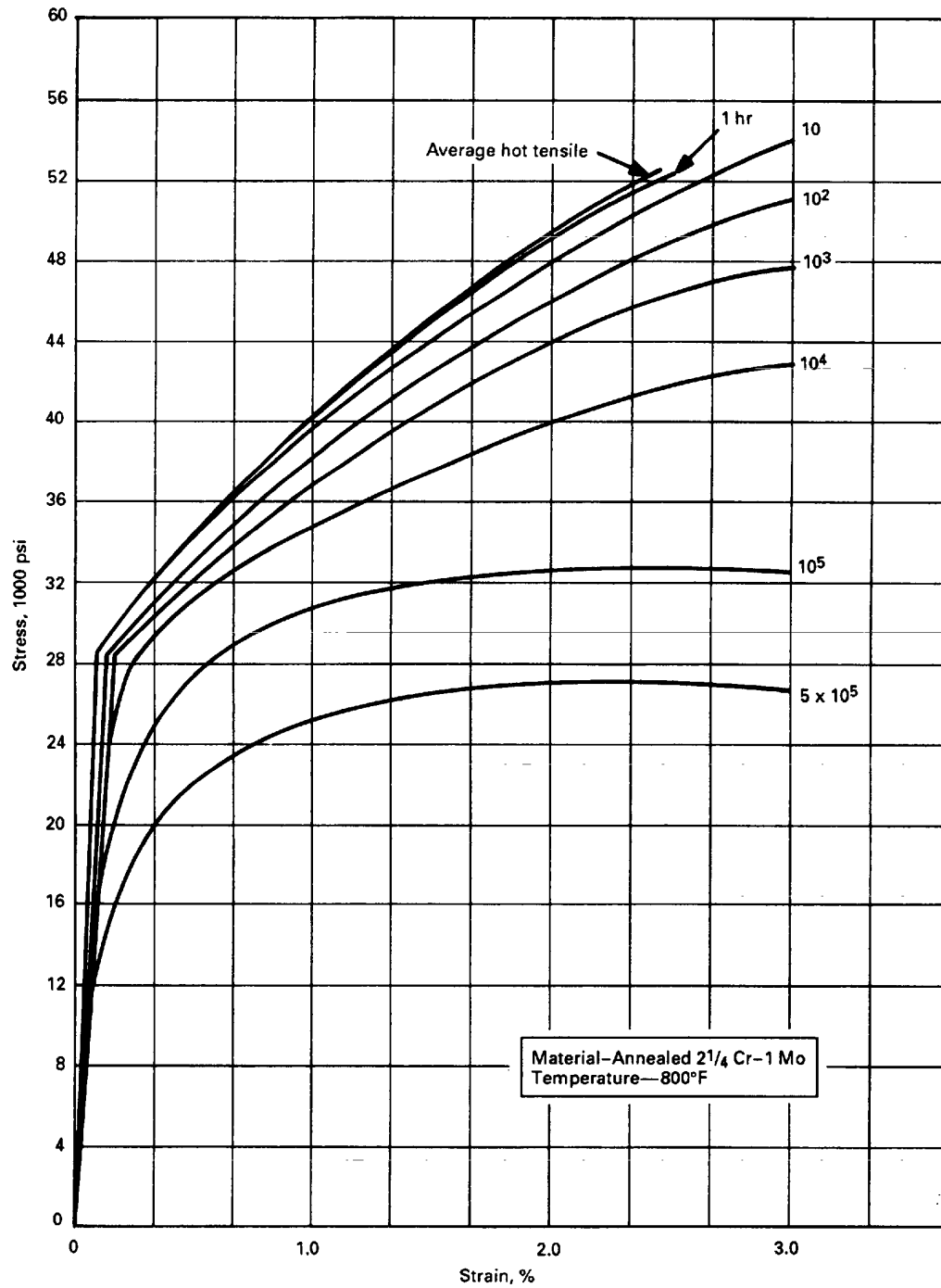


FIG. T-1800-D-3 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

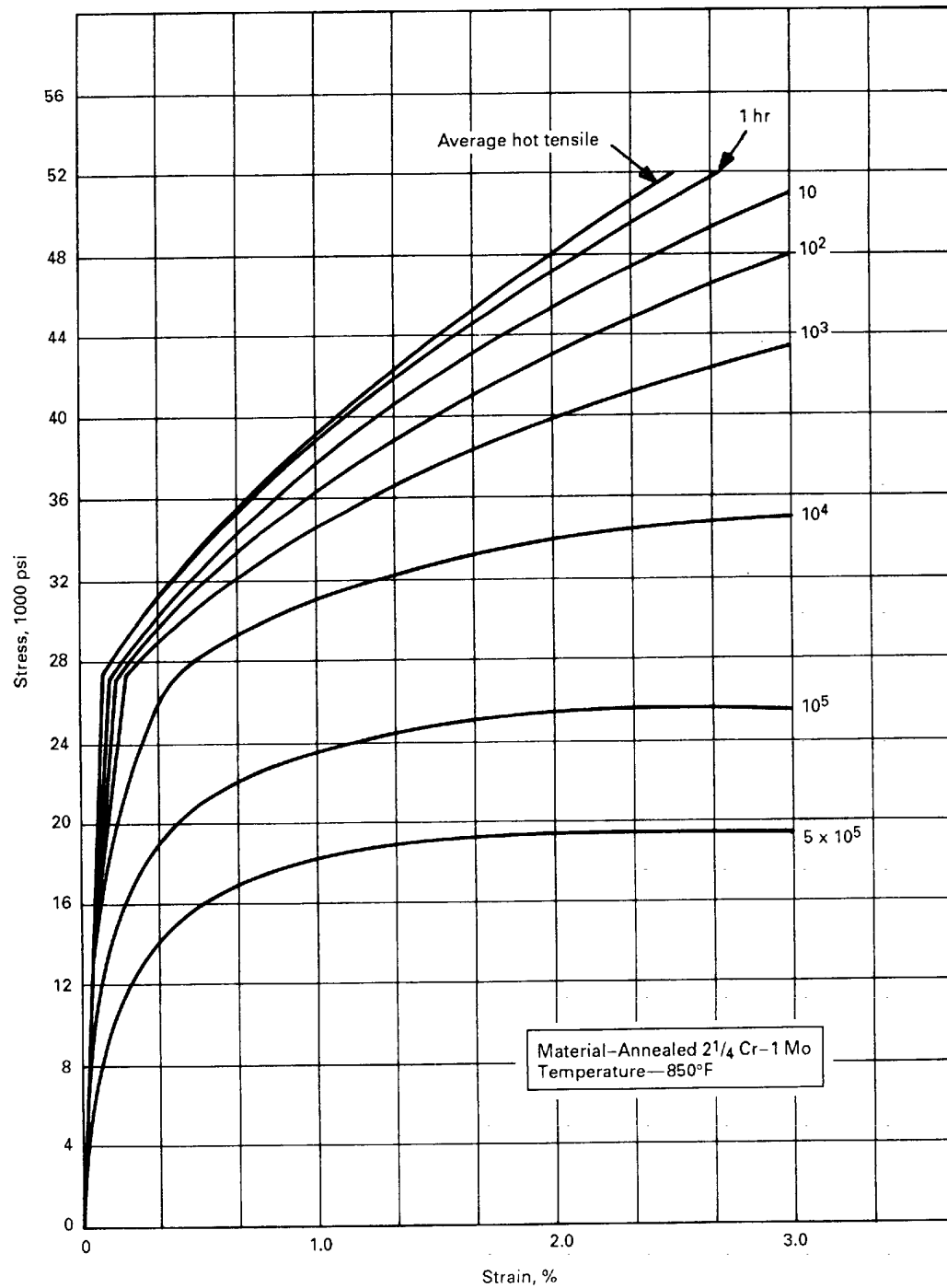


FIG. T-1800-D-4 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

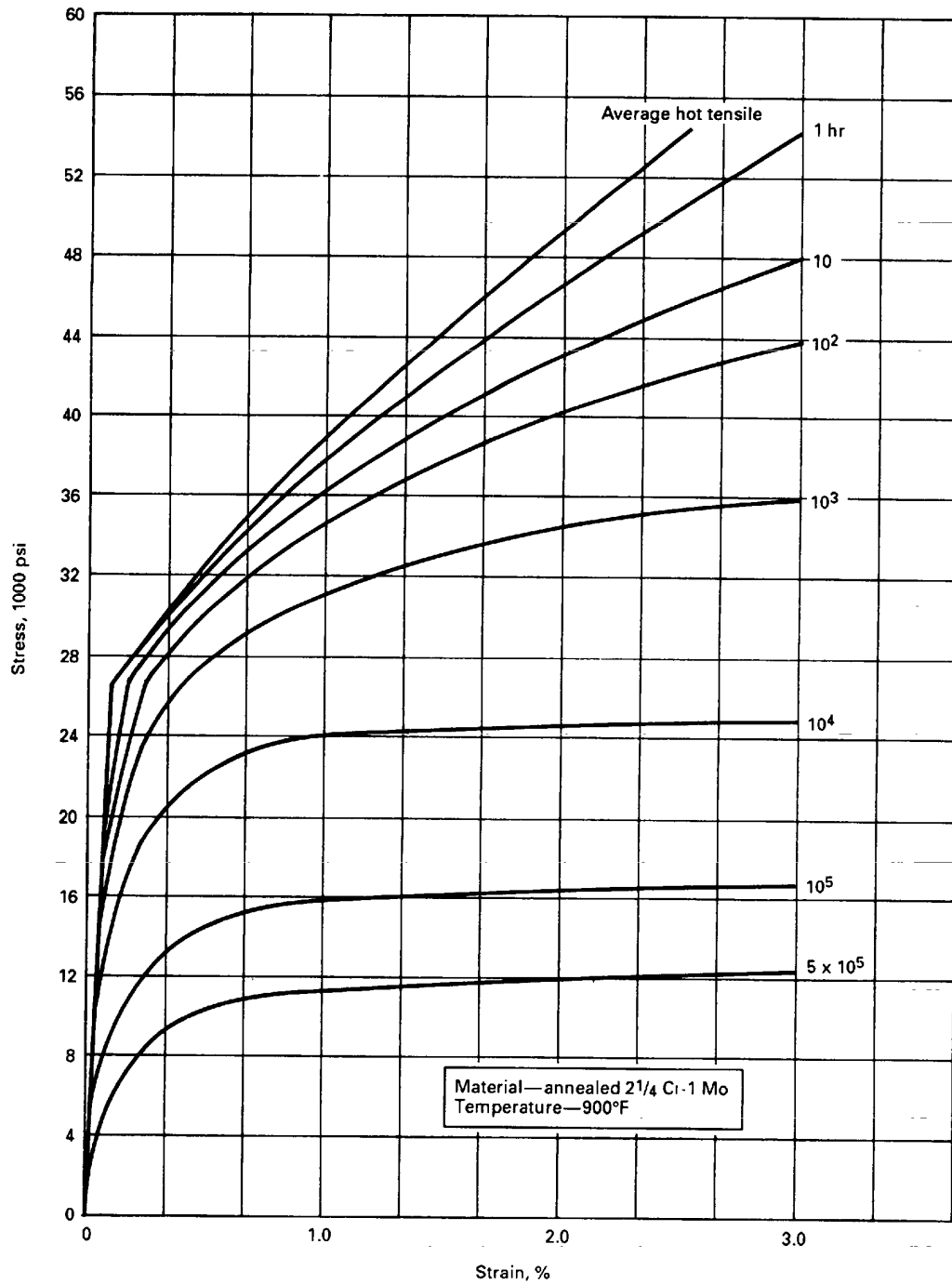


FIG. T-1800-D-5 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

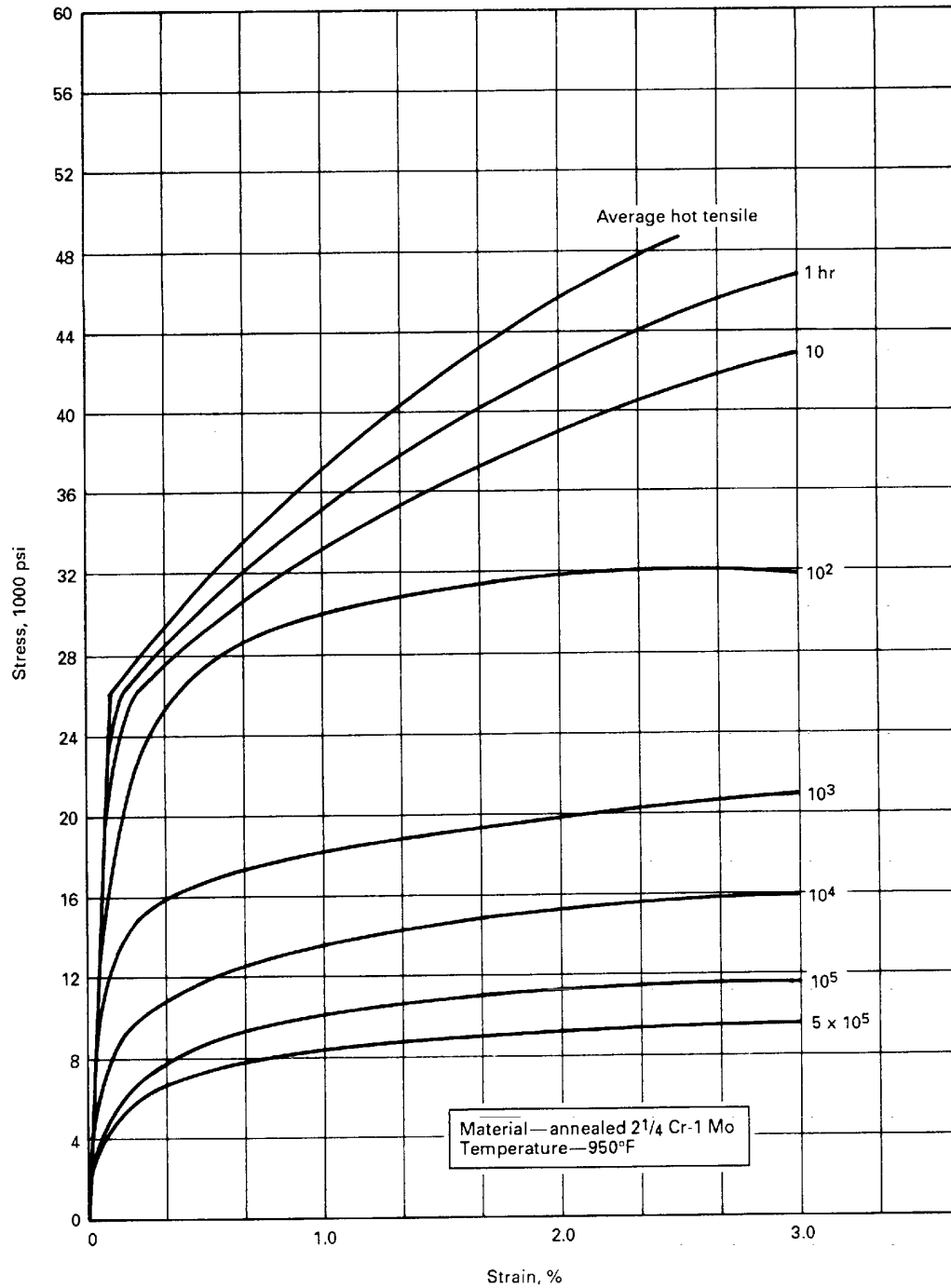


FIG. T-1800-D-6 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

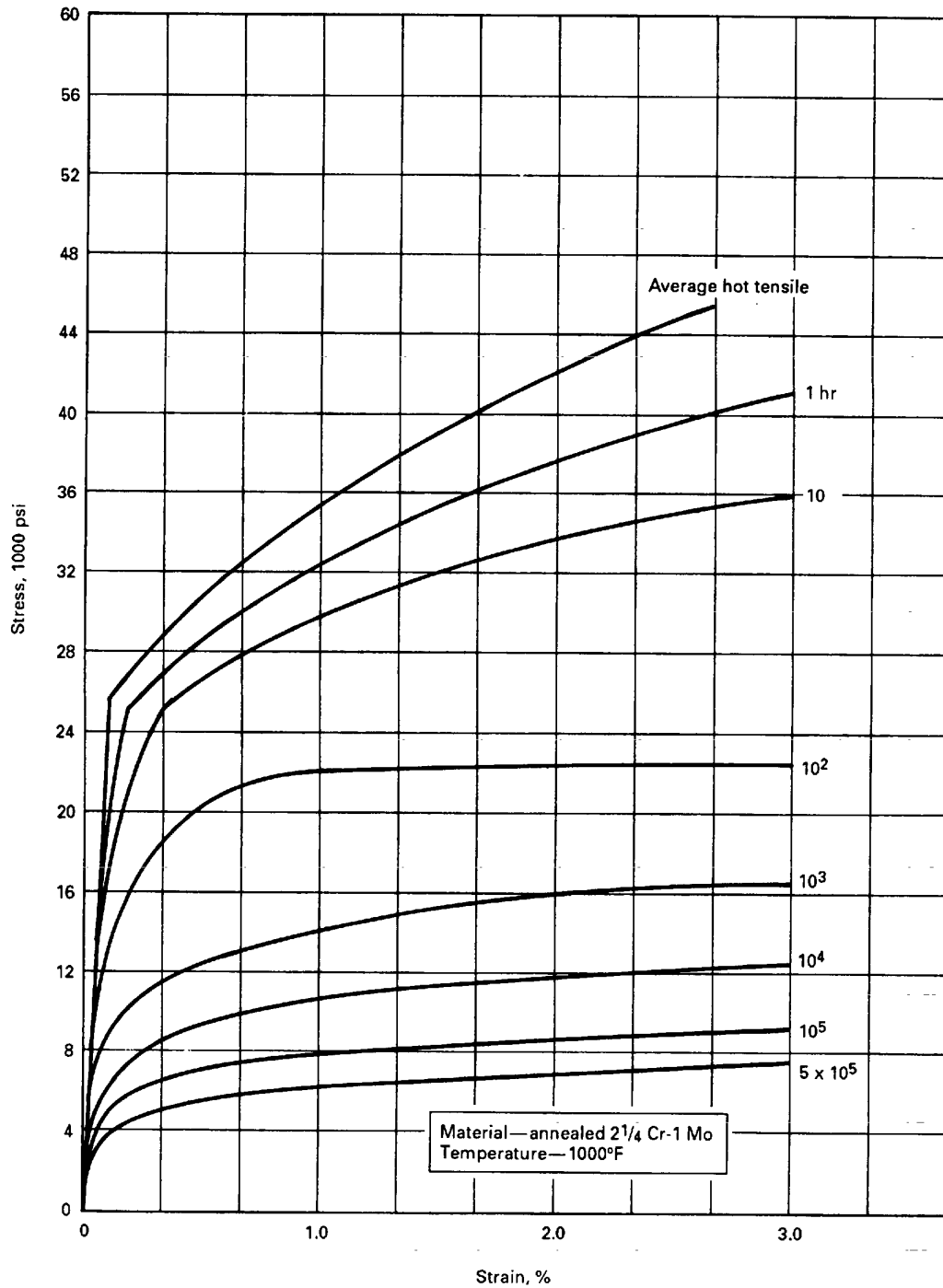


FIG. T-1800-D-7 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

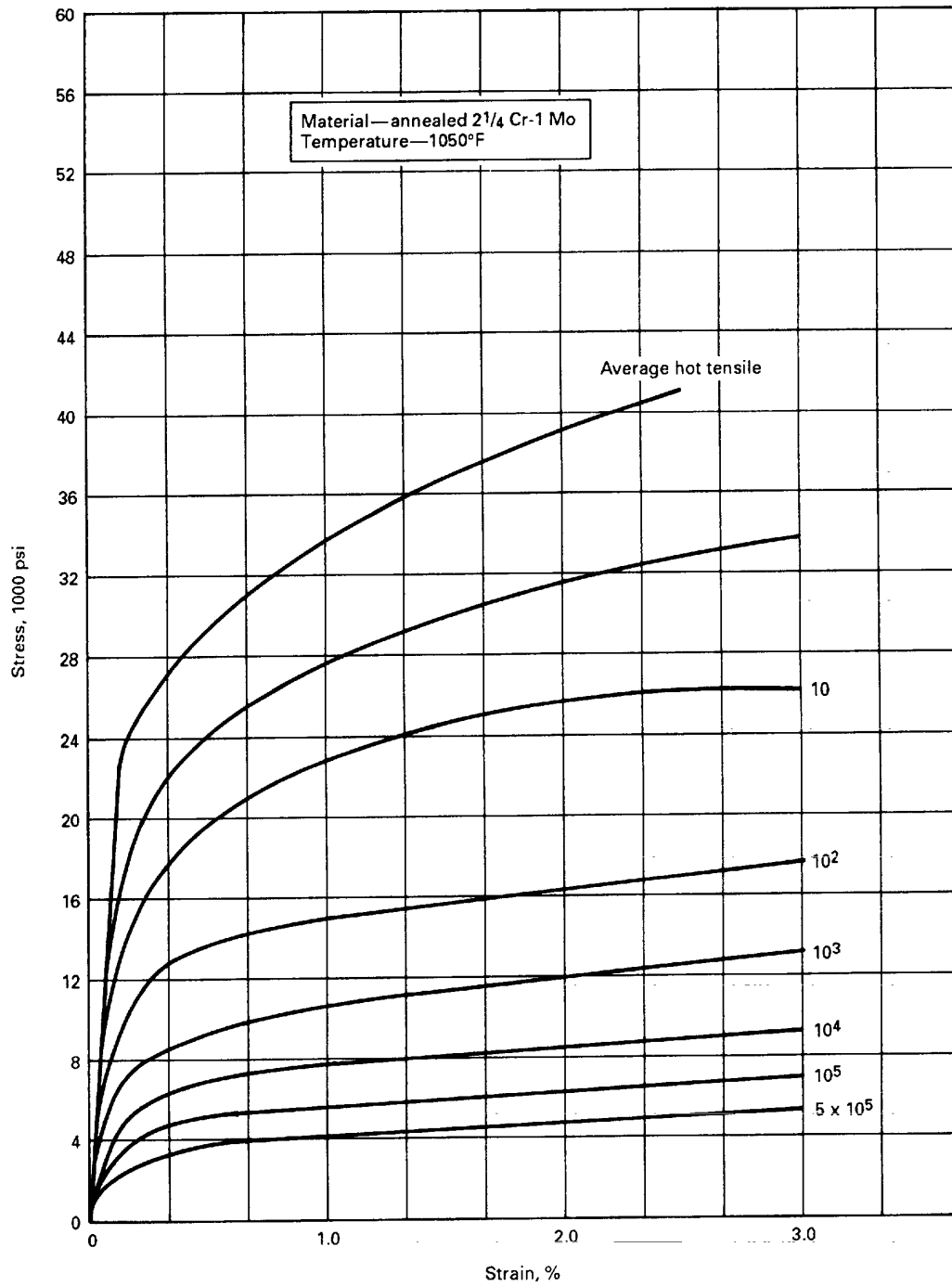


FIG. T-1800-D-8 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

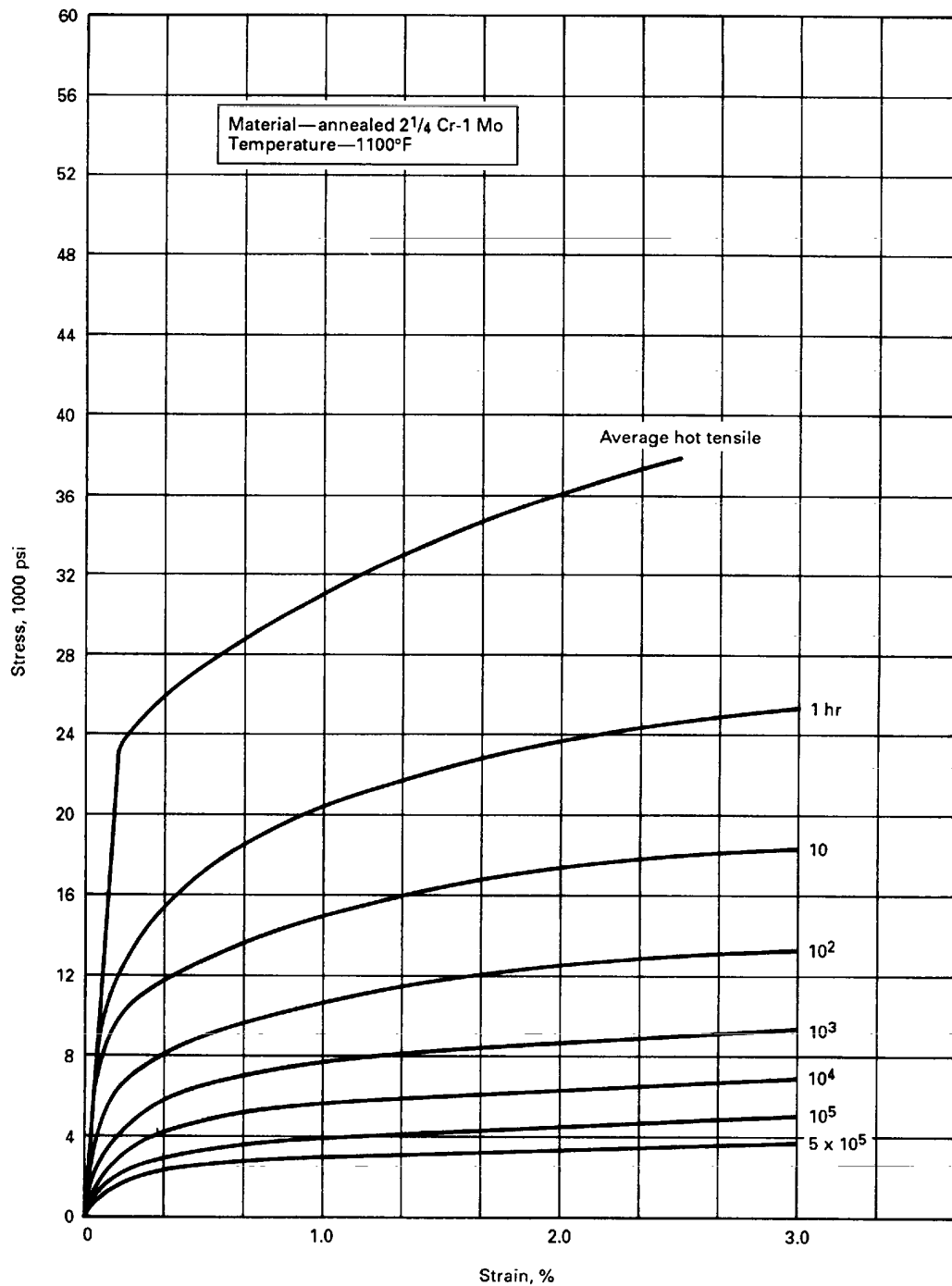


FIG. T-1800-D-9 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

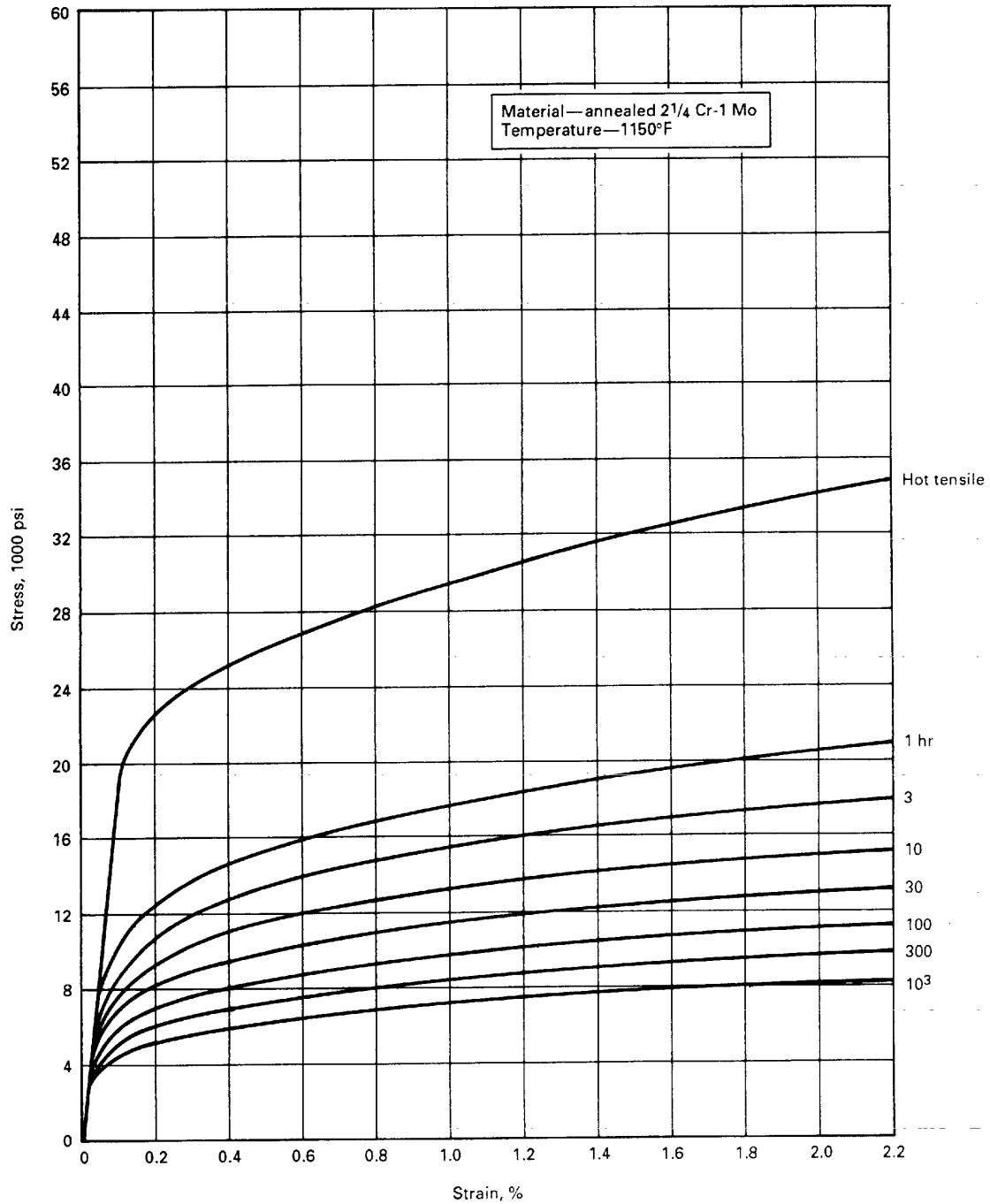


FIG. T-1800-D-10 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

FIG. T-1800-D-10 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

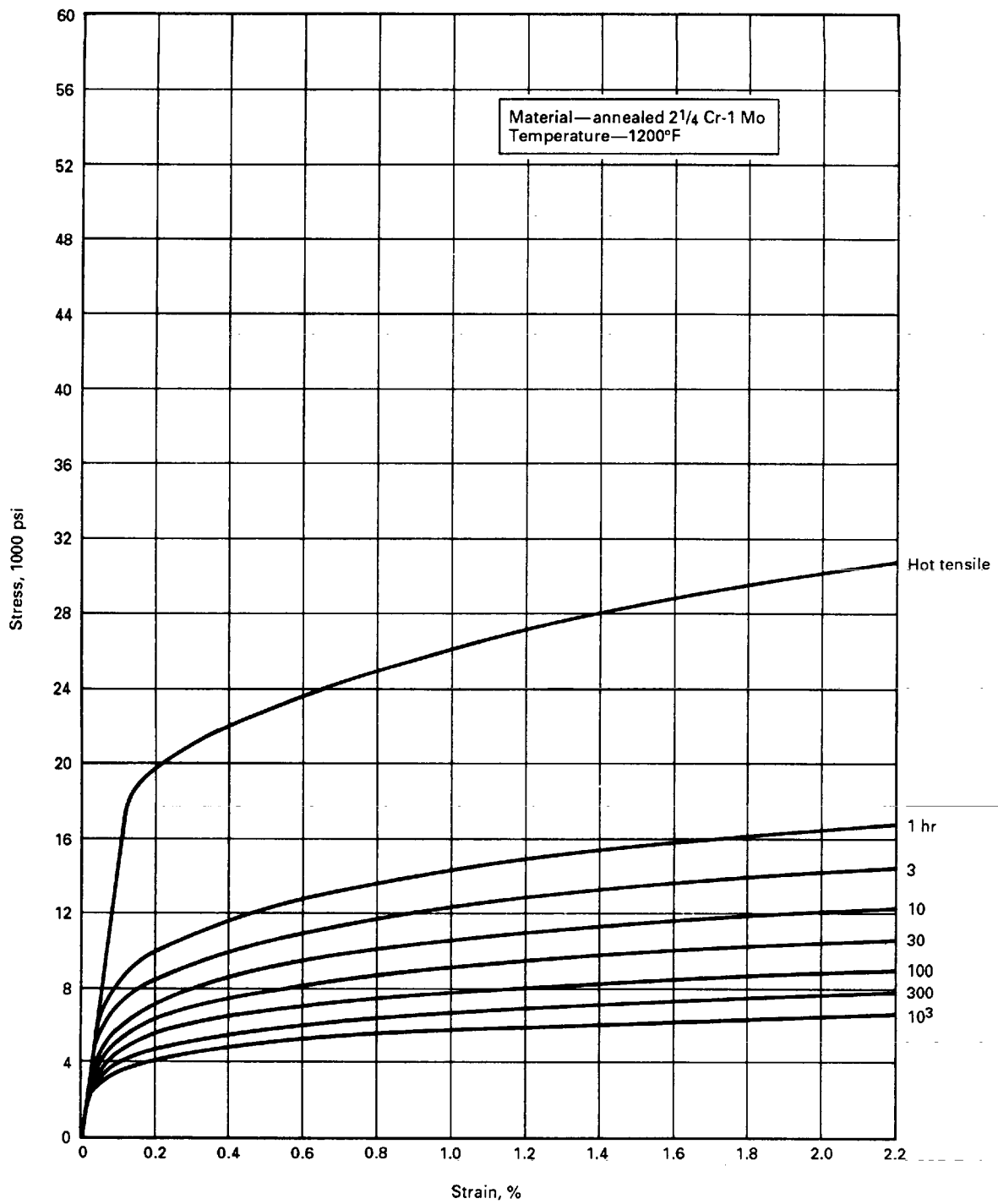


FIG. T-1800-D-11 AVERAGE ISOCHRONOUS STRESS-STRAIN CURVES

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NH NMA X

APPENDIX X GUIDELINES FOR RESTRICTED MATERIAL SPECIFICATIONS TO IMPROVE PERFORMANCE IN CERTAIN SERVICE APPLICATIONS

Page 193

X-1100 SCOPE

This Appendix provides guidelines on specification restrictions for Types 304 and 316 stainless steels which will, in the opinion of the Committee, improve the performance of the permitted materials in certain elevated temperature nuclear applications where creep effects are significant. The restrictions have the effect of narrowing chemical composition, grain size, and other aspects of material quality while staying within the broader specification limits defined in Table I-14.1(a) and its notes.

X-1110 OBJECTIVES

The purpose of these restrictions is to achieve materials which have significantly reduced scatter in creep and rupture properties, with mean strength values consistent with or better than the current database, while maintaining satisfactory weldability and fabricability.

X-1200 SERVICE CONDITIONS

The restrictions of this Appendix will provide improved performance when materials are used within the temperature regimes of 800°F to 1,100°F (427°C to 593°C). For application outside of those regimes, this Appendix provides no guidance.

X-1300 RECOMMENDED RESTRICTIONS

The recommended restrictions are shown in Table X-1.

Page 194

**TABLE X-1
RECOMMENDED RESTRICTIONS**

Element	Type 304	Type 316
(a) Chemical Composition [Note (1)]		
Carbon	0.04–0.06	0.04–0.06
Nitrogen	0.04–0.07	0.04–0.07
Silicon	0.6	0.6
Manganese	1.0–2.0	1.0–2.0
Nickel	8.00–10.00	11.00–12.5
Chromium	18.5–20.00	17.00–18.00
Molybdenum	0.2	2.5–3.0
Sulfur	0.02	<0.02
Phosphorus	0.045	<0.03
Niobium	0.02 [Note (2)]	...
Aluminum	0.05	0.05
Antimony	0.02	0.02
Boron	...	0.003 [Note (3)]
Lead	0.003	0.003
Selenium	0.015	0.015
Tin	0.015	0.015
Vanadium	0.05	0.05
Zinc	0.01	0.01
(b) Grain Size (ASTM)	3–6	3–6
(c) Melt Practice	AOD or AOD/ESR	AOD or AOD/ESR
(d) Suggested upper long-term use limit for improved performance:		
Temperature, °F	1,100	1,100

NOTES:

- (1) All values are maximum percentages unless indicated as ranges.
- (2) To further reduce data scatter, a minimum value of 0.005% should be specified.
- (3) To further reduce data scatter, a minimum value of 0.0015% should be specified.

TABLE X-1 RECOMMENDED RESTRICTIONS

July 1, 1998
American Society Of Mechanical Engineers
SEC III D1 APP A98

SUMMARY OF CHANGES

Changes given below are identified on the pages by a margin note, **98**, placed next to the affected area.

<i>Page</i>	<i>Location</i>	<i>Change</i>
43	IV-1000	Revised in its entirety
48	Form N-1	Authorized Inspector revised by Errata to read Authorized Nuclear Inspector
49	Form N-1A	Authorized Inspector revised by Errata to read Authorized Nuclear Inspector
52	Form N-2	Authorized Inspector revised by Errata to read Authorized Nuclear Inspector
54	Form N-3	Authorized Inspector revised by Errata to read Authorized Nuclear Inspector
56	Form N-5	Authorized Inspector revised by Errata to read Authorized Nuclear Inspector
58	Form N-6	Authorized Inspector revised by Errata to read Authorized Nuclear Inspector
59, 60	Form NPP-1	Authorized Inspector revised by Errata to read Authorized Nuclear Inspector
61, 62	Form NPV-1	(1) Item 7. revised in its entirety (2) Authorized Inspector revised by Errata to read Authorized Nuclear Inspector
64	Form NV-1	Authorized Inspector revised by Errata to read Authorized Nuclear Inspector
65	Form NCS-1	Authorized Inspector revised by Errata to read Authorized Nuclear Inspector
68	Form NF-1	Authorized Inspector revised by Errata to read Authorized Nuclear Inspector
69	Form NM-1	Authorized Inspector revised by Errata to read Authorized Nuclear Inspector
72	Form C-1	Authorized Inspector revised by Errata to read Authorized Nuclear Inspector
95	XI-1110(b)	Fourth line corrected by Errata
	XI-1122.1	Penultimate line corrected by Errata
97	XI-2140(b)(2)	Corrected by Errata
98-102	XI-3130	(1) Definitions for $A, B_1, d, e, G, H_G, H_p, K, M_0, S_a, S_b, S_j$ and S_n corrected by Errata (2) Definitions for D, E, n, s_p and t_s deleted by Errata (3) Definition for L added by Errata
	Fig. XI-3120-1	Sketches (6), (6a), and (7) corrected by Errata
	XI-3211	Redesignated as XI-3212 by Errata
	XI-3212	Redesignated as XI-3211 by Errata
	XI-3221	Fourth line corrected by Errata

Page	Location	Change
106	Table XI-3230-1	(1) Title revised by Errata (2) Under Flange Type column, last line revised by Errata
107	XI-3250(f)	Second line corrected by Errata
111	Fig. XI-3240-1	Subtitle added by Errata
114	Fig. XI-3240-5	Corrected by Errata
201	A-2223	Fifth line corrected by Errata
202	A-2242	Equation (13) corrected by Errata
205	Fig. A-3120-1	Sketch (a) corrected by Errata
216	A-6222	Last line corrected by Errata
220-222	A-6230	(1) In Step 7, (b)(2), equation for σ_t corrected by Errata (2) In Step 8, (a)(1), equation for σ_r corrected by Errata (3) In Step 8, (a)(2), equations for σ_t and σ_r in first paragraph and σ_t and σ_r in third paragraph corrected by Errata (4) In Step 8, (b)(1), equation for σ_r in third paragraph corrected by Errata (5) In Step 8, (b)(2), equation for σ_r in third paragraph corrected by Errata
223	A-7120(a)(3)	Third line corrected by Errata
225	A-8131(c)	Sixth line corrected by Errata
239	A-9310	Fifth line corrected by Errata
	A-9311	Third line corrected by Errata
	A-9314(a)	Corrected by Errata
241	A-9521(c)(1)	Fourth line corrected by Errata
243	A-9523.2(d)	First line corrected by Errata
	A-9531(c)(2)	Third line corrected by Errata
244	A-9535	First paragraph corrected by Errata
246	A-9541	In seventh paragraph, penultimate line corrected by Errata
249	A-9542	Nomenclature for S_y and S_u corrected by Errata
289	E-1110	(1) Definitions for A_{ml} and G revised (2) Definitions added for m, N, P , and T
	E-1210(a)(1)	Third line corrected by Errata
290	E-1210(b)	Corrected by Errata
	E-1210(c)(1)	Second line corrected by Errata
303	F-1341.2(a)	Revised
310	G-2110(a)	Corrected by Errata
	G-2120	Ninth and tenth lines corrected by Errata
311	G-2214.3(b)	Fifth line corrected by Errata

314	G-2215	Callout at top right-hand corner of figure corrected by Errata Penultimate line corrected by Errata
Page	Location	Change
314	G-2222(a)	Last line corrected by Errata
316	G-3100	Sixth line corrected by Errata
317	G-4100	Fifth line corrected by Errata
325	K-1100	First and seventh lines corrected by Errata
	K-1200(a)	Third and fifth lines corrected by Errata
	K-1310	Fourth and eighth lines corrected by Errata
	K-1320	(1) Title corrected by Errata (2) Subparagraphs (a) and (b) corrected by Errata
	K-1330	Subparagraphs (a), (b), and (c) corrected by Errata
328	Table K-1330-1	Under Item III.C, Note editorially corrected by Errata
493-496	Appendix V	Added by Errata

NOTE:

Volume 42 of the Interpretations to Section III, Divisions 1 and 2, of the ASME Boiler and Pressure Vessel Code follows the last page of the Edition to Subsection NCA.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 APP INTRO

INTRODUCTION

1998 ASME
BOILER &
PRESSURE VESSEL CODE
AN INTERNATIONAL CODE

III

Division 1 -
Appendices

RULES FOR
CONSTRUCTION
OF NUCLEAR
POWER PLANT
COMPONENTS

[ASME logo] The American Society of

Mechanical Engineers

IMPORTANT INFORMATION
ON THE 1998 BOILER AND
PRESSURE VESSEL CODE ADDENDA
DISTRIBUTION SCHEDULE

There is a change in the way the Addenda to the 1998 Edition of the ASME Boiler and Pressure Vessel Code are distributed. The 1998 Edition, published July 1, 1998, incorporates the 1998 Addenda revisions, additions, or deletions. There will be no separate 1998 Addenda issued in a replacement page format. Two additional Addenda to the 1998 Edition, in the form of replacement pages, will be issued on July 1, 1999 and July 1, 2000.

The Summary of Changes published with the 1998 Edition lists and describes the revisions that are part of the 1998 Addenda. These changes are identified with a margin note, **98**, denoting the affected area.

The Addenda for 1999 and 2000 will also have a Summary of Changes and identifiers printed on the replacement pages. The revisions, additions, or deletions will be incorporated directly into the affected pages. It is advisable to retain the title sheets and all replaced pages for reference.

The effective dates for Code Editions and Addenda are described in the Foreword.

ASME BOILER AND PRESSURE VESSEL CODE
AN INTERNATIONAL CODE

RULES FOR
CONSTRUCTION OF
NUCLEAR POWER
PLANT COMPONENTS

III

Division 1 -
Appendices

1998 Edition
July 1, 1998

ASME BOILER AND
PRESSURE VESSEL
COMMITTEE
SUBCOMMITTEE ON
NUCLEAR POWER

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
NEW YORK, NEW YORK.

Date of Issue - July 1, 1998
(Includes all Addenda dated December 1997 and earlier)

This code or standard was developed under procedures accredited as meeting the criteria for American National Standards. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment which provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not "approve," "rate," or "endorse" any item, construction, proprietary device, or activity.

ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items

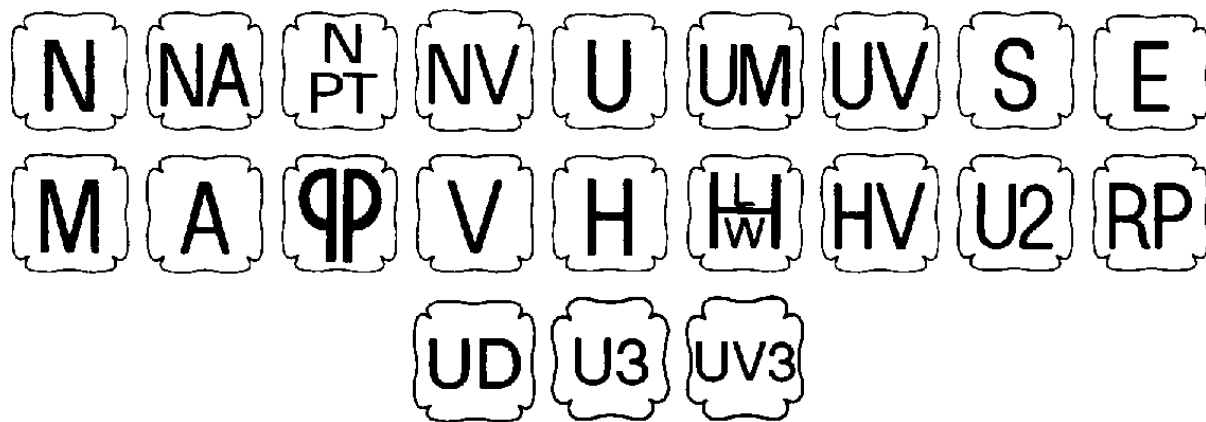
mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of any applicable Letters Patent, nor assume any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations issued in accordance with governing ASME procedures and policies which preclude the issuance of interpretations by individual volunteers.

The footnotes in this document are part of this American National Standard.

[ASME logo] ASME collective membership mark



LOGOS

The above ASME symbols are registered in the U.S. Patent Office.

"ASME" is the trademark of the American Society of Mechanical Engineers.

No part of this document may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Library of Congress Catalog Card Number: 56-3934

Printed in the United States of America

Adopted by the Council of the American Society of Mechanical Engineers, 1914.

Revised 1940, 1941, 1943, 1946, 1949, 1952, 1953, 1956, 1959, 1962, 1965, 1968, 1971, 1974, 1977, 1980, 1983, 1986, 1989, 1992, 1995, 1998

The American Society of Mechanical Engineers

Three Park Avenue, New York, NY 10016-5990

Copyright © 1998 by

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

All Rights Reserved

1998 ASME BOILER AND PRESSURE VESSEL CODE

SECTIONS

I Rules for Construction of Power Boilers

II Materials

Part A - Ferrous Material Specifications

Part B - Nonferrous Material Specifications

Part C - Specifications for Welding Rods, Electrodes, and Filler Metals

Part D - Properties

III Subsection NCA - General Requirements for Division 1 and Division 2

III Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

III Division 2 - Code for Concrete Reactor Vessels and Containments

III Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

IV Rules for Construction of Heating Boilers

V Nondestructive Examination

VI Recommended Rules for the Care and Operation of Heating Boilers

VII Recommended Guidelines for the Care of Power Boilers

VIII Rules for Construction of Pressure Vessels

Division 1

Division 2 - Alternative Rules

Division 3 - Alternative Rules for Construction of High Pressure Vessels

IX Welding and Brazing Qualifications

X Fiber-Reinforced Plastic Pressure Vessels

XI Rules for Inservice Inspection of Nuclear Power Plant Components

ADDENDA

Colored-sheet Addenda, which include additions and revisions to individual Sections of the Code, are published annually and will be sent automatically to purchasers of the applicable Sections up to the publication of the 2001 Code. The 1998 Code is available only in the loose-leaf format; accordingly, the Addenda will be issued in the loose-leaf, replacement-page format.

INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code. The Interpretations for each individual Section will be published separately and will be included as part of the update service to that Section. They will be issued semiannually (July and December) up to the publication of the 2001 Code. Interpretations of Section III, Divisions 1 and 2, will be included with the update service to Subsection NCA.

CODE CASES

The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 1998 Code Cases book: (1) Boilers and Pressure Vessels and (2) Nuclear Components. Supplements will be sent automatically to the purchasers of the Code Cases books up to the publication of the 2001 Code.

Page v

FOREWORD

The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety governing the design, fabrication, and inspection during construction of boilers and pressure vessels, and to interpret these rules when questions arise regarding their intent. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property and to provide a margin for deterioration in service so as to give a reasonably long, safe period of usefulness. Advancements in design and material and the evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction,¹ and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

¹ Construction, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are responsible for the application of these programs to their design.

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practice as determined by the engineer.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Boiler and Pressure Vessel Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Mandatory Appendix covering preparation of technical inquiries). Proposed revisions to the Code resulting from inquiries will be presented to the Main Committee for appropriate action. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by ASME.

Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute and published in *Mechanical Engineering*

Page viii

to invite comments from all interested persons. After the allotted time for public review and final approval by ASME, revisions are published annually in Addenda to the Code.

Code Cases may be used in the construction of components to be stamped with the ASME Code symbol beginning with the date of their approval by ASME.

Code Editions may be used on or after the date of issue shown in the Edition. After Code revisions are approved by ASME, they may be used beginning with the date of issue shown on the Addenda. Revisions to material specifications are originated by the American Society for Testing and Materials (ASTM) and other recognized national or international organizations, and are usually adopted by ASME. However, those revisions may or may not have any effect on the suitability of material, produced to earlier editions of specifications, for use in ASME construction. ASME material specifications approved for use in each construction Code are listed in the Appendices of Section II, Parts A and B. These Appendices list, for each specification, the latest edition adopted by ASME, and earlier and later editions considered by ASME to be identical for ASME construction.

Owners of nuclear power plants are cautioned that Code Editions, Addenda, and Cases to be used in construction shall be acceptable to the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

Each state and municipality in the United States and each province in Canada that adopts or accepts one or more Sections of the Boiler and Pressure Vessel Code is invited to appoint a representative to act on the Conference Committee to the Boiler and Pressure Vessel Committee. Since the members of the Conference Committee are in active contact with the administration and enforcement of the rules, the requirements for inspection in this Code correspond with those in effect in their respective jurisdictions. The required qualifications for an Authorized Inspector under these rules may be obtained from the administrative authority of any state, municipality, or province which has adopted these rules.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, method of fabrication, inspection, and safety devices. Permission may be granted to regulatory bodies and organizations publishing safety standards to use a complete Section of the Code by reference. If usage of a Section, such as Section IX, involves exceptions, omissions, or changes in provisions, the intent of the Code might not be attained.

Where a state or other regulatory body, in the printing of any Section of the Boiler and Pressure Vessel Code, makes additions or omissions, it is recommended that such changes be clearly indicated.

The National Board of Boiler and Pressure Vessel Inspectors is composed of chief inspectors of states and municipalities in the United States and of provinces in Canada that have adopted the Boiler and Pressure Vessel Code. This Board, since its organization in 1919, has functioned to uniformly administer and enforce the rules of the Boiler and Pressure Vessel Code. The cooperation of that organization with the Boiler and Pressure Vessel Committee has been extremely helpful.

The Code Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The Scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Code for vessels or components not considered to be within its Scope or may establish additions or deletions in that Scope. Accordingly, inquiries regarding such laws or regulations are to be directed to the issuing enforcement or regulatory body.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the ASME Boiler and Pressure Vessel Committee. ASME is to be notified should questions arise concerning improper use of an ASME Code symbol.

The specifications for materials given in Section II are identical with or similar to those of specifications published by ASTM, AWS, and other recognized national or international organizations. When reference is made in an ASME material specification to a non- ASME specification for which a companion ASME specification exists, the reference shall be interpreted as applying to the ASME material specification. Not all materials included in the material specifications in Section II have been adopted for use in this Section. Usage is limited to those materials and grades listed in at least one of the tables of Section II, Part D, Subpart 1, identified as applicable to this Section. All materials allowed by this Section and used for construction within the scope of these rules shall be furnished in accordance with material specifications

Page ix

contained in Section II or referenced in Appendices A of Section II, Parts A and B except where otherwise provided in Code Cases or in this Section of the Code. Materials covered by these specifications are acceptable for use in items covered by the Code Sections only to the degree indicated in the applicable Section. Materials for Code use should preferably be ordered, produced, and documented on this basis. Material produced to an acceptable specification with requirements different from the requirements of the corresponding specification listed in Appendix A of Part A or Part B may also be used in accordance with the above, provided the material manufacturer or vessel manufacturer certifies with evidence acceptable to the Authorized Inspector that the corresponding ASME specification requirements of specifications listed in Appendix A of Part A or Part B have been met. Material produced to an acceptable material specification is not limited as to country of origin.

When required by context in this Section, the singular shall be interpreted as the plural, and vice-versa; and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

Publication of the SI (Metric) Edition of the ASME Boiler and Pressure Vessel Code was discontinued with the 1986 Edition. Effective October 1, 1986, the SI Edition was withdrawn as an ASME Boiler and Pressure Vessel Code document.

Page xi

STATEMENT OF POLICY ON THE USE OF CODE SYMBOLS AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use Code Symbols for marking items or constructions which have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the symbols, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications which might so indicate. An organization holding a Code Symbol and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code."

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified items will carry the symbol. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

The ASME logo, which is the cloverleaf with the letters ASME within, shall not be used by any organization other than

ASME.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Code Symbol Stamp described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the various Code Symbols shall not be used on any item which is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME which tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

Page xiii

PERSONNEL ASME Boiler and Pressure Vessel Committee Subcommittees, Subgroups, and Working Groups

As of December 31, 1997

MAIN COMMITTEE

D. A. Canonico, *Chair*

G. G. Karcher, *Vice Chair*

J. S. Brzuszkiewicz, *Secretary*

R. W. Barnes

F. P. Barton

D. L. Berger

M. D. Bernstein

M. N. Bressler

W. J. Carter

T. M. Cullen

J. R. Farr

R. E. Feigel

J. G. Feldstein

M. Gold

O. F. Hedden

A. J. Justin

D. F. Landers

W. M. Lundy

J. R. MacKay

T. J. Mawson

T. G. McCarty

G. C. Millman

R. A. Moen

C. C. Neely

C. J. Pieper

R. F. Reedy

B. W. Roberts

F. J. Schaaf, Jr.
A. Selz
K. K. Tam
D. E. Tanner

EXECUTIVE COMMITTEE (MAIN COMMITTEE)

G. G. Karcher, *Chair*
D. A. Canonico, *Vice Chair*
J. S. Brzuszkiewicz, *Secretary*
F. P. Barton
J. R. Farr
J. G. Feldstein
M. Gold
O. F. Hedden
A. J. Justin
J. R. MacKay
T. G. McCarty
T. P. Pastor
T. E. Quaka
R. F. Reedy
A. J. Spencer

HONORARY MEMBERS (MAIN COMMITTEE)

R. D. Bonner
R. J. Bosnak
H. M. Canavan
L. J. Chockie
J. S. Clarke
W. E. Cooper
W. D. Doty
R. C. Griffin
E. J. Hemzy
E. C. Kistner, Jr.
J. E. Lattan
J. LeCoff
F. N. Moschini
C. E. Rawlins
W. E. Somers
L. P. Zick, Jr.

HONORS AND AWARDS COMMITTEE

J. R. MacKay, *Chair*
A. J. Spencer, *Vice Chair*
F. R. Lyons, *Secretary*
F. P. Barton
W. J. Carter
J. G. Feldstein
M. Gold

F. E. Gregor
E. C. Kistner, Jr.
T. P. Pastor
R. F. Reedy

MARINE CONFERENCE GROUP

J. Tiratto, *Chair*
C. F. Banks
L. W. Douthwaite
J. L. Jones
G. F. Wright

CONFERENCE COMMITTEE

D. E. Tanner - Tennessee (*Chair*)
R. D. Reetz - North Dakota (*Vice Chair*)
A. J. Justin - National Board of Boiler and Pressure Vessel Inspectors (*Secretary*)
R. J. Aben, Jr. - Michigan
J. S. Aclaro - Los Angeles, California
E. A. Anderson - Chicago, Illinois
J. Anderson - South Dakota
R. Barkdoll - Washington
F. P. Barton - Virginia
C. Castle - Nova Scotia, Canada
R. R. Cate - Louisiana
L. Chase - Northwest Territories, Canada
R. A. Coomes - Kentucky
J. Corcoran - Connecticut
M. H. Diehl, Jr. - Maryland
D. A. Douin - Illinois
D. Eastman - Newfoundland and Labrador, Canada
G. L. Ebeyer - New Orleans, Louisiana
F. Ellis - New Hampshire
E. Everett - Georgia
P. C. Hackford - Utah
D. Hanrath - North Carolina
J. B. Harlan - Delaware
K. Hynes - Prince Edward Island, Canada
D. T. Jagger - Ohio
D. J. Jenkins - Kansas
M. Kotb - Quebec, Canada
J. P. Larson - Minnesota
K. T. Lau - Alberta, Canada
J. Lemire - California
G. A. Lundberg - Florida
W. C. Lundine - Oregon
M. A. Malek - Maine
I. W. Mault - Manitoba, Canada
H. T. McEwen - Mississippi

H. T. McEwen - Mississippi
A. W. Meiring - Indiana
R. Mile - Ontario, Canada
T. J. Monroe - Oklahoma
Y. Nagpaul - Hawaii
J. D. Payton - Pennsylvania
D. K. Peetz - Missouri
D. C. Price - Yukon Territory, Canada
R. S. Pucek - Wisconsin
T. E. Rennie - Arizona
L. Roussinos - British Columbia, Canada
M. Shuff - West Virginia
R. Snyder - New Jersey
N. Surtees - Saskatchewan, Canada
M. J. Verhagen - Wisconsin
R. B. West - Iowa
M. J. Wheel - Vermont
K. A. White - Nevada
R. K. White - New York
T. F. Wickham - Rhode Island
C. S. Withers - Colorado

SUBCOMMITTEE ON POWER BOILERS (SC I)

J. R. MacKay, *Chair*
M. D. Bernstein, *Vice Chair*
P. D. Stumpf, *Secretary*
D. L. Berger
E. Everett
D. N. French
F. R. Gerety
J. Hainsworth
T. E. Hansen
J. S. Hunter
W. L. Lowry
T. C. McGough
P. A. Molvie
D. K. Parrish
J. T. Pillow
R. G. Presnak
B. W. Roberts
R. D. Schueler, Jr.
R. V. Wielgoszinski
R. L. Williams

Page xiv

Subgroup on Design (SC I)

M. D. Bernstein, *Chair*
R. D. Schueler, Jr., *Vice Chair*

P. A. Molvie, *Secretary*
M. A. Farrugia
J. D. Fishburn
C. F. Jeerings
K. C. Morrison
A. Nassif
N. Surtees
R. V. Wielgoszinski

Subgroup on Fabrication and Examination (SC I)

D. L. Berger, *Chair*
R. E. McLaughlin, *Secretary*
R. W. Boyce
D. N. French
J. Hainsworth
T. E. Hansen
M. H. Iken
J. M. Lyons
J. T. Pillow
M. E. Reese
R. D. Schueler, Jr.
R. F. Slack, Sr.
R. V. Wielgoszinski

Subgroup on General Requirements (SC I)

T. C. McGough, *Chair*
M. D. Bernstein, *Vice Chair*
W. L. Lowry, *Secretary*
D. L. Berger
E. Everett
F. R. Gerety
J. Hainsworth
C. F. Jeerings
J. M. Lyons
R. E. McLaughlin
D. K. Parrish
J. T. Pillow
W. E. Somers
R. L. Williams

Subgroup on Materials (SC I)

B. W. Roberts, *Chair*
C. E. Spaeder, Jr., *Chair*
J. S. Hunter, *Secretary*
T. M. Cullen
D. N. French
J. F. Henry
J. P. Libbrecht

F. Masuyama
J. M. Tanzosh

Subgroup on Piping (SC I)

T. E. Hansen, *Chair*
D. L. Berger
M. D. Bernstein
P. D. Edwards
W. L. Lowry
T. C. McGough
R. G. Presnak
E. Whittle
P. L. Ziegler

SUBCOMMITTEE ON MATERIALS (SC II)

M. Gold, *Chair*
T. M. Cullen, *Vice Chair*
F. R. Lyons, *Secretary*
A. P. Ahrendt
M. N. Bressler
A. Cohen
R. Dirscherl
W. D. Doty
W. D. Edsall
D. Gandy
M. H. Gilkey
J. J. Heger
J. F. Henry
G. C. Hsu
F. Masuyama
E. Michalopoulos
R. A. Moen
R. K. Nanstad
E. G. Nisbett
J. T. Parsons
D. W. Rahoi
B. W. Roberts
E. Shapiro
C. E. Spaeder, Jr.
R. W. Swindeman
J. M. Tanzosh
B. E. Thurgood
A. W. Zeuthen

Subgroup on External Pressure (SC II)

R. W. Mikitka, *Chair*
D. J. Green
D. S. Griffin
E. Michalopoulos

E. Michalopoulos
B. R. Morelock
D. Nadel
C. E. Spaeder, Jr.
C. H. Sturgeon

Subgroup on Ferrous Specifications (SC II)

E. G. Nisbett, *Chair*
B. M. Dingman
W. D. Edsall
T. Graham
W. N. Holliday
E. A. Jonas
D. C. Krouse
J. F. Longenecker
W. C. Mack
A. S. Melilli
J. T. Parsons
E. J. Rozic, Jr.
E. Upitis
A. W. Zeuthen
R. H. Zong

Subgroup on International Material Specifications (SC II)

J. T. Parsons, *Chair*
D. C. Agarwal
J. Cameron
R. Dirscherl
W. D. Doty
D. M. Fryer
M. Gold
M. H. Iken
W. M. Lundy
H. Masahisa
T. F. Miskell
F. Osweiller
A. P. Povilonis
R. D. Schueler, Jr.
R. R. Seeley
E. A. Steen
E. Upitis
E. O. Woolridge

Subgroup on Nonferrous Alloys (SC II)

D. W. Rahoi, *Chair*
D. C. Agarwal, *Secretary*
W. R. Apblett
L. G. Coffee
A. Cohen

R. Dirscherl
M. H. Gilkey
G. C. Hsu
M. Katcher
E. Shapiro
L. E. Shoemaker
R. C. Sutherlin

Subgroup on Strength, Ferrous Alloys (SC II)

B. W. Roberts, *Chair*
J. M. Tanzosh, *Secretary*
A. P. Ahrendt
W. R. Apblett
T. M. Cullen
M. Gold
J. J. Heger
C. L. Hoffmann
A. Iseda
F. Masuyama
R. A. Moen
D. W. Rahoi
C. E. Spaeder, Jr.
R. W. Swindeman
B. E. Thurgood

Subgroup on Strength of Weldments (SC II & SC IX)

C. E. Spaeder, Jr., *Chair*
W. D. Doty
D. W. Rahoi
B. W. Roberts
C. Robino
W. J. Sperko
J. M. Tanzosh
B. E. Thurgood

Subgroup on Toughness (SC II)

J. M. Barsom
D. A. Hansen
A. Selz
R. S. Vecchio
S. Yukawa
R. Zawierucha

Page xv

SUBCOMMITTEE ON NUCLEAR POWER (SC III)

C. J. Pieper, *Chair*
R. M. Jessee, *Vice Chair*
C. A. Sanna, *Secretary*
J. P. Allen III

Y. Asada
R. W. Barnes
J. N. Baysden
W. H. Borter
E. B. Branch
M. N. Bressler
F. C. Cherny
G. D. Cooper
R. P. Deubler
W. D. Doty
F. R. Drahos
K. Ennis
B. A. Erler
D. Hanrath
C. L. Hoffmann
K.-H. Hsu
D. F. Landers
W. C. LaRochelle
T. J. Mawson
W. N. McLean
R. A. Moen
D. B. Nickerson
R. F. Perrin
R. F. Reedy
M. W. Smith
J. D. Stevenson
R. E. Tome
K. R. Wichman

Subgroup on Containment Systems for Spent Fuel and High-Level Waste Transport Packagings (SC III)

J. D. Stevenson, *Chair*
H. H. Chung
R. R. Doggart
E. L. Farrow
K. Goldmann
R. H. Jones
W. H. Lake
R. W. Lambert
H. W. Lee
P. McConnell
R. E. Nickell
D. J. Nolan
D. T. Raske
T. Saegusa
R. H. Smith
K. B. Sorenson
P. Turula

P. Turula
N. Urabe
C. R. Witt
S. Yukawa

Subgroup on Design (SC III)

R. W. Barnes, *Chair*
E. B. Branch, *Vice Chair*
R. S. Hill III, *Secretary*
Y. Asada
M. N. Bressler
C. W. Bruny
J. R. Cole
G. D. Cooper
R. P. Deubler
N. W. Edwards
R. E. Gimple
D. Hanrath
R. W. Haupt
T. Iida
B. Jarman
D. F. Landers
W. N. McLean
D. B. Nickerson
E. C. Rodabaugh
J. R. Santangelo
G. C. Slagis
J. D. Stevenson
J. H. Wawrzeniak
K. R. Wichman
R. Wray

Working Group on Administration (SG-D) (SC III)

E. B. Branch, *Chair*
R. W. Barnes, *Vice Chair*
R. S. Hill III, *Secretary*
C. W. Bruny
G. D. Cooper
R. P. Deubler
J. T. Land
D. F. Landers
W. N. McLean
D. B. Nickerson
J. R. Santangelo
R. Wray

Working Group on Core Support Structures (SG-D) (SC III)

J. T. Land, *Chair*
R. H. Hansen

K. B. Larsen
J. F. Mullooly
B. L. Silverblatt

Working Group on Dynamic and Extreme Load Conditions (SG-D) (SC III)

R. Wray, *Chair*
A. E. Meligi, *Secretary*
P. L. Anderson
M. K. Au-Yang
R. D. Blevins
G. J. Bohm
D. L. Caldwell
P.-Y. Chen
A. Hadjian
M. Hartzman
W. S. LaPay
H. Lockert
P. R. Olson
R. F. Perry
J. Wallach

Working Group on Piping (SG-D) (SC III)

D. F. Landers, *Chair*
R. S. Hill III, *Vice Chair*
P. Hirschberg, *Secretary*
T. M. Adams
G. A. Antaki
J. R. Cole
A. B. Glickstein
R. W. Haupt
J. C. Hennart
R. D. Hookway
R. B. Jenkins
K. A. Manoly
J. C. Minichiello
S. E. Moore
A. N. Nguyen
D. B. Nickerson
O. O. Oyamada
R. D. Patel
E. C. Rodabaugh
J. R. Santangelo
M. S. Sills
G. C. Slagis
E. A. Wais

Working Group on Pumps (SG-D) (SC III)

D. B. Nickerson, *Chair*

H. L. Brammer
P. Burchett
R. E. Cornman, Jr.
A. A. Fraser
M. Higuchi
G. R. Jones
J. W. Leavitt
J. E. Livingston
R. A. Schussler
H. Tafarrodi
G. K. Vaghasia

Working Group on Supports (SG-D) (SC III)

R. P. Deubler, *Chair*
R. M. Dulin, Jr., *Secretary*
U. S. Bandyopadhyay
F. J. Birch
M. N. Bressler
J. R. Cole
J. C. Finneran, Jr.
R. W. Haupt
J. C. Hennart
A. S. Laurensen
A. Lee
R. J. Masterson
A. E. Meligi
A. N. Nguyen
J. R. Stinson

Working Group on Valves (SG-D) (SC III)

W. N. McLean, *Chair*
E. A. Bake
R. R. Brodin
W. G. Knecht
R. Koester
J. J. McGavin
S. N. Shields
H. R. Sonderegger
J. C. Tsacoyeanes
R. G. Visalli
J. R. Zahorsky

Working Group on Vessels (SG-D) (SC III)

C. W. Bruny, *Chair*
T. K. Burr, Sr.
G. D. Cooper
G. A. Deaver
N. W. Edwards

D. Hanrath
W. J. Heilker
B. Jarman
T. M. Khan
O. Maekawa
K. A. Manoly
A. Merend
G. K. Miller
W. Z. Novak
E. Pelling
H. S. Thornton

Page xvi

Special Working Group on Environmental Effects (SG-D) (SC III)

R. S. Hill III, *Chair*
Y. Asada
W. J. Heilker
C. L. Hoffmann
R. A. Moen
W. Z. Novak
S. Yukawa

Special Working Group on Seismic Piping Rules (SG-D) (SC III)

E. B. Branch, *Chair*
T. M. Adams
G. A. Antaki
R. D. Hookway
J. C. Minichiello
M. S. Sills
E. A. Wais

Subgroup on General Requirements (SC III & SC 3C)

W. C. LaRochelle, *Chair*
K. Ennis, *Secretary*
A. Appleton
J. R. Barbee
J. N. Baysden
L. M. Beason
B. H. Berg
R. E. Kelley
G. S. Korin
A. S. Laurenson
C. Lizotte
M. J. Meyer
M. R. Minick
L. C. Oakes
R. F. Perrin
U. Potapovs

B. B. Scott
D. E. Tanner
D. V. Walshe

Subgroup on Materials, Fabrication, and Examination (SC III)

C. L. Hoffmann, *Chair*
G. P. Milley, *Secretary*
C. W. Allison
D. Doyle
F. R. Drahos
G. M. Foster
G. B. Georgiev
J. E. Harris
R. W. Jackson
R. M. Jessee
C. C. Kim
R. A. Moen
C. J. Pieper
R. R. Seeley
N. M. Simpson
R. C. Soin
W. J. Sperko
K. B. Stuckey
S. Yukawa

Subgroup on Pressure Relief (SC III)

F. C. Cherny, *Chair*
S. F. Harrison, Jr.
E. M. Petrosky
M. W. Smith
A. L. Szeglin
B. S. York
J. R. Zahorsky

Special Working Group on Editing and Review (SC III)

R. F. Reedy, *Chair*
W. H. Borter
M. N. Bressler
R. P. Deubler
B. A. Erler
W. C. LaRochelle
M. W. Smith
J. D. Stevenson
E. O. Woolridge

JOINT ACI-ASME COMMITTEE ON CONCRETE COMPONENTS FOR NUCLEAR SERVICE (SC 3C)

B. A. Erler, *Chair*
C. A. Sanna, *Secretary*
J. P. Allen III

R. M. Attar
A. C. Eberhardt
J. Gutierrez
D. J. Haavik
M. F. Hessheimer
T. E. Johnson
G. R. Murphy
S. F. Putman
B. B. Scott
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Design (SC 3C)

D. G. Adams
A. C. Eberhardt
T. E. Johnson
S. F. Putman
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Materials, Construction, and Examination (SC 3C)

D. J. Haavik, *Chair*
J. F. Artuso
R. M. Attar
B. A. Erler
J. Gutierrez

SUBCOMMITTEE ON HEATING BOILERS (SC IV)

F. P. Barton, *Chair*
P. A. Molvie, *Vice Chair*
B. P. Feder, *Secretary*
R. B. Duggan
W. L. Haag, Jr.
W. M. Hiddleston
J. D. Hoh
K. M. McTague
R. I. Mullican
E. A. Nordstrom
J. L. Seigle
D. E. Tanner
S. V. Voorhees
R. H. Weigel
R. V. Wielgoszinski
J. I. Woodworth
T. L. Bedeaux, *Alternate*

Subgroup on Care and Operation of Heating Boilers (SC IV)

J. I. Woodworth, *Chair*
B. P. Feder, *Secretary*
K. J. Hoey
J. D. Hoh
F. M. Lucas
K. M. McTague
P. A. Molvie
R. I. Mullican
R. H. Weigel
T. F. Wickham
T. L. Bedeaux, Alternate

Subgroup on Cast Iron Boilers (SC IV)

K. M. McTague, *Chair*
R. B. Duggan
R. H. Weigel
T. F. Wickham
J. I. Woodworth
T. L. Bedeaux, Alternate

Subgroup on Water Heaters (SC IV)

W. L. Haag, Jr., *Chair*
T. D. Gantt
W. M. Hiddleston
F. M. Lucas
K. M. McTague
R. I. Mullican
D. Smith
D. E. Tanner
M. A. Taylor

Subgroup on Welded Boilers (SC IV)

P. A. Molvie, *Chair*
T. L. Bedeaux
D. H. Mapes
E. A. Nordstrom
J. L. Seigle
R. F. Slack, Sr.
R. P. Sullivan
D. E. Tanner
R. V. Wielgoszinski

SUBCOMMITTEE ON NONDESTRUCTIVE EXAMINATION (SC V)

T. G. McCarty, *Chair*
J. E. Batey, *Vice Chair*
F. S. Fitzgerald, *Secretary*
A. S. Birks
B. H. Clark, Jr.
W. T. Clayton

R. A. Coomes
N. Y. Faransso
H. C. Graber
O. F. Hedden
G. W. Hembree
F. B. Kovacs
J. F. Manning
W. C. McGaughey
R. D. McGuire

Page xvii

Subgroup on General Requirements/Personnel Qualifications and Inquiries (SC V)

R. D. McGuire, *Chair*
J. E. Batey
W. T. Clayton
N. Y. Faransso
H. C. Graber
G. W. Hembree
J. R. MacKay
J. P. Swezy

Subgroup on Surface Examination Methods (SC V)

H. C. Graber, *Chair*
S. J. Akrin
T. Alexander
A. S. Birks
B. H. Clark
R. A. Coomes
G. W. Hembree

Subgroup on Volumetric Methods (SC V)

J. E. Batey, *Chair*
S. J. Akrin
W. T. Clayton
N. Y. Faransso
H. C. Graber
G. W. Hembree
B. Kellerhall
E. K. Kietzman
F. B. Kovacs
R. W. Kruzic
J. F. Manning
W. C. McGaughey
J. R. Mitchell

Working Group on Acoustic Emissions (SG-VM) (SC V)

B. H. Clark, Jr.
P. M. Horrigan
J. F. Manning

J. R. Mitchell

Working Group on Radiography (SG-VM) (SC V)

G. W. Hembree, *Chair*

S. J. Akrin

T. Alexander

J. E. Batey

N. Y. Faransso

H. C. Graber

F. B. Kovacs

Working Group on Ultrasonics (SG-VM) (SC V)

W. T. Clayton, *Chair*

O. F. Hedden

B. Kellerhall

E. K. Kietzman

J. F. Manning

W. C. McGaughey

R. Paillaman

F. J. Sattler

M. L. Shakinovsky

SUBCOMMITTEE ON PRESSURE VESSELS (SC VIII)

T. P. Pastor, *Chair*

K. Mokhtarian, *Vice Chair*

A. J. Roby, *Secretary*

A. P. Ahrendt

V. Bogosian

S. M. Caldwell

W. J. Carter

S. C. Cyr

R. Dirscherl

R. M. Elliott

J. R. Farr

R. E. Feigel

J. G. Feldstein

G. L. Hollinger

M. J. Houle

W. S. Jacobs

G. G. Karcher

G. B. Komora

K. T. Lau

R. W. Mikitka

U. R. Miller

C. C. Neely

K. J. Schneider

A. Selz

J. R. Sims, Jr.

A. J. Spencer
E. A. Steen
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Design (SC VIII)

U. R. Miller, *Chair*
R. E. Knoblock, *Secretary*
M. R. Bauman
M. R. Breach
S. M. Caldwell
N. W. Edwards
J. R. Farr
J. A. Hayward
G. L. Hollinger
W. S. Jacobs
G. G. Karcher
G. B. Komora
R. W. Mikitka
K. Mokhtarian
T. P. Pastor
M. D. Rana
A. Selz
S. C. Shah
J. W. Stokes
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Fabrication and Inspection (SC VIII)

E. A. Steen, *Chair*
K. Mokhtarian, *Vice Chair*
W. J. Bees
R. W. Boyce
S. C. Cyr
R. E. Feigel
H. E. Gordon
M. J. Houle
W. S. Jacobs
R. A. Johnson
A. S. Lester III
F. C. Ouyang
M. J. Rice
W. P. Webb

Subgroup on General Requirements (SC VIII)

R. M. Elliott, *Chair*
A. P. Ahrendt
V. Bogosian

W. J. Carter
W. P. Crow
J. P. Glaspie
C. R. Good
D. B. Kadakia
J. C. Keenan
W. E. Laveck, Jr.
A. S. Mann
C. C. Neely
A. S. Olivares
K. J. Schneider
A. J. Spencer

Subgroup on Materials (SC VIII)

R. Dirscherl, *Chair*
D. C. Agarwal
A. P. Ahrendt
J. Cameron
W. D. Doty
W. D. Edsall
M. Katcher
W. M. Lundy
E. E. Morgenegg
E. G. Nisbett
J. T. Parsons
D. W. Raho
K. K. Tam
B. K. Thakur

Special Working Group on Heat Transfer Equipment (SC VIII)

G. B. Komora, *Chair*
R. P. Zoldak, *Secretary*
C. F. Andreone
D. E. Bolt
S. M. Caldwell
T. K. Haldas
M. J. Holtz
W. G. Jandrasits
R. Mahadeen
U. R. Miller
F. Osweiller
J. E. Soehrens
A. I. Soler
W. A. Treff
S. Yokell

Special Working Group on High-Pressure Vessels (SC VIII)

J. R. Sims, Jr., *Chair*
P. A. Reddington, *Secretary*
L. P. Antalffy
J. E. Baxter
R. C. Biel
T. B. Boyd
D. J. Burns
P. N. Chaku
E. L. Danfelt
R. E. Feigel
D. M. Fryer
J. L. Heck, Jr.
A. H. Honza
V. T. Hwang
M. M. James
P. Jansson
J. A. Kapp
D. P. Kendall
A. K. Khare
S. C. Mordre
G. J. Mraz
E. H. Perez
L. M. Picqueur
E. D. Roll
W. L. Stewart
J. F. Sullivan
F. W. Tatar

Special Working Group on Toughness (SC VIII)

W. S. Jacobs, *Chair*
J. Cameron
W. D. Doty
D. A. Hansen
G. G. Karcher
G. B. Komora
K. Mokhtarian
J. L. Mooney
C. C. Neely
M. D. Rana
J. W. Stokes

SUBCOMMITTEE ON WELDING (SC IX)

J. G. Feldstein, *Chair*
W. J. Sperko, *Vice Chair*
J. Labrador, *Secretary*
R. Barkdoll
D. A. Bowers
M. L. Carpenter

W. D. Doty
P. D. Flenner
M. J. Houle
R. A. Johnson
W. M. Lundy
R. D. McGuire
J. J. Meyer
A. H. Miller
B. R. Newmark
P. P. Norris
S. D. Reynolds, Jr.
W. K. Scattergood
G. W. Spohn III
M. J. Stanko
J. M. Tanzosh
R. R. Young

Subgroup on Brazing (SC IX)

M. J. Houle, *Chair*
A. S. Artayet
M. L. Carpenter
C. F. Jeerings
A. H. Miller
C. Robino

Subgroup on General Requirements (SC IX)

B. R. Newmark, *Chair*
R. Barkdoll
P. R. Evans
P. C. Filean
R. M. Jessee
D. W. Mann
A. S. Olivares
C. E. Wainwright
R. A. Weiss
K. R. Willens

Subgroup on Materials (SC IX)

M. L. Carpenter, *Chair*
L. P. Connor
P. D. Flenner
R. M. Jessee
A. H. Miller
H. A. Sadler
C. E. Sainz
C. E. Spaeder, Jr.
W. J. Sperko
M. J. Stanko

R. R. Young

Subgroup on Performance Qualification (SC IX)

J. J. Meyer, *Chair*

V. A. Bell

D. A. Bowers

L. P. Connor

R. A. Coomes

P. D. Flenner

G. Herrmann

M. J. Houle

W. M. Lundy

R. D. McGuire

S. R. Nordman

P. P. Norris

W. K. Scattergood

G. W. Spohn III

Subgroup on Procedure Qualification (SC IX)

J. J. Meyer, *Chair*

R. K. Brown, Jr.

R. A. Johnson

A. H. Miller

P. P. Norris

A. S. Olivares

F. C. Ouyang

S. D. Reynolds, Jr.

M. J. Rice

W. K. Scattergood

W. J. Sperko

T. C. Wiesner

SUBCOMMITTEE ON FIBER-REINFORCED PLASTIC PRESSURE VESSELS (SC X)

P. J. Conlisk, *Chair*

D. Eisberg, *Vice Chair*

A. J. Roby, *Secretary*

K. M. Agrawal

F. L. Brown

J. L. Bustillos

T. W. Cowley

T. J. Fowler

S. V. Hoa

L. E. Hunt

J. C. Murphy

A. L. Newberry

D. J. Painter

J. A. Rolston

B. F. Shelley

P. R. Wilt

SUBCOMMITTEE ON NUCLEAR INSERVICE INSPECTION (SC XI)

O. F. Hedden, *Chair*

T. J. Mawson, *Vice Chair*

G. L. Fechter, *Secretary*

C. W. Allison

W. H. Bamford, Jr.

R. L. Beverly

J. M. Bloom

R. W. Boyce

C. D. Cowfer

D. D. Davis

R. L. Dyle

T. N. Epps III

R. E. Gimple

F. E. Gregor

L. B. Gross

K. Iida

C. A. Ireland

R. D. Kerr

D. F. Landers

T. F. Lentz

J. T. Lindberg

G. C. Millman

C. R. Osman

P. C. Riccardella

L. Sage

F. J. Schaaf, Jr.

J. E. Staffiera

R. P. Sullivan

R. W. Swayne

R. J. Tamminga

J. C. Tobin

R. A. Yonekawa

Honorary Members (SC XI)

S. H. Bush

L. J. Chockie

J. P. Houstrup

L. R. Katz

R. R. MacCary

Page xix

Subgroup on Evaluation Standards (SC XI)

W. H. Bamford, Jr., *Chair*

M. Kupinski, *Secretary*

J. M. Bloom

R. C. Cipolla

R. M. Gamble
T. J. Griesbach
P. J. Hijeck
K. Iida
Y. Imamura
J. G. Merkle
S. Ranganath
P. C. Riccardella
D. A. Scarth
W. L. Server
C. A. Tomes
W. A. Van Der Sluys
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa

Working Group on Flaw Evaluation (SG-ES) (SC XI)

R. C. Cipolla, *Chair*
W. H. Bamford, Jr.
M. Basol
J. M. Bloom
E. Friedman
T. J. Griesbach
F. D. Hayes
D. N. Hopkins
K. Iida
Y. Imamura
M. Kupinski
H. S. Mehta
J. G. Merkle
J. S. Panesar
R. K. Qashu
S. Ranganath
D. A. Scarth
T. S. Schurman
W. L. Server
F. A. Simonen
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Working Group on Operating Plant Criteria (SG-ES) (SC XI)

T. J. Griesbach, *Chair*

W. H. Bamford, Jr.
H. Behnke
B. A. Bishop
W. F. Brady
E. Friedman
S. R. Gosselin
E. M. Hackett
P. J. Hijeck
S. D. Leshnoff
P. Manbeck
J. S. Panesar
W. E. Pennell
J. H. Phillips
S. Ranganath
S. T. Rosinski
W. L. Server
E. A. Siegel
F. A. Simonen
T. D. Spry
K. K. Yoon
S. Yukawa

Working Group on Pipe Flaw Evaluation (SG-ES) (SC XI)

D. A. Scarth, *Chair*
G. M. Wilkowski, *Secretary*
W. H. Bamford, Jr.
J. M. Bloom
R. C. Cipolla
N. G. Cofie
S. K. Daftuar
G. H. De Boo
E. Friedman
D. N. Hopkins
K. Iida
H. S. Mehta
J. G. Merkle
J. S. Panesar
D. Quinones
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Subgroup on Liquid-Metal-Cooled Systems (SC XI)

C. G. McCargar, *Chair*
W. L. Chase
S. Hattori
R. Hundal

W. Kwant
J. C. Tobin

Working Group on Liquid-Metal Reactor Covers (SG-LMCS) (SC XI)

W. L. Chase, *Chair*
S. Hattori
R. Hundal
W. Kwant

Subgroup on Nondestructive Examination (SC XI)

R. L. Beverly, *Chair*
N. R. Bentley, *Secretary*
D. C. Adamonis
F. L. Becker
F. T. Carr
C. B. Cheezem
W. T. Clayton
C. D. Cowfer
F. J. Dodd
T. N. Epps III
D. O. Henry
M. R. Hum
S. N. Liu
R. D. McGuire
M. C. Modes
C. R. Osman
F. J. Schaaf, Jr.
J. C. Spanner, Jr.
C. J. Wirtz

Working Group on Personnel Qualification and Surface Visual and Eddy Current Examination (SG-NDE) (SC XI)

C. J. Wirtz, *Secretary*
B. L. Curtis
N. Economos
H. B. Garland
D. O. Henry
H. E. Houserman
J. J. McArdle III
R. D. McGuire
S. A. Redner
M. F. Sherwin
A. L. Smith
D. Spake
J. C. Spanner, Sr.
J. C. Spanner, Jr.
T. V. Tran

Working Group on Pressure Testing (SG-NDE) (SC XI)

G. P. Alexander

T. M. Anselmi
T. B. Basso
J. Boughman
T. R. Bugelholl
R. J. Cimocho
C. E. Jensen
W. N. Keisler
D. Lamond
F. J. Schaaf, Jr.
D. Terao

Working Group on Procedure Qualification and Volumetric Examination (SG-NDE) (SC XI)

C. D. Cowfer, *Chair*
C. E. Larsen, *Secretary*
D. C. Adamonis
F. L. Becker
N. R. Bentley
B. Bevins
F. T. Carr
C. B. Cheezem
W. T. Clayton
S. R. Doctor
F. J. Dodd
T. N. Epps III
B. Kellerhall
G. A. Lofthus
J. K. McClanahan
M. C. Modes
M. Saporito
T. T. Taylor
S. M. Walker

Subgroup on Repairs, Replacements, and Modifications (SC XI)

R. E. Gimple, *Chair*
W. C. Holston, *Secretary*
R. W. Boyce
M. N. Bressler
S. B. Brown
C. E. Hartz
R. A. Hermann
C. A. Ireland
R. D. Kerr
D. F. Landers
R. S. Lewis
T. J. Mawson
M. S. McDonald
R. R. Stevenson

R. P. Sullivan
R. W. Swayne
R. E. Tome
D. E. Waskey
R. A. Yonekawa

Page xx

Working Group on Design Reconciliation (SG-RR&M) (SC XI)

W. C. Holston, *Chair*
J. T. Conner, *Secretary*
R. W. Boyce
S. B. Brown
J. E. Charnley
T. E. Hiss
E. V. Imbro
D. N. Irvine, Jr.
D. F. Landers
R. W. Swayne
F. Tehranchi
H. J. Thailer
R. E. Tome

Working Group on Responsibilities and Program Requirements (SG-RR&M) (SC XI)

R. A. Yonekawa, *Chair*
R. R. Stevenson, *Secretary*
S. K. Fisher
G. M. Foster
C. E. Hartz
R. S. Lewis
M. S. McDonald
U. Potapovs
S. M. Swilley
A. J. Walcutt
J. Ghergurovich, *Alternate*

Working Group on Welding and Special Repair Processes (SG-RR&M) (SC XI)

D. E. Waskey, *Chair*
R. E. Cantrell, *Secretary*
D. A. Delsignore
A. L. Finney
P. D. Fisher
A. J. Giannuzzi
R. A. Hermann
R. P. Indap
R. D. Kerr
B. R. Newton
P. P. Norris
J. E. O'Sullivan

J. H. Sodergren
K. R. Willens

Subgroup on Water-Cooled Systems (SC XI)

T. F. Lentz, *Chair*
K. Christian, *Secretary*
C. W. Allison
W. J. Briggs
T. R. Bugelholli
D. D. Davis
A. F. Deardorff
R. L. Dyle
L. B. Gross
T. C. Hinkle
S. D. Kulat
M. P. Lintz
J. E. Staffiera
C. W. Tahnk
R. J. Tamminga
D. Terao
S. M. Walker
R. A. West

Working Group on Concrete Containment (SG-WCS) (SC XI)

W. J. Briggs, *Chair*
B. Talmadge, *Secretary*
H. G. Ashar
K. K. N. Chao
M. J. Ferlisi
H. T. Hill
R. D. Hough
C. N. Krishnaswamy
D. Naus
S. C. Petitgout
C. G. Ranganath

Working Group on Implementation of Risk-Based Examination (SG-WCS) (SC XI)

T. J. Mawson, *Chair*
A. McNeill III, *Secretary*
J. Agold
S. A. Ali
B. A. Bishop
J. W. Connor
A. F. Deardorff
H. Q. Do
R. Fougrousse
S. R. Gosselin
J. T. Lindberg
I. Mach

R. K. Mattu
P. J. O'Regan
J. H. Phillips
F. A. Simonen
T. V. Vo
R. A. West

Working Group on Inspection of Systems and Components (SG-WCS) (SC XI)

R. L. Dyle, *Chair*
G. C. Park, *Secretary*
G. L. Belew
T. W. Brombach
R. Fougrousse
T. C. Hinkle
M. R. Hum
S. D. Kulat
J. T. Lindberg
M. P. Lintz
T. K. McLellan
C. Pendleton
C. M. Ross
C. W. Tahnk
K. B. Thomas
E. Throckmorton
R. A. West
J. Whitiman

Working Group on Metal Containment (SG-WCS) (SC XI)

J. E. Staffiera, *Chair*
W. E. Norris, *Secretary*
W. J. Briggs
K. K. N. Chao
M. J. Ferlisi
R. W. Hammelmann
M. P. Lintz
S. C. Petitgout
C. G. Ranganath
G. W. Robin
R. T. Zak

Special Working Group on Low-Temperature Heavy Water Reactors (SG-WCS) (SC XI)

C. D. Cowfer, *Chair*
J. M. Morrison, *Secretary*
B. Awadalla
K. F. Schmidt
P. R. Vormelker
S. H. Zaidi

Working Group on General Requirements (SC XI)

Working Group on General Requirements (SC XI)

A. T. Roberts III, *Chair*
R. G. Edl, *Secretary*
D. A. Graham
L. B. Gross
C. A. Ireland
D. A. Jackson
R. K. Mattu
L. Sage
R. J. Scott
J. C. Shropshire
R. J. Tamminga

Special Working Group on Editing and Review (SC XI)

R. W. Swayne, *Chair*
R. L. Beverly
L. B. Gross
M. P. Lintz
J. E. Staffiera
C. J. Wirtz

Special Working Group on Plant Life Extension (SC XI)

F. E. Gregor, *Chair*
L. B. Gross, *Secretary*
D. D. Davis
D. A. Graham
D. L. Harrison
M. P. Lintz
P. Manbeck
H. W. Massie, Jr.
D. W. Peltola
D. A. Piccione
C. M. Regan
V. N. Shah
R. J. Tamminga

SUBCOMMITTEE ON TRANSPORT TANKS (SC XII)

A. Selz, *Chair*
P. D. Stumpf, *Secretary*
A. N. Antoniou
S. C. Cyr
K. Ennis
M. Hennemand
C. H. Hochman
G. G. Karcher
P. P. Laluc
G. McRae
M. R. Minick
T. P. Pastor

M. D. Rana
C. M. Serratella
G. R. Stoeckinger
N. Surtees
J. P. Swezy
A. P. Varghese
S. V. Voorhees
W. L. White

Page xxi

Subgroup on Design and Materials (SC XII)

M. D. Rana, *Chair*
D. A. Canonico
W. D. Doty
G. G. Karcher
P. P. Laluc
T. P. Pastor
T. A. Rogers
C. M. Serratella
A. P. Varghese
E. Whittle

Subgroup on Fabrication and Inspection (SC XII)

S. V. Voorhees, *Chair*
D. A. Canonico
M. L. Coats
M. Hennemand
D. J. Kreft
G. McRae
M. R. Minick
N. Surtees
J. P. Swezy

Subgroup on General Requirements (SC XII)

C. H. Hochman, *Chair*
T. Alexander
A. N. Antoniou
D. Carter
K. Ennis
M. A. Garrett
J. C. Keenan
F. A. Licari
G. R. Stoeckinger
W. L. White

SUBCOMMITTEE ON BOILER AND PRESSURE VESSEL ACCREDITATION (SC-BPVA)

A. J. Spencer, *Chair*
A. J. Justin, *Vice Chair*
K. I. Baron, *Secretary*

M. B. Doherty
D. A. Douin
P. D. Edwards
R. M. Elliott
C. E. Ford
J. J. Greene
R. C. Howard
B. B. MacDonald
M. L. Sisk
B. C. Turczynski
R. V. Wielgoszinski
R. L. Williams
V. A. Bell, Alternate
V. Bogosian, Alternate
M. A. De Vries, Alternate
J. R. Farr, Alternate
R. G. Friend, Alternate
W. C. LaRochelle, Alternate
A. S. Lester III, Alternate
K. M. McTague, Alternate
G. P. Milley, Alternate
R. E. Muise, Alternate
P. G. Scheckermann, Alternate
N. Surtees, Alternate

SUBCOMMITTEE ON NUCLEAR ACCREDITATION (SC-NA)

T. E. Quaka, *Chair*
R. R. Stevenson, *Vice Chair*
S. Griffin, *Secretary*
C. W. Allison
M. N. Bressler
G. Deily
F. R. Drahos
J. E. Harris
M. Kotb
W. C. LaRochelle
U. Potapovs
H. B. Prasse
A. J. Spencer
G. M. Tolson
L. M. Beason, Alternate
R. W. Boyce, Alternate
S. Dasgupta, Alternate
P. D. Edwards, Alternate
J. P. Ellenberger, Alternate
R. E. Feigel, Alternate
D. Hanrath, Alternate

D. Hanrath, Alternate
K. A. Huber, Alternate
A. J. Justin, Alternate
N. C. Kist, Alternate
A. A. Lotfi, Alternate
R. P. McIntyre, Alternate
O. E. Trapp, Staff Representative

SUBCOMMITTEE ON DESIGN (SC-D)

W. J. Carter, *Chair*
F. S. Fitzgerald, *Secretary*
R. W. Barnes
C. Becht IV
O. F. Hedden
R. W. Mikitka
K. Mokhtarian
W. J. O'Donnell
R. D. Schueler, Jr.
M. P. Schwartz
A. Selz

Subgroup on Design Analysis (SC-D)

T. P. Pastor, *Secretary*
P. J. Conlisk
A. G. Eggers
J. L. Hechmer
G. L. Hollinger
D. P. Jones
A. Kalnins
W. J. Koves
T. H. Liu
O. Maekawa
A. Merend
T. V. Narayanan
E. L. Thomas, Jr.

Subgroup on Elevated Temperature Design (SC-D)

C. Becht IV, *Chair*
J. M. Corum, *Secretary*
C. R. Brinkman
R. D. Campbell
D. S. Griffin
R. I. Jetter
C. Lawton
W. J. O'Donnell
D. A. Osage
C. C. Schultz, Jr.
L. K. Severud
D. F. Shaw

A. L. Snow
B. E. Thurgood

Subgroup on Fatigue Strength (SC-D)

C. R. Brinkman
P. R. Donavin
J. A. Hayward
J. L. Hechmer
D. P. Jones
G. Kharshafdjian
C. Lawton
A. Merend
H. H. Ziada

Subgroup on Openings (SC-D)

M. P. Schwartz, *Chair*
R. W. Mikitka, *Secretary*
M. R. Breach
V. T. Hwang
S. C. Lou
R. B. Luney
J. P. Madden
K. C. Morrison
D. R. Palmer
M. D. Rana
E. C. Rodabaugh

Special Working Group on Bolted Flanged Joints (SC-D)

R. W. Mikitka, *Chair*
G. D. Bibel
G. Kharshafdjian
D. L. Kurle
E. Michalopoulos
S. N. Pagay
J. R. Payne
R. W. Schneider
R. D. Schueler, Jr.
A. Selz

SUBCOMMITTEE ON SAFETY VALVE REQUIREMENTS (SC-SVR)

E. C. Kistner, Jr., *Chair*
M. D. Bernstein, *Vice Chair*
U. D'Urso, *Secretary*
J. F. Ball
J. A. Cox
R. D. Danzy
R. J. Doelling
D. A. Douin
R. G. Friend

H. I. Gregg
S. F. Harrison, Jr.
C. F. Laitner
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson
D. J. Scallan
C. M. Schroepfer
A. J. Spencer
J. C. Standfast
E. A. Steen
L. L. Thompson
J. A. West
T. J. Ferrigan, Alternate

Page xxii

Subgroup on Design (SC-SVR)

R. G. Friend, *Chair*
J. Cahoon, Jr.
R. D. Danzy
D. B. DeMichael
R. J. Doelling
H. I. Gregg
S. R. Irvin
C. F. Laitner
P. R. Sievert
A. J. Spencer
E. A. Steen
T. R. Tarbay
J. A. West

Subgroup on General Requirements (SC-SVR)

M. D. Bernstein, *Chair*
J. F. Ball
V. M. Deluca
D. A. Douin
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson
J. C. Standfast
L. L. Thompson

Subgroup on Testing (SC-SVR)

S. F. Harrison, Jr., *Chair*
S. Cammeresi
J. A. Cox

ORGANIZATION OF SECTION III

1. GENERAL

Section III consists of Division 1, Division 2, and Division 3. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter "N" for Division 1, by the letter "C" for Division 2, and by the letter "W" for Division 3. The following eleven books make up the three Divisions.

Subsection NCA - General Requirements for Division 1 and Division 2

Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

Division 2 - Code for Concrete Reactor Vessels and Containments

Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

The Division 2 book includes Subsection CC - Concrete Containments and Division 2 Appendices.

The Division 3 book includes Subsections WA and WB for General Requirements and Class TP (Type B) Containment, respectively.

2. SUBSECTIONS

Subsections are divided into Articles, Subarticles, paragraphs, and, where necessary, subparagraphs and subsubparagraphs.

3. ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections followed by Arabic numbers, such as NB-1000. Where possible, Articles dealing with the same topics are given the same number in each Subsection in accordance with the following general scheme:

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination

6000	Examination
7000	Testing
8000	Overpressure Protection
	Nameplates, Stamping, and Reports

The numbering of Articles and the material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the rules have been prepared with some gaps in the numbering.

4. SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

5. SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as NB-2130, and generally have no text. When a number such as NB-1110 is followed by text, it is considered a paragraph.

6. PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

7. SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as NB-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

8. SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

Page xxiv

9. REFERENCES

References used within Section III generally fall into one of the following four categories.

A. References to Other Portions of Section III

When a reference is made to another Article, Subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to NB-3000 includes all material in Article NB-3000; reference to NB-3200 includes all material in Subarticle NB-3200; reference to NB-3230 includes all paragraphs NB-3231 through NB-3236.

B. References to Other Sections

Other Sections referred to in Section III are:

Section II, Materials. When a requirement for a material, or for the examination or testing of a material, is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II. These references begin with the letter "S."

Section V, Nondestructive Examination. Section V references begin with the letter "T" and relate to the nondestructive examination of material or welds.

Section IX, Welding and Brazing Qualifications. Section IX references begin with the letter "Q" and relate to welding and brazing requirements.

Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components. When a reference is made to inservice

inspection, the rules of Section XI shall apply.

C. Reference to Specifications and Standards Other Than Published in Code Sections

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials. At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E 71-64 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

2 The American National Standards Institute (ANSI) was formerly known as the American Standards Association. Standards approved by the Association were designated by the prefix "ASA" followed by the number of the standard and the year of publication. More recently, the American National Standards Institute was known as the United States of America Standards Institute. Standards were designated by the prefix "USAS" followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the numbers of the standards have remained unchanged.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by the American Society of Mechanical Engineers and approved by the American National Standards Institute.² When a product is to conform to such a standard, for example ANSI B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NB-3132-1, for example ANSI B16.5-1977. Standards published by the American Society of Mechanical Engineers are available from ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-6, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, 127 Park Street, N.E., Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NB-3132-1, for example MSS SP-6-1963.

(4) Specifications for welding and brazing materials are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33135. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix "SF," for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-620 and API-2000. When documents so designated are referred to in Section III, they are standards published by the American Petroleum Institute.

D. References to Appendices

Two types of Appendices are used in Section III and are designated Mandatory and Nonmandatory.

(1) Mandatory Appendices contain requirements which must be followed in construction; such references are designated by a Roman numeral followed by Arabic numerals. References to II-1100 or XI-3212, for example, relate to the Mandatory Appendices.

(2) Nonmandatory Appendices provide information or guidance for the use of Section III; such references are designated by a capital letter followed by Arabic numerals. A reference to D-1100, for example, relates to a Nonmandatory Appendix.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 APP SI UNITS

SI UNITS

The 1998 Edition of the Boiler and Pressure Vessel Code is based on U.S. Customary (ft-lb) units of measurement which are to be regarded as the standard. This supplement is provided as a convenience to the Code user and contains SI conversion factors for units contained in the Code.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

Quantity	Unit	Symbol	Other Units or Limitations
Space and Time			
plane angle	radian	rad	degree (decimalized)
length	meter	m	
area	square meter	m ²	
volume	cubic meter	m ³	liter (L) for liquid only (use without prefix other than in milliliter, mL)
time	second	s	minute (min), hour (h), day (d), week, and year
Periodic and Related Phenomena			
frequency	hertz	Hz	revolutions per second (r/s)
rotational frequency	revolutions per second	s ⁻¹	revolutions per minute (r/m)
Mechanics			
mass	kilogram	kg	
density	kilogram per cubic meter	kg/m ³	
moment of inertia	kilogram · meter ²	kg · m ²	
force	newton	N	
moment of force (torque)	newton-meter	N · m	
pressure and stress	pascal	Pa	(pascal = newton per square meter)
energy, work	joule	J	kilowatt-hour (kW · h)
power	watt	W	
impact strength	joule	J	
section modulus	meter ³	m ³	
moment of section (second moment of area)	meter ⁴	m ⁴	
fracture toughness	Pa · $\sqrt{m}$		
Heat			
temperature — thermodynamic [Note (2)]	kelvin	K	degree Celsius (°C)
temperature — other than thermodynamic	degree Celsius	°C	kelvin (K)
linear expansion coefficient	meter per meter-kelvin	K ⁻¹	°C ⁻¹
quantity of heat	joule	J	
heat flow rate	watt	W	
thermal conductivity	watt per meter-kelvin	W/(m · K)	W/(m · °C)
thermal diffusivity	square meter per second	m ² /s	
specific heat capacity	joule per kilogram-kelvin	J/(kg · K)	J/(kg · °C)
Electricity and Magnetism			
electric current	ampere	A	
electric potential	volt	V	
current density	ampere per meter ²	A/m ²	
magnetic field strength	ampere per meter	A/m	

NOTES:

- (1) Conversion factors between SI units and U.S. customary are given in SI-1, "ASME Orientation and Guide for Use of SI (Metric) Units," and ASTM E 380.
- (2) Preferred use for temperature and temperature interval is degrees Celsius (°C), except for thermodynamic and cryogenic work where kelvins may be more suitable. For temperature interval, 1 K = 1°C exactly.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

COMMONLY USED CONVERSION FACTORS (For Others See ASTM E 380) [See Note (1)]

Quantity	To Convert From	To	Multiply by [Note (2)]	
plane angle	degree	rad	1.745 329	E-02
length	in	m	2.54*	E-02
	ft	m	3.048*	E-01
	yd	m	9.144*	E-01
area	in ²	m ²	6.451 6*	E-04
	ft ²	m ²	9.290 304*	E-02
	yd ²	m ²	8.361 274	E-01
volume	in ³	m ³	1.638 706	E-05
	ft ³	m ³	2.831 685	E-02
	US gallon	m ³	3.785 412	E-03
	Imperial gallon	m ³	4.546 09	E-03
	liter	m ³	1.0*	E-03
mass	lbm	kg	4.535 924	E-01
	ton (metric) (mass)	kg	1.000 00*	E+03
	ton (short 2000 lbm)	kg	9.071 847	E+02
force	kgf	N	9.806 65*	E+00
	lbf	N	4.448 222	E+00
bending, torque	kgf · m	N · m	9.806 65*	E+00
	lbf · in	N · m	1.129 848	E-01
	lbf · ft	N · m	1.355 818	E+00
pressure, stress	kgf/m ²	Pa	9.806 65*	E+00
	lbf/ft ²	Pa	4.788 026	E+01
	lbf/in ² (psi)	Pa	6.894 757	E+03
	kips/in ²	Pa	6.894 757	E+06
	bar	Pa	1.0*	E+05
energy, work	Btu (IT) [Note (3)]	J	1.055 056	E+03
	ft · lbf	J	1.355 818	E+00
power	hp (550 ft · lbf/s)	W	7.456 999	E+02
fracture toughness	ksi $\sqrt{\text{in}}$	Pa · $\sqrt{\text{m}}$	1.098 843	E+06
temperature	°C	K	$t_K = t_C + 273.15$	
	°F	K	$t_K = (t_F + 459.67)/1.8$	
	°F	°C	$t_C = (t_F - 32)/1.8$	
temperature interval	°C	K	1.0*	E+00
	°F	K or °C	5.555 555	E-01

NOTES:

(1) Care should be taken when converting formulas or equations that contain constant terms or factors. The value of these terms must be understood and may also require conversion.

(2)(a) Relationships that are exact in terms of the base units are followed by a single asterisk.

(b) The factors are written as a number greater than 1 and less than 10 with 6 or less decimal places. The number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example: 3.523 907 E-02 is $3.523\ 907 \times 10^{-2}$ or 0.035 239 07.

(3) International Table

July 1, 1998

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

SEC III D1 MA APP I

APPENDIX I DESIGN STRESS INTENSITY VALUES, ALLOWABLE STRESSES, MATERIAL PROPERTIES, AND DESIGN FATIGUE CURVES

Page 3

Tables I-1.0 Design Stress Intensity Values S_m for Class 1 Components

Refer to Section II, Part D, Subpart 1, Tables 2A, 2B, and 4

Tables I-2.0 Yield Strength Values S_y

Refer to Section II, Part D, Subpart 1, Tables Y-1 and Y-2

Tables I-3.0 Tensile Strength Values S_u

Refer to Section II, Part D, Subpart 1, Table U

Table I-4.0 Nominal Coefficients of Thermal Conductivity (TC) and Thermal Diffusivity (TD)

Refer to Section II, Part D, Subpart 1, Table TCD Table TCD

Table I-5.0 Nominal Coefficients of Thermal Expansion

Refer to Section II, Part D, Subpart 1 Tables TE

Table I-6.0 Moduli of Elasticity E of Materials for Given Temperatures

Refer to Section II, Part D, Subpart 1, Tables TM

Tables I-7.0 Allowable Stress Values S for Class 3 Components

Refer to Section II, Part D, Subpart 1, Tables 1A, 1B, and 3

Tables I-8.0 Allowable Stress Values S for Class 3 Components

Refer to Section II, Part D, Subpart 1, Tables 1A, 1B, and 3

Page 4

Tables I-9.0 Design Fatigue Curves

Table I-9.1 Tabulated Values of S_a ksi, From Figs. I-9.0 ...5

Fig. I-9.1 Design Fatigue Curves for Carbon, Low Alloy, and High Tensile Steels for Metal Temperatures Not Exceeding 700°F ...6

Fig. I-9.2.1 Design Fatigue Curve for Austenitic Steels, Nickel-Chromium-Iron Alloy, Nickel-Iron-Chromium Alloy, and Nickel-Copper Alloy for $S_a > 28.2$ ksi, for Temperatures Not Exceeding 800°F ...7

Fig. I-9.2.2 Design Fatigue Curves for Austenitic Steels, Nickel-Chromium-Iron Alloy, Nickel-Iron-Chromium Alloy, and Nickel-Copper Alloy for $S_a \leq 28.2$ ksi, for Temperatures Not Exceeding 800°F ...8

Table I-9.2.2 Tabulated Values of S_a ksi, From Fig. I-9.2.2 ...9

Fig. I-9.2.3 Flow Chart for Use of Curves in Fig. I-9.2.2 ...10

Fig. I-9.3 Design Fatigue Curves for Wrought 70 Copper-30 Nickel Alloy for Temperatures Not Exceeding 800°F ...11

Fig. I-9.4 Design Fatigue Curves for High Strength Steel Bolting for Temperatures Not Exceeding 700°F ...12

Fig. I-9.5 Design Fatigue Curve for Nickel-Chromium-Molybdenum-Iron Alloys (UNS N06003, N06007, N06455, and N10276) for Temperatures Not Exceeding 800°F ...13

Table I-9.5 Tabulated Values of S_a , ksi, From Fig. I-9.5 ...14

Fig. I-9.6 Design Fatigue Curve for Grade 9 Titanium for Temperatures Not Exceeding 600°F ...15

Tables I-11.0 Design Stress Intensity Values S_m for Class 1 Plate and Shell Type Supports

Refer to Section II, Part D, Subpart 1, Tables 2A and 2B

Tables I-12.0 Allowable Stress Values S for Class 2, 3, and MC Plate and Shell Type Supports

Refer to Section II, Part D, Subpart 1, Tables 1A and 1B

Tables I-13.0 Yield Strength Values S_y for Class 1, 2, 3, and MC Linear Type Supports

Refer to Section II, Part D, Subpart 1, Table Y-1

Tables I-14.0 External Pressure Chart References

Table I-14.1 External Pressure Chart References for Ferrous Steels ...17

Table I-14.2 External Pressure Chart References for Nonferrous Materials ...20

Page 5

TABLE I-9.0

Page 6

TABLE I-9.1
TABULATED VALUES OF S_a , ksi, FROM FIGS. I-9.3-9.6

Figure	Curve	Number of Cycles (Note D3)															
		1E1	2E1	3E1	1E2	2E2	3E2	1E3	2E3	3E3	1E4	2E4	3E4	1E5	2E5	3E5	1E6
I-9.1	UTS 115-130 ksi	420	320	230	175	135	105	...	70	62	49	44	43	36	29	26	24
I-9.1	UTS 140 ksi	580	410	275	205	155	105	...	83	64	48	38	...	31	23	20	16.5
I-9.2.1	...	708	512	345	261	201	148	...	119	97	76	64	...	55.5	46.3	40.8	35.9
I-9.2.2	See Table I-9.2.2.1	260	190	125	95	73	52	...	44	36	28.5	24.5	...	21	17	15	13.5
I-9.3	$S_y = 18.0$ ksi	260	190	125	95	73	52	...	44	36	28.5	24.5	...	19.5	15	13	11.5
I-9.3	$S_y = 30.0$ ksi	260	190	125	95	73	52	...	44	36	28.5	24.5	...	13.5	9.5	8.0	6.0
I-9.3	$S_y = 45.0$ ksi	260	190	125	95	73	52	46	39	24.5	15.5	12	...	9.4	7.7	6.7	5.2
I-9.4	MIS 52.7 S_a (Note D3)	1150	760	500	320	225	143	...	100	71	45	34	...	27	22	19	15
I-9.4	MIS = 352 (Note D3)	1150	760	500	300	200	122	...	81	55	33	22.5	...	15	10.5	8.4	7.1

NOTES:
(1) These data points are included to provide accurate representation of curves at branches or cusps.
(2) Interpolation between tabular values is permissible based upon data representation by straight lines on a log-log plot. Accordingly, for $S_a > S_y$.

(3) The number of cycles indicated shall be read as follows: 1E1 = 1×10^1 cycles, 2E2 = 2×10^2 or 200 cycles, etc.

(4) These data points are included to provide accurate representation of curves at branches or cusps.

(5) MIS is the Minimum Tensile Stress.

(6) The number of cycles indicated shall be read as follows: 1E1 = 1×10^1 cycles, 2E2 = 2×10^2 or 200 cycles, etc.

(7) MIS is the Minimum Tensile Stress.

(8) The number of cycles indicated shall be read as follows: 1E1 = 1×10^1 cycles, 2E2 = 2×10^2 or 200 cycles, etc.

(9) The number of cycles indicated shall be read as follows: 1E1 = 1×10^1 cycles, 2E2 = 2×10^2 or 200 cycles, etc.

(10) The number of cycles indicated shall be read as follows: 1E1 = 1×10^1 cycles, 2E2 = 2×10^2 or 200 cycles, etc.

(11) The number of cycles indicated shall be read as follows: 1E1 = 1×10^1 cycles, 2E2 = 2×10^2 or 200 cycles, etc.

(12) The number of cycles indicated shall be read as follows: 1E1 = 1×10^1 cycles, 2E2 = 2×10^2 or 200 cycles, etc.

(13) The number of cycles indicated shall be read as follows: 1E1 = 1×10^1 cycles, 2E2 = 2×10^2 or 200 cycles, etc.

(14) The number of cycles indicated shall be read as follows: 1E1 = 1×10^1 cycles, 2E2 = 2×10^2 or 200 cycles, etc.

(15) The number of cycles indicated shall be read as follows: 1E1 = 1×10^1 cycles, 2E2 = 2×10^2 or 200 cycles, etc.

(16) The number of cycles indicated shall be read as follows: 1E1 = 1×10^1 cycles, 2E2 = 2×10^2 or 200 cycles, etc.

(17) The number of cycles indicated shall be read as follows: 1E1 = 1×10^1 cycles, 2E2 = 2×10^2 or 200 cycles, etc.

(18) The number of cycles indicated shall be read as follows: 1E1 = 1×10^1 cycles, 2E2 = 2×10^2 or 200 cycles, etc.

(19) The number of cycles indicated shall be read as follows: 1E1 = 1×10^1 cycles, 2E2 = 2×10^2 or 200 cycles, etc.

(20) The number of cycles indicated shall be read as follows: 1E1 = 1×10^1 cycles, 2E2 = 2×10^2 or 200 cycles, etc.

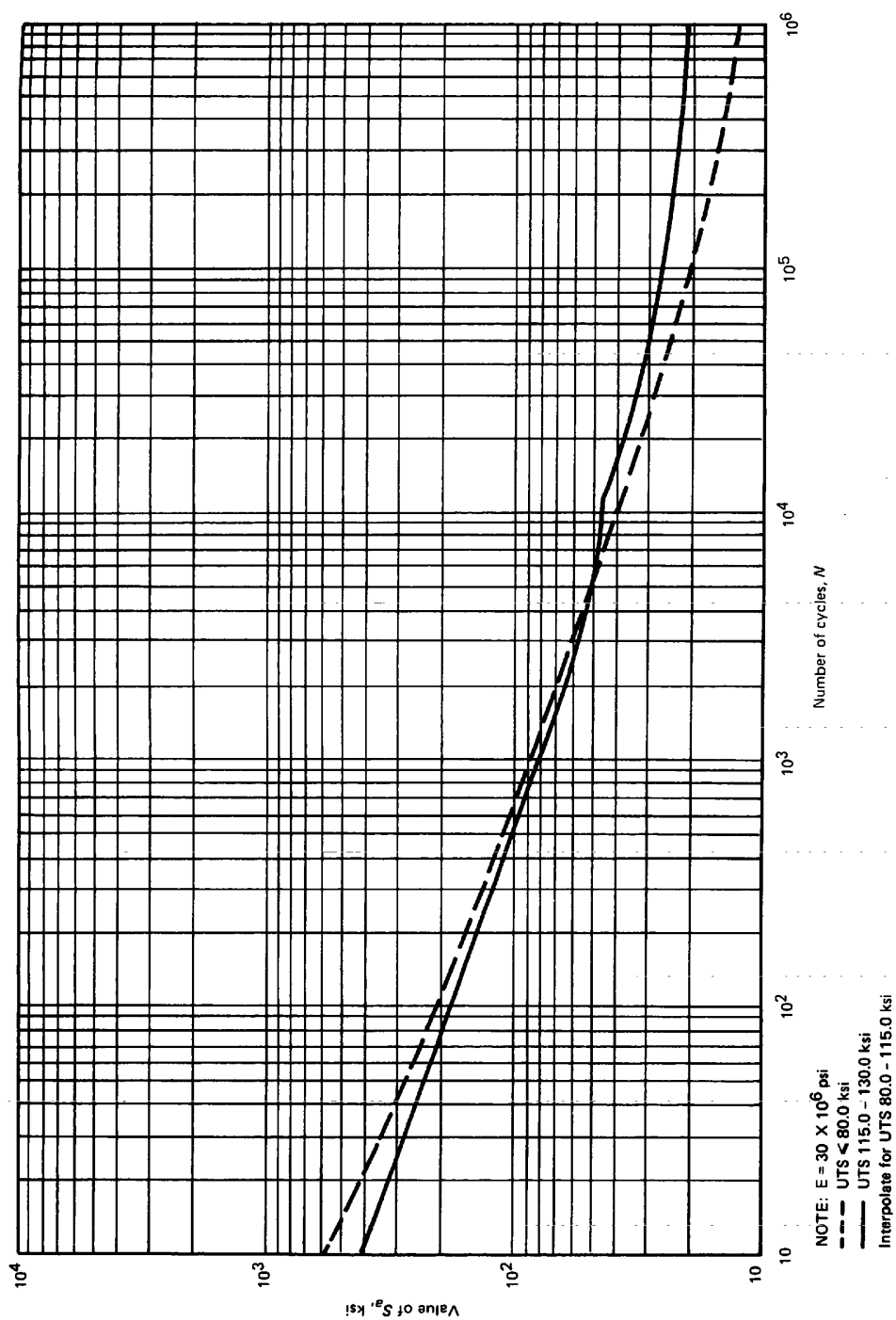


FIG. 1-9.1 DESIGN FATIGUE CURVES FOR CARBON, LOW ALLOY, AND HIGH TENSILE STEELS FOR METAL TEMPERATURES NOT EXCEEDING 700°F

TEMPERATURES NOT EXCEEDING 700 F

FIG. I-9.1 DESIGN FATIGUE CURVES FOR CARBON, LOW ALLOY, AND HIGH TENSILE STEELS FOR METAL TEMPERATURES NOT EXCEEDING 700°F

FIG. I-9.2

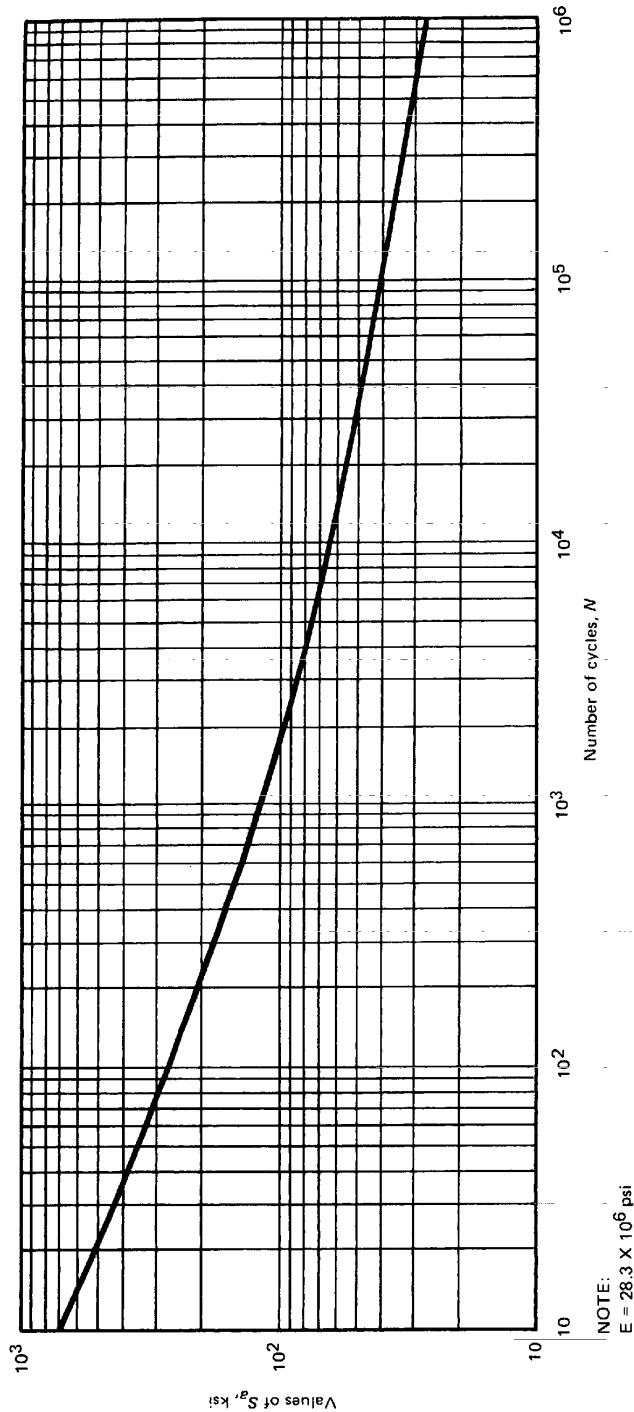
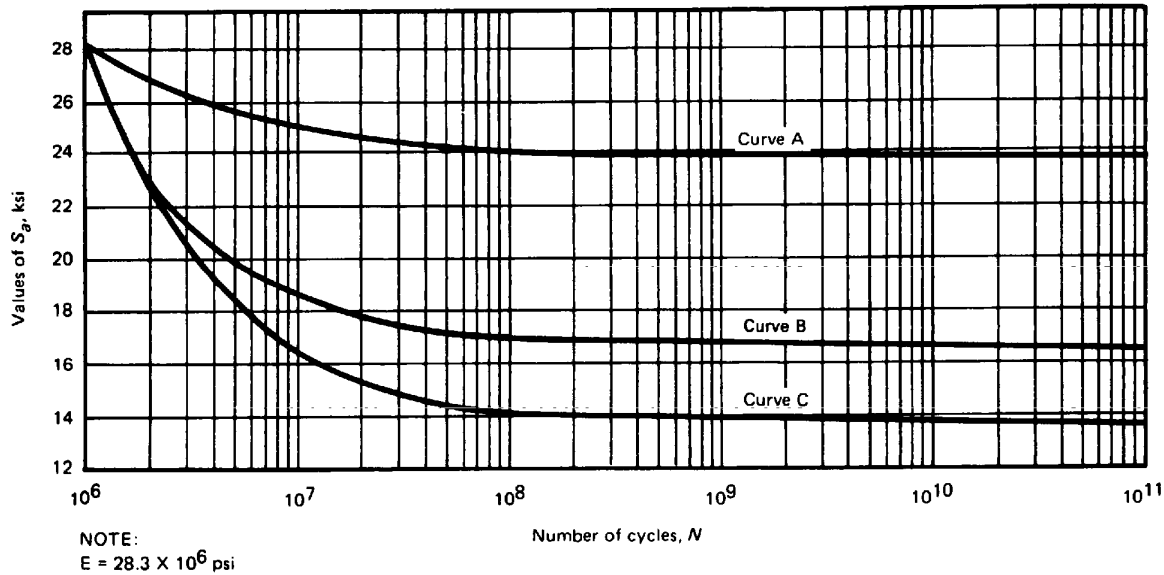


FIG. I-9.2.1 DESIGN FATIGUE CURVE FOR AUSTENITIC STEELS, NICKEL-CHROMIUM-IRON ALLOY, NICKEL-IRON-CHROMIUM ALLOY, AND NICKEL-COPPER ALLOY FOR $S_u > 28.2 \text{ ksi}$, FOR TEMPERATURES NOT EXCEEDING 800°F
(For $S_u \leq 28.2 \text{ ksi}$, use Fig. I-9.2.2.)

Table I-9.1 Contains Tabulated Values and a Formula for Accurate Interpolation of This Curve

FIG. I-9.2.1 DESIGN FATIGUE CURVE FOR AUSTENITIC STEELS, NICKEL-CHROMIUM-IRON ALLOY, NICKEL-IRON-CHROMIUM ALLOY, AND NICKEL-COPPER ALLOY FOR $S_a > 28.2$ ksi, FOR TEMPERATURES NOT EXCEEDING 800°F



Criteria for the Use of the Curves in This Figure
 [Notes (1)–(5)]

Curve	Elastic Analysis of Material Other Than Welds and Adjacent Base Metal	Elastic Analysis of Welds and Adjacent Base Metal
A	$(P_L + P_b + Q)_{\text{Range}} \leq 27.2$ ksi	...
B	$(P_L + P_b + Q)_{\text{Range}} > 27.2$ ksi and S_a is corrected for applied mean stress	$(P_L + P_b + Q)_{\text{Range}} \leq 27.2$ ksi
C	$(P_L + P_b + Q)_{\text{Range}} > 27.2$ ksi	$(P_L + P_b + Q)_{\text{Range}} > 27.2$ ksi

- NOTES:
- (1) Range applies to the individual quantities P_L , P_b , and Q and applies to the set of cycles under consideration.
 - (2) Thermal bending stresses resulting from axial and radial gradients are excluded from Q .
 - (3) Curve A is also to be used with inelastic analysis with $S_a = \frac{3}{2} \Delta \epsilon_t E$, where $\Delta \epsilon_t$ is the total effective strain range.
 - (4) The maximum effect of retained mean stress is included in Curve C.
 - (5) The adjacent base metal is defined as three wall thicknesses from the center line of the weld.

FIG. I-9.2.2 DESIGN FATIGUE CURVES FOR AUSTENITIC STEELS, NICKEL-CHROMIUM-IRON ALLOY, NICKEL-IRON-CHROMIUM ALLOY, AND NICKEL-COPPER ALLOY FOR $S_a \leq 28.2$ ksi, FOR TEMPERATURES NOT EXCEEDING 800°F
 (For $S_a > 28.2$ ksi, use Fig. I-9.2.1.)

Table I-9.2.2 Contains Tabulated Values for Accurate Interpolation of This Curve

FIG. I-9.2.2 DESIGN FATIGUE CURVES FOR AUSTENITIC STEELS, NICKEL-CHROMIUM-IRON ALLOY, AND NICKEL-IRON-CHROMIUM ALLOY, AND NICKEL-ALLOY FOR $S_a \leq 28.2$ ksi, FOR TEMPERATURES NOT EXCEEDING 800°F

TABLE I-9.2

Page 10

TABLE I-9.2.2
TABULATED VALUES OF S_a , ksi, FROM FIG. I-9.2.2^{1,2}

Number of Cycles [Note (3)]	Curve A	Curve B	Curve C
1E6	28.2	28.2	28.2
2E6	26.9	22.8	22.8
5E6	25.7	19.8	18.4
1E7	25.1	18.5	16.4
2E7	24.7	17.7	15.2
5E7	24.3	17.2	14.3
1E8	24.1	17.0	14.1
1E9	23.9	16.8	13.9
1E10	23.8	16.6	13.7
1E11	23.7	16.5	13.6

NOTES:

- (1) All notes on Fig. I-9.2.2 apply to these data.
- (2) Interpolation between tabular values is permissible based upon data representation by straight lines on log-log plot. See Table I-9.1, Note (2).
- (3) The number of cycles indicated shall be read as follows:
1EJ = 1×10^J , e.g., 5E6 = 5×10^6 or 5,000,000

TABLE I-9.2.2 TABULATED VALUES OF S_a , ksi, FROM FIG. I-9.2.2^{1,2}

Page 11

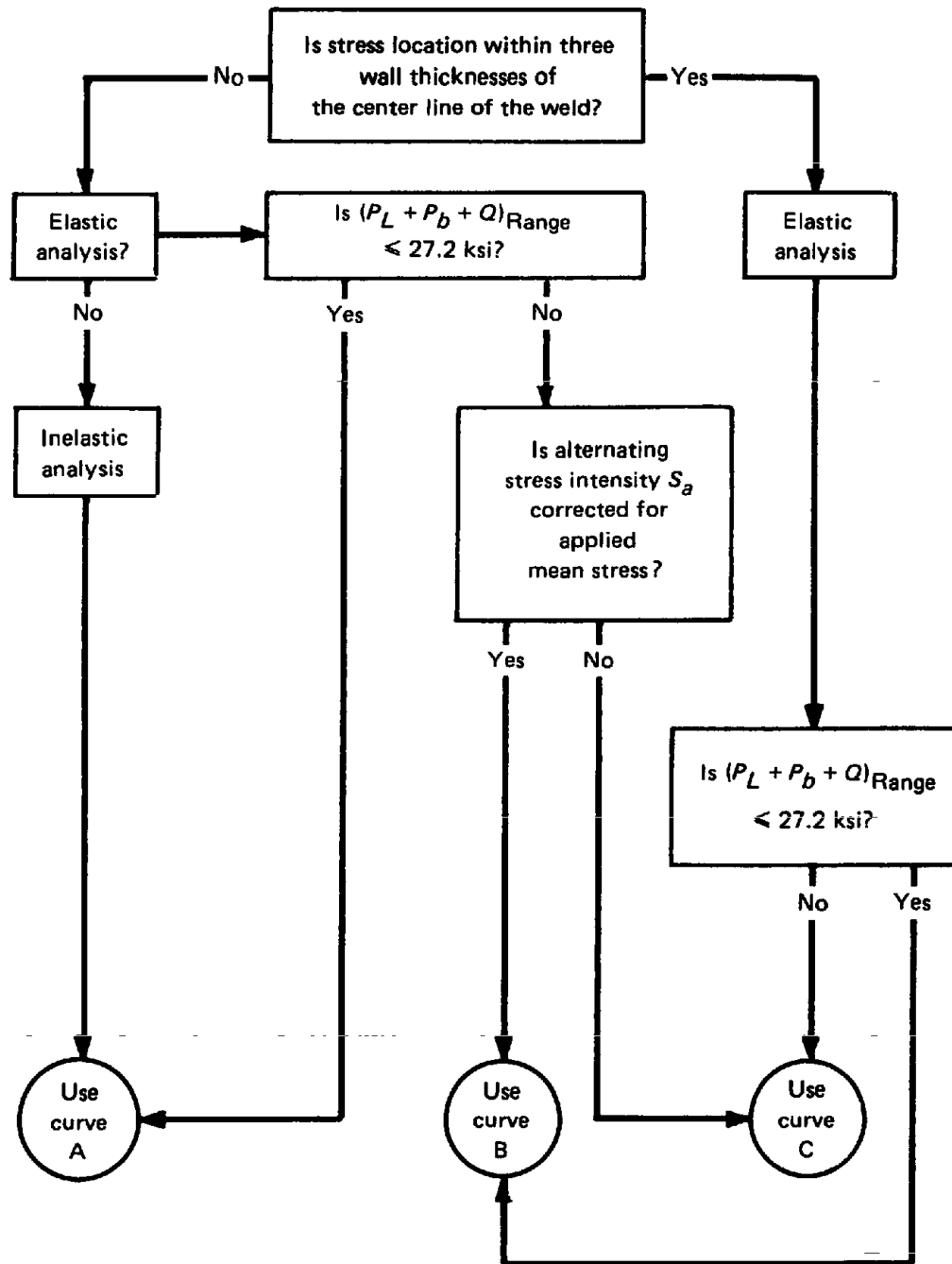


FIG. I-9.2.3 FLOW CHART FOR USE OF CURVES IN FIG. I-9.2.2

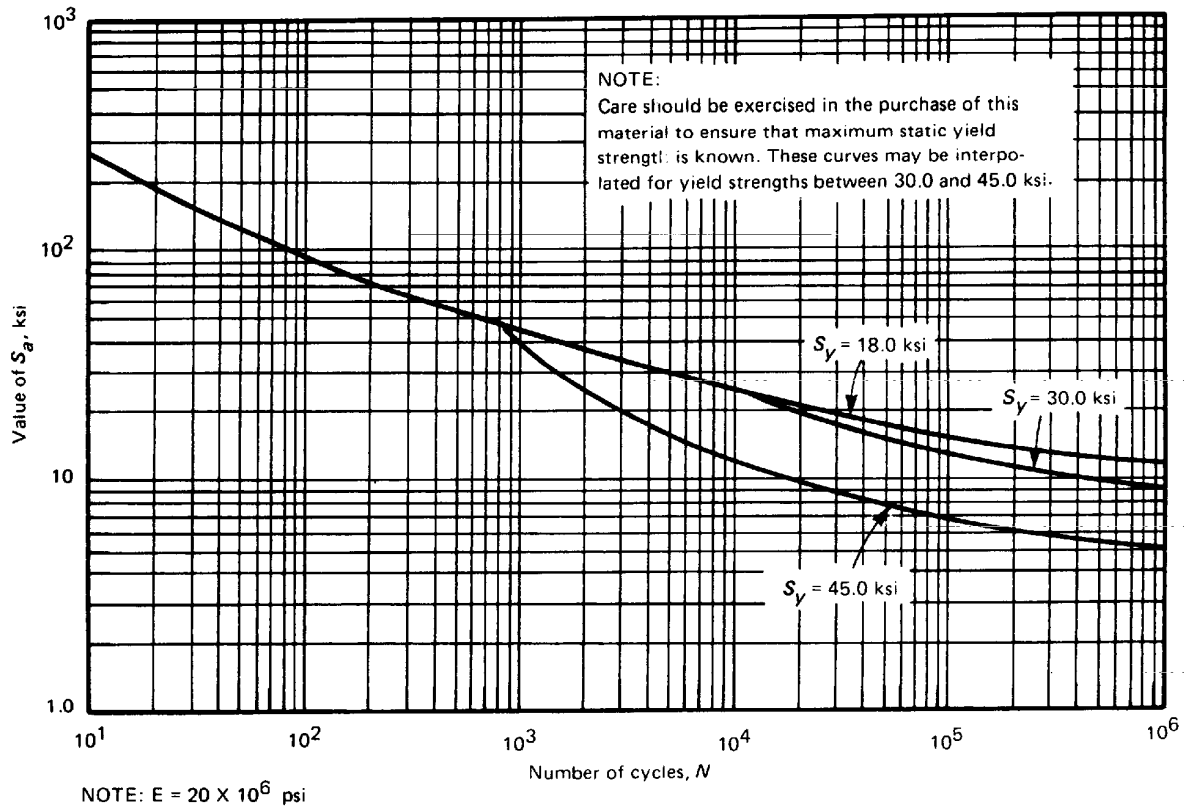


FIG. I-9.3 DESIGN FATIGUE CURVES FOR WROUGHT 70 COPPER-30 NICKEL ALLOY FOR TEMPERATURES NOT EXCEEDING 800°F
Table I-9.1 Contains Tabulated Values and a Formula for Accurate Interpolation of These Curves

FIG. I-9.3 DESIGN FATIGUE CURVES FOR WROUGHT 70 COPPER-30 NICKEL ALLOY FOR TEMPERATURES NOT EXCEEDING 800°

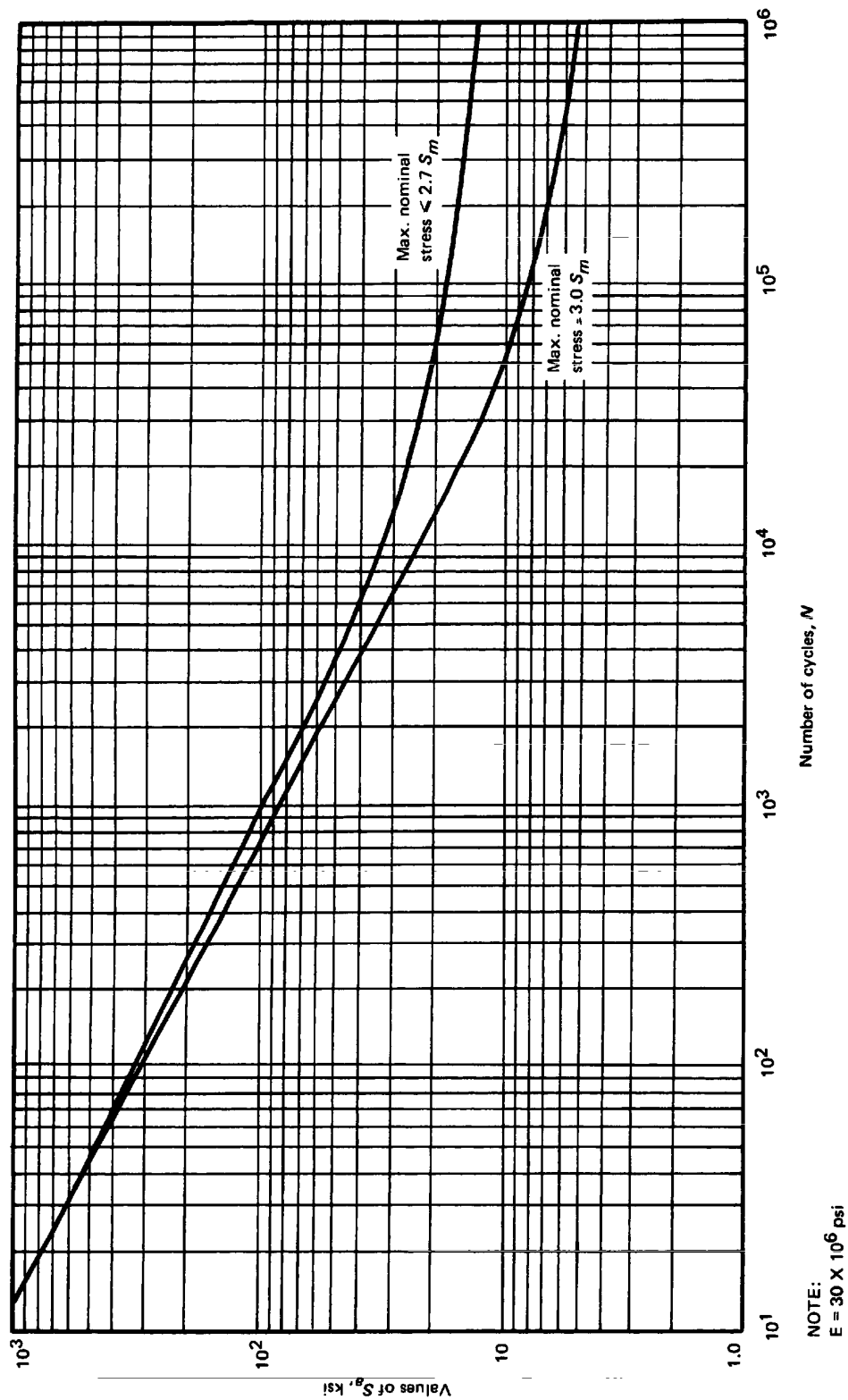
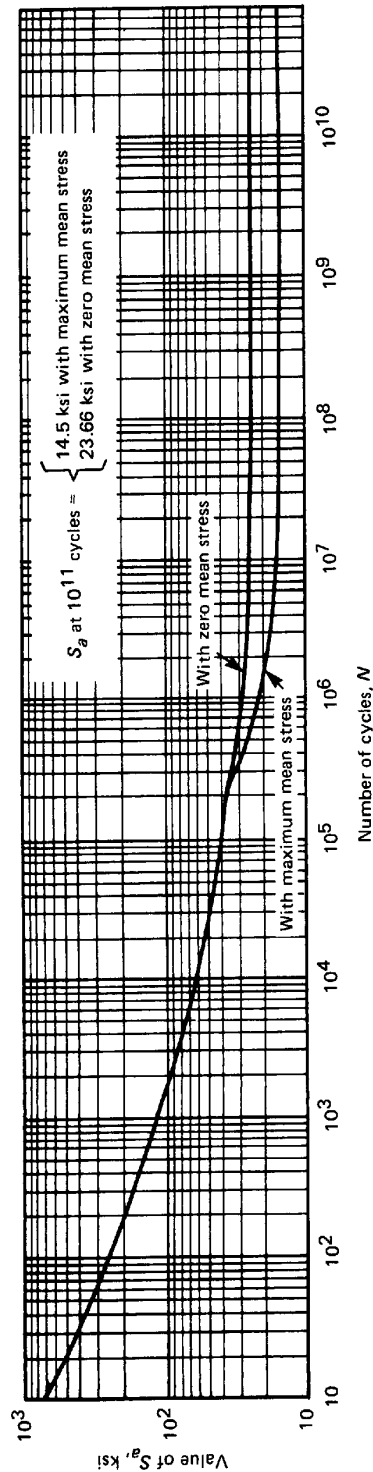


FIG. I-9.4 DESIGN FATIGUE CURVES FOR HIGH STRENGTH STEEL BOLTING FOR TEMPERATURES NOT EXCEEDING 700°F
 Table I-9.1 Contains Tabulated Values and a Formula for Accurate Interpolation of These Curves



NOTES:
 $E = 28.3 \times 10^6$ psi

FIG. I-9.5 DESIGN FATIGUE CURVE FOR NICKEL-CHROMIUM-MOLYBDENUM-IRON ALLOYS (UNS N06003, N06007, N06455, AND N10276) FOR TEMPERATURES NOT EXCEEDING 800°F
Table I-9.5 Contains Tabulated Values, Table I-9.1 Contains a Formula for Accurate Interpolation of This Curve

TABLE I-9.5
TABULATED VALUES OF S_a , ksi, FROM FIG. I-9.5

Number of Cycles [Note (2)]	Zero Mean Stress	Maximum Mean Stress
1E1	708.0	708.0
2E1	512.0	512.0
5E1	345.0	345.0
1E2	261.0	261.0
2E2	201.0	201.0
5E2	148.0	148.0
1E3	119.0	119.0
2E3	97.0	97.0
5E3	76.0	76.0
1E4	64.0	64.0
2E4	56.0	56.0
5E4	46.3	46.3
1E5	40.8	40.8
2E5	35.9	35.9
5E5	31.0	26.0
1E6	28.2	20.7
2E6	26.9	18.7
5E6	25.7	17.0
1E7	25.1	16.2
2E7	24.7	15.7
5E7	24.3	15.3
1E8	24.1	15.0
1E11	23.7	14.5

NOTES:

- (1) Interpolation between tabular values is permissible based upon data representation by straight lines on a log-log plot. See Table I-9.1, Note (2).
- (2) The number of cycles indicated shall be read as follows:
 $1EJ = 1 \times 10^J$, e.g., $5E6 = 5 \times 10^6$ or 5,000,000

TABLE I-9.5 TABULATED VALUES OF S_a , ksi, FROM FIG. I-9.5

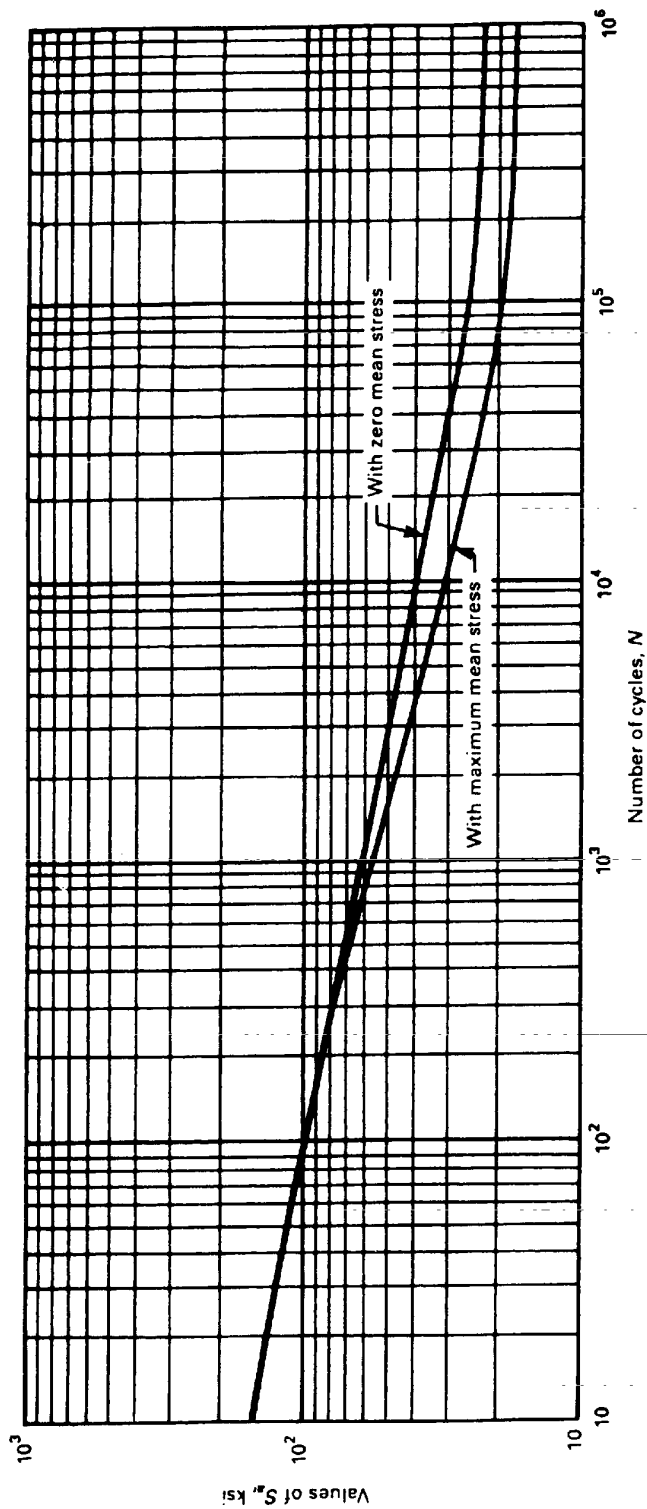


FIG. I-9.6 DESIGN FATIGUE CURVE FOR GRADE 9 TITANIUM FOR TEMPERATURES NOT EXCEEDING 600°F

TABLE I-9.6
TABULATED VALUES OF S_a , ksi FOR GRADE 9
TITANIUM FROM FIG. I-9.6

Number of Cycles	Zero Mean Stress	Maximum Mean Stress
10	151.6	151.6
20	132.4	132.4
50	110.8	110.8
100	96.8	96.8
200	84.6	84.6
500	70.8	67.9
1000	61.9	56.7
2000	54.2	47.3
5000	45.2	37.4
10000	39.4	31.4
20000	34.4	26.6
50000	28.9	21.8
100000	25.8	19.1
200000	24.6	18.5
500000	23.4	17.9
1000000	22.6	17.4

TABLE I-9.6 TABULATED VALUES OF S_a , ksi FOR GRADE 9 TITANIUM FROM FIG. I-9.6

TABLE I-14.1
EXTERNAL PRESSURE CHART REFERENCES FOR FERROUS STEELS¹

Spec. No.	Type or Grade	External Pressure Chart
SA-36	...	CS-2
SA-53	A, B, E/A, E/B, S/A, S/B	CS-2
SA-105	...	CS-2
SA-106	A, B	CS-2
SA-106	C	CS-3
SA-134	A283A, A283B	CS-1
SA-134	A283C, A283D	CS-2
SA-178	C	CS-2
SA-181	60, 70	CS-2
SA-182	F304, F304H, F304LN, 304N	HA-1
SA-182	F304L	HA-3
SA-182	F316, F316H, FXM-19, F316LN, 316N, F321, F321H, F347, F347H, F348, F348H	HA-2
SA-182	F316L	HA-4
SA-203	B, E	CS-3
SA-204	A	CS-2
SA-204	B, C	CS-3
SA-210	A-1	CS-2
SA-213	T2	CS-2
SA-213	TP304, TP304H, TP304LN, TP304N	HA-1
SA-213	TP304L	HA-5
SA-213	TP309, TP316, TP316H, TP316LN, TP316N	HA-2
SA-213	TP316L	HA-4
SA-213	TP321, TP321H, TP347, TP347H, TP348, TP348H	HA-2
SA-216	WCA, WCB	CS-2
SA-234	WPB, WPBW	CS-2
SA-240	304, 304H, 304LN, 304N	HA-4
SA-240	304L	HA-5
SA-240	309S, 310S, 316, 316H, XM-19, 316LN, 316N	HA-2
SA-240	316L	HA-4
SA-240	321, 321H, 347, 347H, 348, 348H	HA-2
SA-240	405, 410S	NFN-8
SA-249	TP304, TP304H, TP304LN, TP304N	HA-1
SA-249	TP304L	HA-8
SA-249	TP309, TP310, TP316, TP316H, TPXM-19, TP316LN, TP316N	HA-2
SA-249	TP316L	HA-4
SA-249	TP321, TP321H, TP347, TP347H, TP348, TP348H	HA-2
SA-266	1, 2, 3	CS-2
SA-283	A, B	CS-1
SA-283	C, D	CS-2
SA-285	A, B	CS-1
SA-285	C	CS-2
SA-299	...	CS-3
SA-302	A, B, C, D	CS-3
SA-312	TP304, TP304H, TP304LN, TP304N	HA-4
SA-312	TP304L	HA-5
SA-312	TP309, TP310, TP316, TP316H, TPXM-19, TP316LN, TP316L	HA-2
SA-312	TP316L	HA-4
SA-312	TP321, TP321H, TP347, TP347H, TP348, TP348H	HA-2
SA-333	1, 6	CS-2
SA-333	9	CS-3
SA-334	1, 6	CS-2
SA-335	P1, P2	CS-2
SA-336	F304N, F304LN, F304, F304H	HA-1
SA-336	F316N, F316LN, F316, F316H	HA-2

TABLE I-14.1 (CONT'D)
EXTERNAL PRESSURE CHART REFERENCES FOR FERROUS STEELS¹

Spec. No.	Type or Grade	External Pressure Chart
SA-350	LF1, LF2	CS-2
SA-352	LCB	CS-2
SA-352	LC2, LC3	CS-3
SA-358	304, 304LN	HA-1
SA-358	309, 310, 316, 321, 347, 348, TP321, TP347, TP348, XM-19, 316LN	HA-2
SA-369	FP1, FP2	CS-2
SA-376	TP304, TP304H, TP304LN	HA-4
SA-376	TP316, TP316H, TP321, TP321H, TP347, TP347H, TP348, TP348H, TP316LN	HA-2
SA-387	2	CS-2
SA-403	WP304, WP304W, WP304H, WP304HW, WP304LN, WP304LNW, WP304N, WP304NW	HA-1
SA-403	WP304L, WP304LW	HA-3
SA-403	WP309, WP309W, WP310, WP310W, WP316, WP316W, WP316H, WP316HW, WP316LN, WP316LNW, WPXM-19, WPXM-19W, WP316N, WP316NW	HA-2
SA-403	WP316L, WP316LW	HA-4
SA-403	WP321, WP321W, WP321H, WP321HW, WP347, WP347W, WP347H, WP347HW, WP348, WP348W, WP348H, WP348HW	HA-2
SA-409	321, 347, 348	HA-2
SA-409	TP304	HA-4
SA-409	TP304L	HA-3
SA-409	TP309, TP310, TP316, TP321, TP347, TP348	HA-2
SA-409	TP316L	HA-4
SA-414	C	CS-2
SA-420	WPL6, WPL6W	CS-2
SA-420	WPL9	CS-3
SA-426	CP2	CS-2
SA-430	FP304, FP304H	HA-4
SA-430	FP316, FP316H, FP321, FP321H, FP347, FP347H	HA-2
SA-442	55, 60	CS-2
SA-479	304L	HA-3
SA-479	321	HA-2
SA-479	304LN	HA-4
SA-508	1, 1a	CS-2
SA-508	2, 2a, 3	CS-4
SA-515	55, 60, 65	CS-2
SA-516	55, 60, 65	CS-2
SA-515	70	CS-3
SA-516	70	CS-3
SA-533	Class 1, Grades A, B, C, D	CS-5
SA-537	...	CS-4
SA-541	1, 1a	CS-2
SA-587	...	CS-2
SA-612	...	CS-3
SA-660	WCA, WCB	CS-2
SA-671	CA55, CB60, CB65, CB60, CC65	CS-2
SA-671	CD80	CS-4
SA-671	CE55, CE60	CS-2
SA-671	CB70, CC70	CS-3
SA-672	A45, A50	CS-1
SA-672	A55, B55, B60, B65, B70, C55, C60, C65, C70	CS-2
SA-672	D80, H80, J80	CS-3
SA-672	E55, E60, L65	CS-2

TABLE I-14.1 (CONT'D) EXTERNAL PRESSURE CHART REFERENCES FOR FERROUS STEELS¹

TABLE I-14.1 (CONT'D)
EXTERNAL PRESSURE CHART REFERENCES FOR FERROUS STEELS¹

Spec. No.	Type or Grade	External Pressure Chart
SA-672	B70, C70, L70, L75	CS-3
SA-688	TP304LN	HA-1
SA-688	TP316LN	HA-2
SA-691	CMSH70, CMSH80, CM70, CM75, 1¼CR, 2¼CR	CS-4
SA-691	½CR, CM65	CS-2
SA-737	B, C	CS-3
SA-813	TP304, TP304H, TP304LN, TP304N	HA-1
SA-813	TP304L	HA-3
SA-813	TP309, TP310, TP316, TP316H, TPXM-19, TP316LN, TP316N	HA-2
SA-813	TP316L	HA-4
SA-813	TP321, TP321H, TP347, TP347H, TP348, TP348H	HA-2
SA-814	TP304, TP304H, TP304LN, TP304N	HA-1
SA-814	TP304L	HA-3
SA-814	TP309, TP310, TP316, TP316H, TPXM-19, TP316LN, TP316N	HA-2
SA-814	TP316L	HA-4
SA-814	TP321, TP321H, TP347, TP347H, TP348, TP348H	HA-2

NOTE:

¹ The referenced external pressure charts are located in Section II, Part D, Subpart 3.

TABLE I-14.1 (CONT'D) EXTERNAL PRESSURE CHART REFERENCES FOR FERROUS STEELS¹

TABLE I-14.2
EXTERNAL PRESSURE CHART REFERENCES FOR NONFERROUS MATERIALS¹

Spec. No.	Grade, Type, or Alloy Designation	Condition or Temper	External Pressure Chart
SB-42 Copper Pipe	C10200, C12000, C12200	061, H80, H55	NFC-1
SB-75 Copper Smls. Tube	C10200, C12000, C12200, C14200	050, 060, H55, H80	NFC-1
SB-96 Cu-Si A Plates & Sheet	C65500	Annealed	NFC-1
SB-111 Copper Smls. Cond. Tube	C10200, C12000, C12200, C14200	H55, H80	NFC-1
SB-111 Cu-Ni 90/10 Smls. Cond. Tube	C70600	061, H55	NFC-3
SB-111 Cu-Ni 70/30 Smls. Cond. Tube	C71500	H55, HR50	NFC-4
SB-127 Ni-Cu Plate, Sheet, & Strip	N04400	Annealed Hot Rolled	NFN-3
SB-152 Copper Plate, Sheet, & Strip	C10200, C10400, C10500, C10700, C12200, C12300	025	NFC-1
SB-161	N02200	Annealed	NFN-2
SB-161	N02201	Stress relieved Annealed	NFN-1
SB-162	N02200	Stress relieved Annealed	NFN-2
SB-162	N02201	Hot rolled Hot rolled	NFN-1
SB-163	N02200	Annealed	NFN-2
SB-163	N02201	Stress relieved Annealed	NFN-1
SB-163	N04400	Stress relieved Annealed	NFN-3
SB-163	N06600	Annealed	NFN-4
SB-163	N08800	Annealed	NFN-8
SB-163	N08810	Annealed	NFN-9
SB-163	N08825	Annealed	NFN-7
SB-165	N04400	Annealed	NFN-3
SB-167	N06600	Stress relieved Annealed	NFN-4
SB-168	N06600	Hot finished Stress relieved Cold drawn/annealed Annealed	NFN-4
		Hot rolled	

TABLE I-14.2 EXTERNAL PRESSURE CHART REFERENCES FOR NONFERROUS MATERIALS¹

TABLE I-14.2 (CONT'D)
EXTERNAL PRESSURE CHART REFERENCES FOR NONFERROUS MATERIALS¹

Spec. No.	Grade, Type, or Alloy Designation	Condition or Temper	External Pressure Chart
SB-169 Al-Bronze D Plate & Sheet	C61400	Annealed	NFA-4
SB-163	N06690	Annealed	NFN-21
SB-171 Al-Bronze D Tube Plates	C61400	Annealed	NFA-4
SB-171 Cu-Ni 90/10 Tube Plates	C70600	Annealed	NFC-3
SB-171 Cu-Ni 70/30 Tube Plates	C71500	Annealed	NFC-4
SB-209	1060	0, H12, H14, H112	NFA-7
SB-209	3003	0, H12, H112	NFA-1
SB-209	3003	H14	NFA-2
SB-209	3004	0, H32, H112	NFA-3
SB-209	3004	H34	NFA-4
SB-209	5052 & 5652	0, H112	NFA-8
SB-209	5083	0, H112	NFA-11
SB-209	5086	0, H112	NFA-9
SB-209	5154 & 5254	0, H112	NFA-5
SB-209	5454	0, H32, H34, H112	NFA-14
SB-209	5456	0	NFA-10
SB-210	1060	0	NFA-7
SB-210	3003	0, H113	NFA-1
SB-210	3003	H14	NFA-2
SB-210	5052	0	NFA-8
SB-210	5154	0	NFA-5
SB-234	5454	H32, H34	NFA-14
SB-241	1060	0	NFA-7
SB-241	3003	0, H112	NFA-1
SB-241	5052	0	NFA-8
SB-241	5086	0, H112	NFA-9
SB-241	5083	0, H111, H112	NFA-11
SB-241	5454	0, H112	NFA-14
SB-241	5456	0	NFA-10
SB-265	Titanium	Grade 3 annealed	NFT-1
SB-315 Cu-Si A Pipe and tube	C65500	Annealed	NFC-2
SB-333	N10001	Annealed	NFN-5
SB-333	N10665 (B-2)	Annealed	NFN-16
SB-335	N10665 (B-2)	Annealed	NFN-16
SB-337	Pipe	Grade 3 smls. annealed	NFT-1
SB-338	Tubing	Grade 3 smls. annealed	NFT-1
SB-348	Bar, Billet	Grade 3 annealed	NFT-1
SB-359	C12200	061 or as-finned	NFC-1
SB-359	C70600	061 or as-finned	NFC-3

TABLE I-14.2 (CONT'D) EXTERNAL PRESSURE CHART REFERENCES FOR NONFERROUS MATERIALS¹

TABLE I-14.2 (CONT'D)
EXTERNAL PRESSURE CHART REFERENCES FOR NONFERROUS MATERIALS¹

Spec. No.	Grade, Type, or Alloy Designation	Condition or Temper	External Pressure Chart
SB-359	C71500	061 or as-finned	NFC-4
SB-381	Forgings	Grade F3 annealed	NFT-1
SB-395	C10200, C12000, C12200, C14200	Light drawn	NFC-1
Copper U-Bend Smls. Tube			
SB-395	C70600	Annealed	NFC-3
Cu-Ni 90/10 U-Bend Smls. Tube			
SB-395	C71500	Annealed or drawn & stress relieved	NFC-4
Cu-Ni 70/30 U-Bend Smls. Tube			
SB-171	C70600	Annealed	NFC-3
Cu-Ni 90/10 Plate & Sheet			
SB-171	C71500	Annealed	NFC-4
Cu-Ni 70/30			
SB-407	N08800	Annealed	NFN-8
SB-407	N08810	Annealed	NFN-9
SB-409	N08800	Annealed	NFN-8
SB-409	N08810	Annealed	NFN-9
SB-462	N08020	Annealed	NFN-12
SB-462	N08367	Annealed	NFN-12
SB-463	N08020	Annealed	NFN-12
SB-464	N08020	Annealed	NFN-12
SB-468	N08020	Annealed	NFN-12
SB-466	C70600	Annealed	NFC-3
Cu-Ni 90/10 Smls. Pipe & Tube			
SB-466	C71500	Annealed	NFC-4
Cu-Ni 70/30 Smls. Pipe & Tube			
SB-467	C70600	Annealed (W061)	NFC-3
Cu-Ni 90/10 Welded Pipe & Tube			
SB-467	C71500	Annealed (W061) Welded, drawn, & tempered (WH04)	NFC-4
Cu-Ni 70/30 Welded Pipe & Tube			
SB-473	N08020	Annealed	NFN-12
SB-543	C12200	As-welded	NFC-1
Welded Copper Tube			
SB-543	C70600	Annealed As-welded	NFC-3
Welded Cu-Ni 90/10 Tube			
SB-543	C71500	Annealed As-welded	NFC-4
Welded Cu-Ni 70/30 Tube			
SB-564	N04400	Annealed	NFN-3
SB-564	N06600	Annealed	NFN-4
SB-564	N08367	Annealed	NFN-4

TABLE I-14.2 (CONT'D) EXTERNAL PRESSURE CHART REFERENCES FOR NONFERROUS MATERIALS¹TABLE I-14.2 (CONT'D)
EXTERNAL PRESSURE CHART REFERENCES FOR NONFERROUS MATERIALS¹

Spec. No.	Grade, Type, or Alloy Designation	Condition or Temper	External Pressure Chart
SB-564	N08800	Annealed	NFN-8
SB-564	N08810	Annealed	NFN-9
SB-574	N10276 (C-276)	Annealed	NFN-10
SB-575	N10276 (C-276)	Annealed	NFN-10
SB-619	N06002 (X)	Annealed	NFN-15
SB-619	N10276 (C-276)	Annealed	NFN-10
SB-619	N10665 (B-2)	Annealed	NFN-11
SB-622	N06002 (X)	Annealed	NFN-15
SB-622	N10276 (C-276)	Annealed	NFN-10
SB-622	N10665 (B-2)	Annealed	NFN-16
SB-626	N06002 (X)	Annealed	NFN-15
SB-626	N10276 (C-276)	Annealed	NFN-10
SB-626	N10665 (B-2)	Annealed	NFN-15
SB-675	N08367	Annealed	NFN-12
SB-676	N08367	Annealed	NFN-12
Welded Tube			
SB-688	N08367	Annealed	NFN-12
SB-690	N08367	Annealed	NFN-12
SB-691	N08367	Annealed	NFN-12

NOTE:

¹The referenced external pressure charts are located in Section II, Part D, Subpart 3TABLE I-14.2 (CONT'D) EXTERNAL PRESSURE CHART REFERENCES FOR NONFERROUS MATERIALS¹

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 MA APP II

APPENDIX II EXPERIMENTAL STRESS ANALYSIS

Page 25

ARTICLE II-1000 EXPERIMENTAL STRESS ANALYSIS**II-1100 INTRODUCTION****II-1110 GENERAL REQUIREMENTS****II-1111 When Experimental Stress Analysis Is Required**

The critical or governing stresses in parts for which theoretical stress analysis is inadequate or for which design rules are unavailable shall be substantiated by experimental stress analysis.

II-1112 When Reevaluation Is Not Required

Reevaluation is not required for configurations for which there are available detailed experimental results that are

consistent with the requirements of this Article.

II-1113 Discounting of Corrosion Allowances

The test procedures followed and the interpretation of the results shall be such as to discount the effects of material added to the thickness of members, such as corrosion allowance, or of other material which cannot be considered as contributing to the strength of the part.

II-1114 Inspection and Reports

Tests conducted in accordance with this Article need not be witnessed by the Inspector. However, a detailed report of the test procedure and the results obtained shall be included with the Design Report (NCA-3551). The report shall show that the instrumentation used was within calibration.

II-1200 PERMISSIBLE TYPES OF NONCYCLIC TESTS AND CALCULATION OF STRESSES

II-1210 TESTS FOR DETERMINING GOVERNING STRESSES

Permissible types of tests for the determination of governing stresses are strain measurement tests and photoelastic tests. Brittle coating tests may be used only for the purpose described in II-1310.

II-1220 TESTS FOR DETERMINING COLLAPSE LOAD

Strain measurement tests may be used for the determination of collapse load. Distortion measurement tests may be used for the determination of collapse load if it can be clearly shown that the test setup and the instrumentation used will give valid results for the configuration on which the measurements are made.

II-1221 Fatigue Tests for Evaluation of Cyclic Loading

Fatigue tests as described in II-1500 may be used to evaluate the adequacy of a component or portion thereof for cyclic loading.

II-1230 TESTS TO DESTRUCTION

Results of tests to destruction are not acceptable except as provided for piping in NB-3649.

II-1240 CALCULATION OF STRESSES

A modified Poisson's ratio is given by NB-3227.6 and identified as being applicable only to local thermal stresses. It should be noted that some situations can arise in which the use of the modified value of Poisson's

Page 28

ratio is indicated for the calculation of stresses of other than thermal origin. Strictly speaking, this modified value should be used in any calculation which results in stresses which exceed a stress intensity range of $2S_y$. For designs which meet the basic stress limits this modification is important only for local thermal stresses such as skin stresses. When calculating the stress range in an element such as a fatigue test model which does not meet the basic stress limits, the effect of the modified Poisson's ratio should be considered.

II-1250 STRAIN MEASUREMENT TEST PROCEDURE

II-1251 Requirements for Strain Gages

Strain gages of any type capable of indicating strains to 0.00005 in./in. may be used. It is recommended that the gage length be such that the maximum strain within the gage length does not exceed the average strain within the gage length by more than 10%. Instrumentation shall be such that both surface principal stresses may be determined at each gage location in the elastic range of material behavior at that gage location. A similar number and orientation of gages at each gage location are required to be used in tests beyond the elastic range of material behavior. The strain gages and cements

that are used shall be shown to be reliable for use on the material surface finish and configuration considered to strain values at least 50% higher than those expected.

II-1252 Use of Models for Strain or Distortion Measurements

(a) Except in tests made for the measurement of collapse load, strain gage data may be obtained from the actual component or from a model component of any scale that meets the gage length requirements of II-1251. The model material need not be the same as the component material but shall have an elastic modulus which is either known or has been measured at the test conditions. The requirements of dimensional similitude shall be met as nearly as possible.

(b) In the case of collapse load tests, only full scale models, prototypical in all respects, are permitted unless the experimenter can clearly demonstrate the validity of the scaling laws used.

II-1260 PHOTOELASTIC TEST TECHNIQUES

Either two dimensional or three dimensional techniques may be used in photoelastic testing as long as the model represents the structural effects of the loading.

II-1300 TEST PROCEDURES

II-1310 LOCATION OF TEST GAGES

(a) In tests for determination of governing stresses, sufficient locations on the component shall be investigated to ensure that the measurements are taken at the most critical areas and to permit conservative determination of the bending and peak stress components. The location of the critical areas and the optimum orientation of test gages may be determined by a brittle coating test.

(b) In tests made for the measurement of collapse load, sufficient measurements must be taken so that all areas which have any reasonable probability of indicating a minimum collapse load are adequately covered. If strain gages are used to determine the collapse load, particular care should be given to assuring that strains (either membrane, bending or a combination) are being measured which are actually indicative of the load carrying capacity of the structure. If distortion measurement devices are used, care should be given to assure that it is the change in cardinal dimensions or deflections which are measured, such as diameter or length extension, or beam or plate deflections that are indicative of the tendency of the structure to actually collapse.

II-1320 REQUIREMENTS FOR PRESSURE GAGES

Pressure gages shall meet the requirements of NB-6400.

II-1330 APPLICATION OF PRESSURE OR LOAD

(a) In tests for determining governing stresses, the internal pressure or mechanical load shall be applied in such increments that the variation of strain with load can be plotted so as to establish the ratio of stress to load in the elastic range. If the first loading results in strains which are not linearly proportional to the load, it is permissible to unload and reload successively until the linear proportionality has been established. When frozen stress photoelastic techniques are used,

Page 29

only one load value can be applied, in which case the load shall not be so high as to result in deformations that invalidate the test results.

(b) In tests made for the measurement of collapse load, the proportional load shall be applied in sufficiently small increments so that an adequate number of data points for each gage are available for statistical analysis in the linear elastic range of behavior. All gages should be evaluated prior to increasing the load beyond this value. A least square fit (regression) analysis shall be used to obtain the best fit straight line, and the confidence interval shall be compared to preset values for acceptance or rejection of the strain gage or other instrumentation. Unacceptable instrumentation will be replaced and the replacement instrumentation tested in the same manner.

(c) After all instrumentation has been deemed acceptable, the test should be continued on a strain or displacement controlled basis with adequate time permitted between load changes for all metal flow to be completed.

II-1400 INTERPRETATION OF RESULTS

II-1410 INTERPRETATION TO BE ON ELASTIC BASIS

The experimental results obtained shall be interpreted on an elastic basis to determine the stresses corresponding to the design loads; that is, in the evaluation of stresses from strain gage data, the calculations shall be performed under the assumption that the material is elastic. The elastic constants used in the evaluation of experimental data shall be those applicable to the test material at the test temperature.

II-1420 REQUIRED EXTENT OF STRESS ANALYSIS

The extent of experimental stress analysis performed shall be sufficient to determine the governing stresses for which design values are unavailable, as described in II-1111. When possible, combined analytical and experimental methods shall be used to distinguish among primary, secondary, and local stresses so that each combination of categories can be controlled by the applicable stress limit.

II-1430 CRITERION OF COLLAPSE LOAD

(a) For distortion measurement tests, the loads are plotted as the ordinate and the measured deflections are plotted as the abscissa. For strain gage tests, the loads are plotted as the ordinate and the maximum principal strains on the surface as the abscissa.

(b) The least square fit (regression) line as determined from the data in the linear elastic range is drawn on each plot considered. The angle that the regression line makes with the ordinate is called θ . A second straight line, hereafter called the collapse limit line, is drawn through the intersection of the regression line with the abscissa so that it makes an angle $\phi = \tan^{-1} (2 \tan \theta)$ with the ordinate. (See Fig. II-1430-1.) The test collapse load is determined from the maximum principal strain or deflection value at the first data point for which there are three successive data points that lie *outside* of the collapse limit line. This first data point is called the *collapse load point*. The test collapse load is taken as the load on the collapse limit line which has the maximum principal strain or deflection of the collapse load point. The collapse load used for design or evaluation purposes shall be the test collapse load multiplied by the ratio of the material yield strength at Design Temperature (Section II, Part D, Subpart 1, Table Y-1) to the test material yield strength at the test temperature. Careful attention shall be given to the actual as-built dimensions of the test model when correlating the collapse load of the test model to that expected for the actual structure being designed.

II-1500 CYCLIC TESTS

II-1510 WHEN CYCLIC TESTS MAY BE USED

1 Throughout the remainder of this Article, wherever the words component or components are used, they shall be understood to include portions thereof, and also appurtenances and portions thereof.

(a) Experimental methods constitute a reliable means of evaluating the capability of components and appurtenances to withstand cyclic loading. In addition, when it is desired to use higher peak stresses than can be justified by the methods of II-1200 to II-1400 and the fatigue curves of Figs. I-9.0, the adequacy of a component, appurtenance, or portion thereof¹ to withstand cyclic loading may be demonstrated by means of a

Page 30

Page 31

fatigue test. The fatigue test shall not be used, however, as justification for exceeding the allowable values of primary or primary plus secondary stresses.

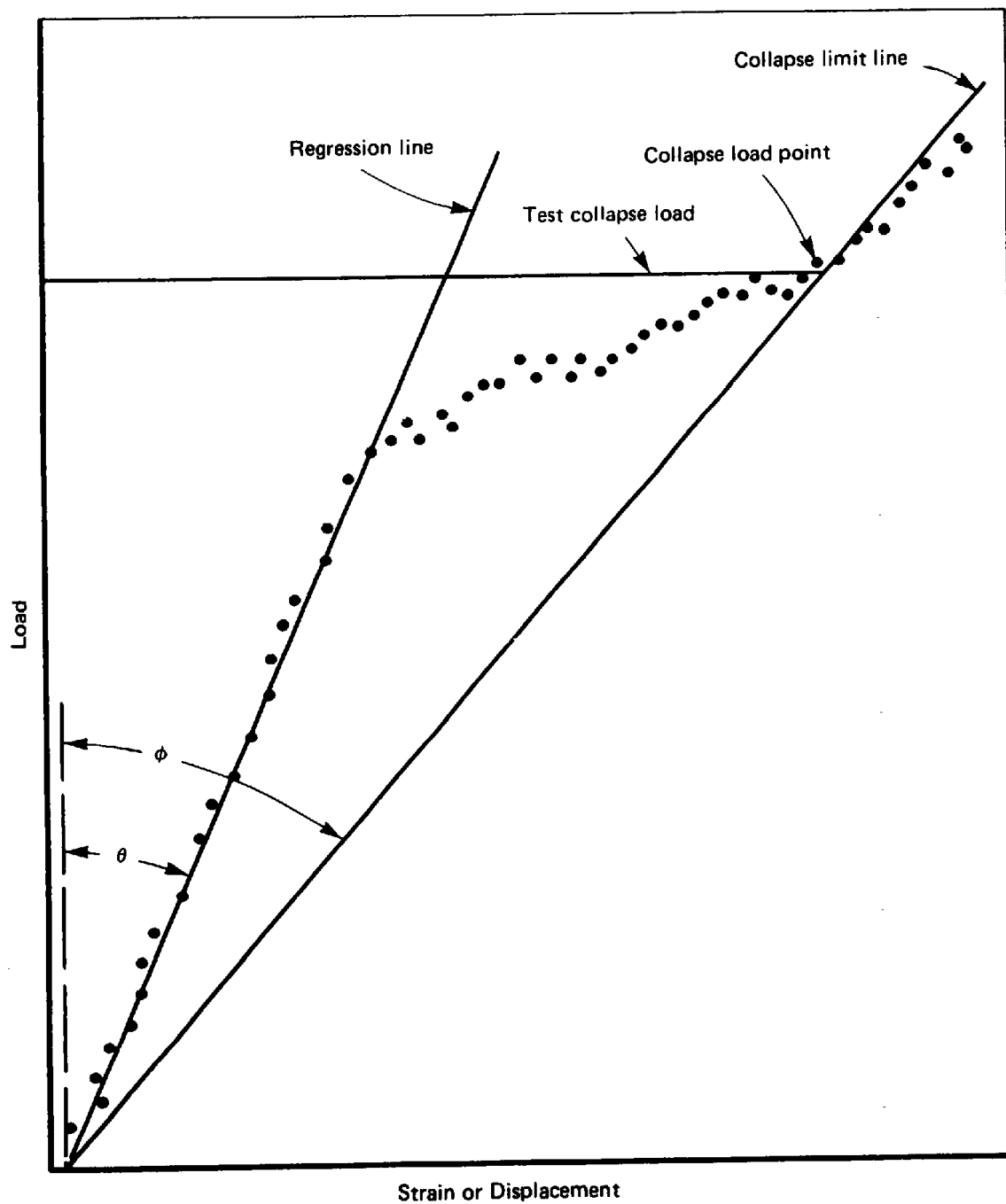


FIG. II-1430-1 CONSTRUCTION FOR II-1430

FIG. II-1430-1 CONSTRUCTION FOR II-1430

(b) When a fatigue test is used to demonstrate the adequacy of a component or a portion thereof to withstand cyclic loading, a description of the test shall be included in the Design Report. This description shall contain sufficient detail to show compliance with the requirements of this Subarticle.

II-1520 REQUIREMENTS FOR CYCLIC TESTING OF COMPONENTS

The requirements of (a) through (g) below shall be met.

(a) The test component or portion being tested shall be constructed of material having the same composition and subjected to mechanical working and heat treating so as to produce mechanical properties equivalent to those of the material in the prototype component. Geometrical similarity must be maintained, at least in those portions whose ability to withstand cyclic loading is being investigated, and in those adjacent areas which affect the stresses in the portion under test.

(b) The test component or portion thereof shall withstand the number of cycles as set forth in (c) below before failure occurs. Failure is herein defined as a propagation of a crack through the entire thickness, such as would produce a measurable leak in a pressure retaining member.

(c) The minimum number of cycles (hereinafter referred to as test cycles), which the component shall withstand and the magnitude of the loading (hereinafter referred to as the test loading) to be applied to the component during test, shall be determined by multiplying the specified service cycles by a specified factor K_{TN} and the specified service loads by K_{TS} . Values of these factors shall be determined by means of the testing parameters ratio diagram, the construction of which is given in (1) through (5) below and is illustrated in Fig. II-1520(c)-1.

(1) Project a vertical line from the specified service cycles N_D on the abscissa of S_a of Figs. I-9.0 to an ordinate value of K_s [II-1520(g)] times S_{aD} . Label this point *A*.

(2) Extend a horizontal line through the point *D* until its length corresponds to an abscissa value of K_n [II-1520(g)] times N_D . Label this point *B*.

(3) Connect the points *A* and *B*. The segments *AB* embrace all the allowable combinations K_{TS} and K_{TN} [see II-1520(d) for accelerated testing]. Any point *C* on this segment may be chosen at the convenience of the tester. Referring to Fig. II-1520(c)-1, the factors K_{TS} and K_{TN} are defined by:

$$K_{TS} = \frac{\text{Value of Ordinate at Point A}}{\text{Value of Ordinate at Point D}}$$

and

$$K_{TN} = \frac{\text{Value of Abscissa at Point } B}{\text{Value of Abscissa at Point } D}$$

thus,

$$P_T (\text{test loading}) = K_{TS} \times \text{specified service loading}$$

$$N_T (\text{test cycles}) = K_{TN} \times \text{specified service cycles}$$

(4) It should be noted that, if the test article is not a full size component but a geometrically similar model, then the value P_T shall be adjusted by the appropriate scale factor to be determined from structural similitude principles if the loading is other than pressure. The number of cycles that the component shall withstand during this test without failure shall not be less than N_T while subjected to a cyclic test loading P_T which shall be adjusted, if required, using model similitude principles if the component is not full size.

(5) In certain instances, it may be desirable (or possible) in performing the test to increase only the loading or number of cycles, but not both, in which event two special cases of interest result from the above general case, as described in (e) and (f) below.

(d) Accelerated fatigue testing (test cycles N_T are less than design cycles N_D) may be conducted if the design cycles N_D are greater than 10^4 and the testing conditions are determined by the procedures of (1) through (3) below which are illustrated in Fig. II-1520(c)-2. In this figure, the points A , B , and D correspond to similar labeled points in Fig. II-1520(c)-1.

(1) The minimum number of test cycles N_{Tmin} shall be

$$N_{Tmin} = 10^2 \sqrt{N_D}$$

Project a vertical line through N_{Tmin} on the abscissa of S_a versus N diagram such that it intersects and extends beyond the fatigue design curve.

(2) Construct a curve through the point A and intersect the vertical projection of N_T [II-1520(d)(1)] by multiplying every point on the fatigue design curve by the factor K_S [II-1520(g)]. Label the intersection of this curve and the vertical projection of N_{Tmin} as A' .

(3) Any point C on the segment A', A, B determines the allowable combinations of K_{TS} and K_{TN} . The factors

Page 32

Page 33

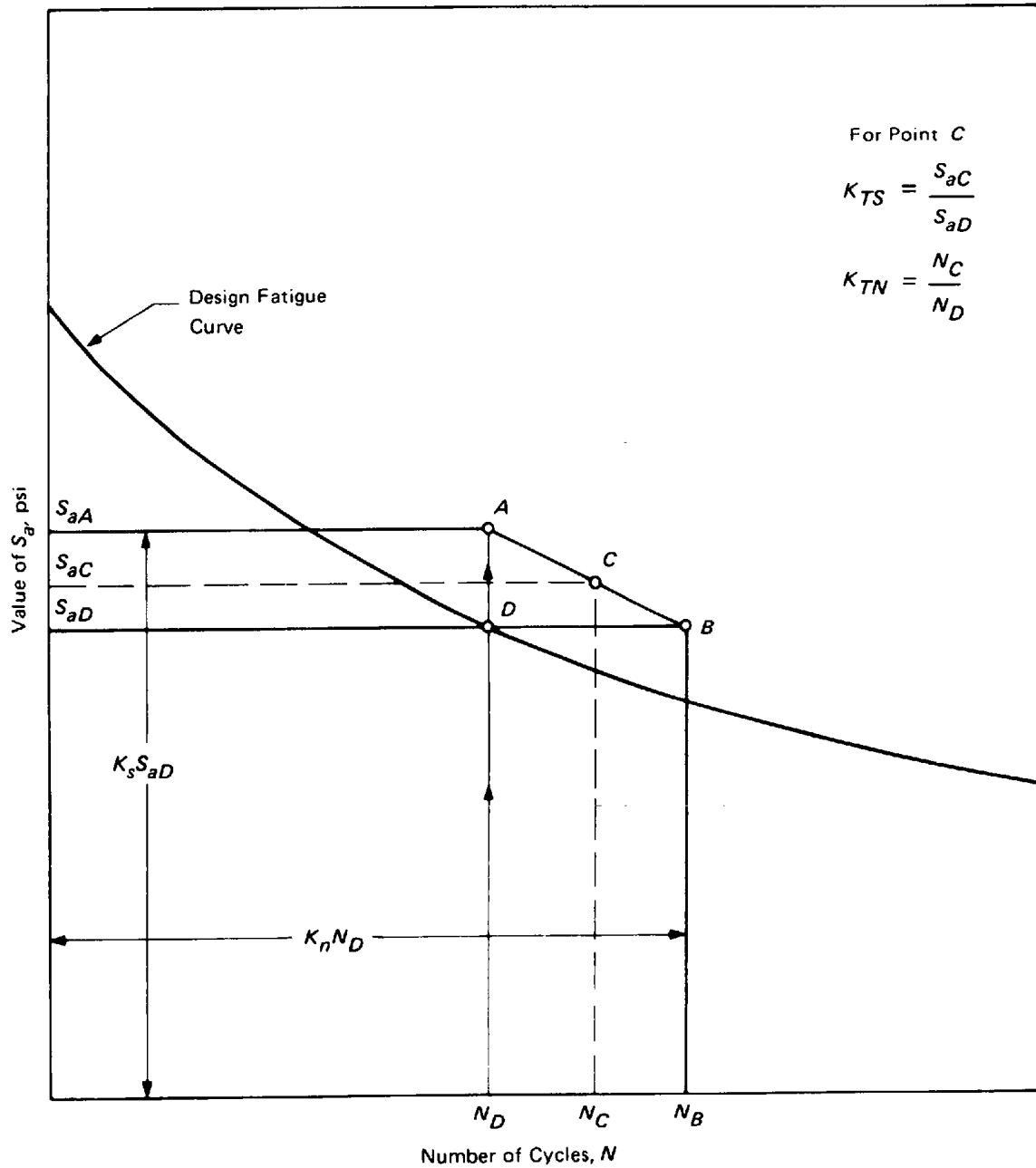


FIG. II-1520(c)-1 CONSTRUCTION OF THE TESTING PARAMETERS RATIO DIAGRAM

FIG. II-1520(c)-1 CONSTRUCTION OF THE TESTING PARAMETERS RATIO DIAGRAM

K_{TS} and K_{TN} are obtained in the same manner as in II-1520(c).

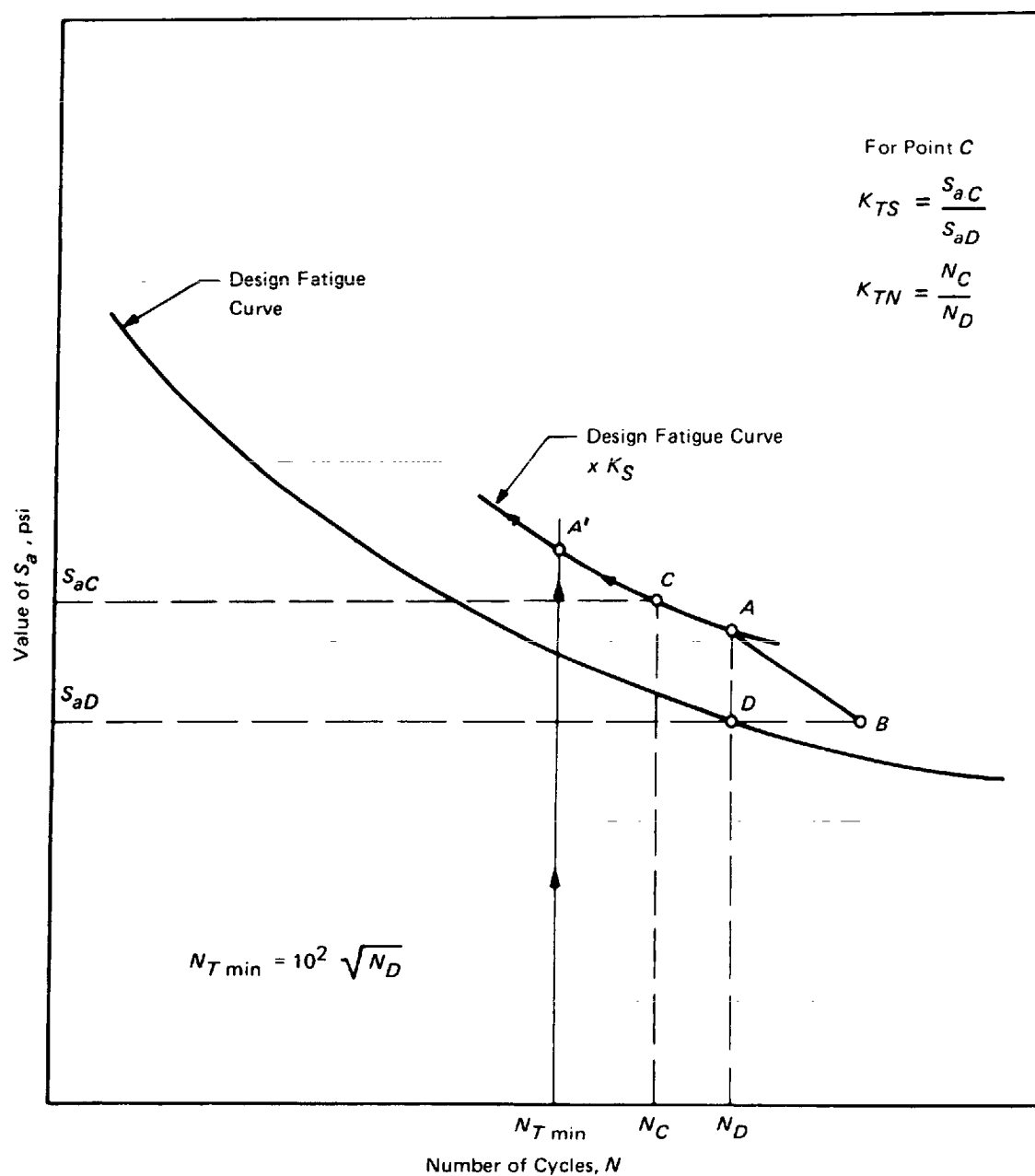


FIG. II-1520(c)-2 CONSTRUCTION OF THE TESTING PARAMETERS RATIO DIAGRAM FOR ACCELERATED TESTS

FIG. II-1520(c)-2 CONSTRUCTION OF THE TESTING PARAMETERS RATIO DIAGRAM FOR ACCELERATED TESTS

(e) Case 1 (Factor Applied to Cycles Only). In this case, $K_{TS} = 1$ and

$$K_{TN} = \frac{\text{Value of Abscissa at Point C}}{\text{Value of Abscissa at Point A}}$$

The number of test cycles that the component shall withstand during this test shall not be less than $N_T = K_{TN} \times$ specified service cycles, while subjected to the cyclic design service loading, adjusted as required, if a model is used.

(f) Case 2 (Factor Applied to Loading Only). In this case, $K_{TN} = 1$ and

$$K_{TS} = \frac{\text{Value of the Ordinate at Point D}}{\text{Value of the Ordinate at Point A}}$$

The component shall withstand a number of cycles at least equal to the number of specified service cycles, while subjected to a cyclic test loading $P_N = K_{TS} \times$ specified service loading, again adjusted as required, if a model is used.

(g) The values of K_s and K_n are the multiples of factors which account for the effects of size, surface finish, cyclic rate, temperature, and the number of replicate tests performed. They shall be determined as follows:

$$K_s = K_{sl} \times K_{sf} \times K_{sc} \times K_{st} \times K_{ss}$$

but shall never be allowed to be less than 1.25 and

$$K_n = K_s^{4.3}$$

but shall never be allowed to be less than 2.6, where

K_{sl}

= factor for the effect of size on fatigue life

= $1.5 - 0.5 (LM/LP)$, where LM/LP is the ratio of linear model size to prototype size

K_{sf}

= factor for the effect of surface finish

= $1.175 - 0.175 (SFM/SFP)$, where SFM/SFP is the ratio of model surface finish to prototype surface finish, in. $\times 10^{-6}$ arithmetic average (AA)

K_{st}

= factor for the effect of test temperature

K_{ss}

= ($S_d N$ at test temperature) / ($S_d N$ at Design Temperature),
where $S_d N$ equals S_a from applicable fatigue curve at N cycles

= factor for the statistical variation in test results

= $1.470 - 0.044 \times \text{number of replicate tests}$

K_{sc}

= factor for differences in design fatigue curves at various temperatures

No value of K_{sp} , K_{sf} , K_{sc} , K_{sp} , or K_{ss} less than 1.0 may be used in calculating K_s .

II-1600 DETERMINATION OF FATIGUE STRENGTH REDUCTION FACTORS

II-1610 PROCEDURES

Experimental determination of fatigue strength reduction factors shall be in accordance with the procedures of (a) through (e) below.

(a) The test part shall be fabricated from a material within the same P-Number grouping of QW-442 of Section IX and shall be subjected to the same heat treatment as the component.

(b) The stress level in the specimen shall be such that the stress intensity does not exceed the limit prescribed by NB-3222.2 and so that failure does not occur in less than 1000 cycles.

(c) The configuration, surface finish, and stress state of the specimen shall closely simulate those expected in the components. In particular, the stress gradient shall not be more abrupt than that expected in the component.

(d) The cyclic rate shall be such that appreciable heating of the specimen does not occur.

(e) The fatigue strength reduction factor shall preferably be determined by performing tests on notched and unnotched specimens and calculated as the ratio of the unnotched stress to the notched stress for failure.

II-1700 EXPERIMENTAL STRESS ANALYSIS OF OPENINGS

II-1710 GENERAL REQUIREMENTS

The stress intensities for opening configurations which do not meet the requirements of NB-3331, NB-3338.2(d), or NB-3339.1 shall be determined in accordance with the methods of this Subarticle.

II-1720 APPLICABILITY OF AVAILABLE EXPERIMENTAL DATA

In accordance with II-1112 reevaluation is not required for configurations for which there are available detailed experimental results that are consistent with the requirements of this Appendix. In order that available

Page 35

experimental data may be interpreted as providing information pertinent to the analysis of slightly different configurations, thereby possibly minimizing the need for additional investigations, the guidelines of II-1730 are presented.

II-1730 GUIDELINES FOR USE OF AVAILABLE EXPERIMENTAL DATA

II-1731 Effect of d/D Ratio

For an unreinforced opening or for an opening where the reinforcement is provided primarily by a uniform increase in component wall thickness, the stresses around the opening will increase with increasing d/D ratio of the opening (diameter of nozzle or opening to diameter of shell). Therefore, experimental data for a small d/D ratio cannot be safely applied to a larger d/D ratio but can be applied to a smaller d/D ratio provided the experiments were made at a d/D ratio < 0.5 .

II-1732 Effect of D/T Ratio

For an unreinforced opening or for an opening where the reinforcement is provided primarily by a uniform increase in component wall thickness, the stresses around the opening will increase with increasing D/T ratio (thinner shell component). Therefore, experimental data for a relatively small D/T ratio cannot be safely applied to a larger D/T ratio but can be applied to a smaller D/T ratio.

II-1733 Proximity to Gross Discontinuities

Generally, the stress data available in the literature are applicable only to single openings. Such data shall be considered valid only for a connection sufficiently removed from another nozzle, opening, flange, or other major discontinuity so that superposition of stresses will not produce an unacceptable value of stress intensity.

II-1734 Requirements for Fillets

Stresses at the outside juncture of a nozzle and shell are greatly influenced by the fillet or transition at the juncture. Generally speaking, stress data available in the literature are for certain specific fillet radii. Other factors being equal, these stress data may be considered valid for fillet radii equal to or greater than those used in the test but shall not be considered valid for smaller fillet radii or undefined fillets and transitions such as for a triangular weld fillet, as commonly used.

II-1800 EXPERIMENTAL DETERMINATION OF STRESS INDICES FOR PIPING

In course of preparation. Pending publication, stress indices for piping shall be determined in accordance with the rules of NB-3680.

II-1900 EXPERIMENTAL DETERMINATION OF FLEXIBILITY FACTORS

In course of preparation. Pending publication, flexibility factors shall be determined in accordance with the rules of NB-3686

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 MA APP III

APPENDIX III BASIS FOR ESTABLISHING DESIGN STRESS INTENSITY VALUES AND ALLOWABLE STRESS VALUES

Page 37

ARTICLE III-1000 INTRODUCTION

III-1100 DERIVATION OF VALUES AND THEIR TABULAR ORGANIZATION

III-1110 RESPONSIBILITY FOR ASSIGNING STRESS INTENSITY AND ALLOWABLE STRESS VALUES

(a) The Boiler and Pressure Vessel Committee evaluates the available data and assigns stress values for materials in accordance with the basis given in this Article.

(b) Where suitable test data on a specification material are not available, the Committee may base design stress values on the available data for similar materials or on an evaluation of known experience with the material.

III-1120 DERIVATION OF STRESS INTENSITY AND ALLOWABLE STRESS VALUES

The values are obtained by applying factors to the mechanical properties of the materials. Consideration is given to the minimum properties specified and the properties at various temperatures as determined by tests on specimens of the material. For all materials, and especially those whose properties are affected by heat treatment, the data for establishing allowable stresses are from test specimens that are representative of the material supplied in accordance with the

specification including the specified heat treatment.

III-1130 LOCATION AND APPLICATION OF STRESS INTENSITY, ALLOWABLE STRESS, AND YIELD STRENGTH VALUES

III-1131 Location

All stress intensity, allowable stress, and yield strength values for use in design under the rules of this Section are given in Section II, Part D. These values are grouped according to temperature. In every application of the values, the temperature is to be understood as being the actual metal temperature.

III-1132 Application

III-1132.1 Design Stress Intensity Values.

Design stress intensity values are given in Section II, Part D, Subpart 1, Tables 2A and 2B for Class 1 components and for Class 1 plate and shell type component supports.

III-1132.2 Allowable Stress Values

(a) Allowable stress values are given in Section II, Part D, Subpart 1, Tables 1A and 1B for Class 2 and 3 components and for Class 2, 3, and MC plate and shell type supports.

(b) Allowable stress values for linear type and component standard supports of all classes of construction except Class 1 plate and shell type component supports (III-1132.1) are derived from the yield strength values given in Section II, Part D, Subpart 1, Table Y-1 by applying the stipulated design factors given in NF-3300.

III-1132.3 Design Stress Intensity and Allowable Stress Values.

The design stress intensity and allowable stress values for Class MC vessels are given in Section II, Part D, Subpart 1, Tables 1A and 1B, except that 90% of the yield strength at temperature shall not be exceeded. Only the material specifications and grades listed in Table NE-2121(a)-1 and bolting material specifications listed in Table NE-2121(a)-2 may be used for Class MC construction.

Page 40

ARTICLE III-2000 DESIGN STRESS INTENSITY VALUES FOR CLASS 1 COMPONENTS

III-2100 MECHANICAL PROPERTY CRITERIA

III-2110 FOR MATERIALS OTHER THAN BOLTING

(a) The mechanical properties considered and factors applied for Section II, Part D, Subpart 1, Tables 2A and 2B are given in that Section.

(b) The upper temperature limit for the tabulated design stress intensity values in Section II, Part D, Subpart 1, Tables 2A and 2B are the temperatures to the next lowest 50°F (28°C) increment at which the creep rate or the stress rupture effects would produce design stresses lower than those from tensile and yield strength data.

III-2120 FOR BOLTING MATERIALS

For bolting materials, the stress values in Section II, Part D, Subpart 1, Table 4 are based on one-third of the minimum specified yield strength at room temperature or one-third of the yield strength at temperature up to a temperature of 800°F (427°C).

III-2200 FATIGUE STRENGTH CRITERIA FOR ALL MATERIALS

The fatigue curves of Figs. I-9.0 are obtained from uniaxial strain cycling data in which the imposed strain amplitude (half range) is multiplied by the elastic modulus to put the values in stress units. A best fit to the experimental data is obtained by

applying the method of least squares to the logarithms of the stress values. The curves are adjusted where necessary to include the maximum effect of mean stress. The design stress intensity values are obtained from the best fit curve by applying a factor of 2 on stress or a factor of 20 on cycles, whichever is the more conservative at each point. Figure I-9.1 is applicable to the carbon and low alloy steels; Figs. I-9.2 and I-9.3 are applicable to the high alloy steels and nonferrous alloys listed in Section II, Part D, Subpart 1, Tables 2A and 2B; and Fig. I-9.4 applies to bolting materials listed in Section II, Part D, Subpart 1, Table 4.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 MA APP IV

APPENDIX IV APPROVAL OF NEW MATERIALS UNDER THE ASME BOILER AND PRESSURE VESSEL CODE

Page 41

[98]

(See Appendix 5 of Section II, Part D.)

[98]

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 MA APP V

APPENDIX V CERTIFICATE HOLDERS' DATA REPORT FORMS, INSTRUCTIONS, AND APPLICATION FORMS FOR CERTIFICATES OF AUTHORIZATION FOR USE OF CODE SYMBOL STAMPS

Page 45

Page 47

Page 49

Pages 48-48

FORM N-1 CERTIFICATE HOLDER'S DATA REPORT FOR NUCLEAR VESSELS*
As Required by the Provisions of the ASME Code, Section III, Division 1

FORM N-1 (Back — Pg. 2 of 59)

Certificate Holder's Serial No. ⑥

17. Nozzles, inspection and safety valve openings: ④④ ①⑤ ①⑥ ①⑦

Purpose (inlet, outlet, drain, etc.)	Quantity	Dia. or Size	Type	How Attached	Mat'l.	Thickness	Reinforcement Material	Location

18. Supports: Skirt ④⑤ Lugs ④⑤ Legs ④⑤ Other ④⑤ Attached ④⑤
(yes or no) (quantity) (quantity) (quantity) (describe) (where & how)

19. Remarks: ④⑤

CERTIFICATION OF DESIGN	
Design specification certified by ④⑤	P.E. State _____ Reg. no. _____
Design report certified by ⑤③	P.E. State _____ Reg. no. _____
CERTIFICATE OF SHOP COMPLIANCE	
⑤② We certify that the statements made in this report are correct and that this nuclear vessel conforms to the rules for construction of the ASME Code, Section III, Division 1. N Certificate of Authorization No. _____ Expires _____ Date _____ Name _____ Signed _____ (N Certificate Holder) (authorized representative)	
CERTIFICATE OF SHOP INSPECTION	
⑤③ I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of _____ and employed by _____ of _____ have inspected the component described in this Data Report on _____, and state that to the best of my knowledge and belief, the Certificate Holder has constructed this component in accordance with the ASME Code, Section III, Division 1. By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied, concerning the component described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection. Date _____ Signed _____ Commissions ⑥⑦ (Authorized Nuclear Inspector) [Nat'l. Bd. (incl. endorsements) and state or prov. and no.]	
CERTIFICATE OF FIELD ASSEMBLY COMPLIANCE	
⑦② We certify that the statements on this report are correct and that the field assembly construction of all parts of this nuclear vessel conforms to the rules of construction of the ASME Code, Section III, Division 1. N Certificate of Authorization No. _____ Expires _____ Date _____ Name _____ Signed _____ (N Certificate Holder) (authorized representative)	
CERTIFICATE OF FIELD ASSEMBLY INSPECTION	
⑦③ I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of _____ and employed by _____ of _____ have compared the statements in this Data Report with the described component and state that parts referred to as data items _____, not included in the certificate of shop inspection, have been inspected by me on _____ and that to the best of my knowledge and belief the Certificate Holder has constructed and assembled this component in accordance with the ASME Code, Section III, Division 1. By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied, concerning the component described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection. Date _____ Signed _____ Commissions ⑥⑦ (Authorized Nuclear Inspector) [Nat'l. Bd. (incl. endorsements) and state or prov. and no.]	

98

¹ If postweld heat treated. ² List other internal or external pressure with coincident temperature when applicable.

* Supplemental information in form of lists, sketches, or drawings may be used provided (1) size is 8 1/2 x 11, (2) information in items 1 through 4 on this Data Report is included on each sheet, (3) each sheet is numbered and number of sheets is recorded at top of this form.

This form (E00039) may be obtained from the Order Dept., ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

[98]

FORM N-1A CERTIFICATE HOLDER'S DATA REPORT FOR NUCLEAR VESSELS*

Alternate Form for Single Chamber Completely Shop-Fabricated Vessels Only As Required by the Provisions of the ASME Code, Section III, Division 1

As Required by the Provisions of the ASME Code, Section III, Division 1

Page 53

Pages 52-52

FORM N-2 CERTIFICATE HOLDERS' DATA REPORT FOR IDENTICAL
NUCLEAR PARTS AND APPURTENANCES*

98

As Required by the Provisions of the ASME Code, Section III
Not to Exceed One Day's Production

Pg. 1 of 99

1. Manufactured and certified by (1) (name and address of NPT Certificate Holder)

2. Manufactured for (2) (name and address of purchaser)

3. Location of installation (3) (name and address)

4. Type (4) (drawing no.) (5) (mat'l. spec. no.) (6) (tensile strength) (7) (CRM) (8) (year built)

5. ASME Code, Section III, Division 1: (9) (edition) (10) (addenda date) (11) (class) (12) (Code Case no.)

6. Fabricated in accordance with Const. Spec. (Div. 2 only) (13) (no.) Revision (14) (no.) Date (15) (no.)

7. Remarks: (16)

8. Nom. thickness (in.) (17) Min. design thickness (in.) (18) Dia. ID (ft & in.) (19) Length overall (ft & in.) (20)

9. When applicable, Certificate Holders' Data Reports are attached for each item of this report:

Part or Appurtenance Serial Number (21)	National Board No. in Numerical Order (22)	Part or Appurtenance Serial Number (23)	National Board No. in Numerical Order (24)
(1)		(26)	
(2)		(27)	
(3)		(28)	
(4)		(29)	
(5)		(30)	
(6)		(31)	
(7)		(32)	
(8)		(33)	
(9)		(34)	
(10)		(35)	
(11)		(36)	
(12)		(37)	
(13)		(38)	
(14)		(39)	
(15)		(40)	
(16)		(41)	
(17)		(42)	
(18)		(43)	
(19)		(44)	
(20)		(45)	
(21)		(46)	
(22)		(47)	
(23)		(48)	
(24)		(49)	
(25)		(50)	

10. Design pressure (25) psi. Temp. (26) °F. Hydro. test pressure (27) (when applicable) (28) at temp. (29) °F

*Supplemental information in the form of lists, sketches, or drawings may be used provided (1) size is 8 1/2 x 11, (2) information in items 2 and 3 on this Data Report is included on each sheet, (3) each sheet is numbered and the number of sheets is recorded at the top of this form.

This form (E00040) may be obtained from the Order Dept., ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

[98]

FORM N-2 CERTIFICATE HOLDERS' DATA REPORT FOR IDENTICAL NUCLEAR PARTS AND APPURTENANCES*

As Required by the Provisions of the ASME Code, Section III Not to Exceed One Day's Production

Page 52

FORM N-2 (Back — Pg. 2 of 59)

Certificate Holder's Serial Nos. 58 through

CERTIFICATION OF DESIGN	
Design specifications certified by 48 (when applicable)	P.E. State Reg. no.
Design report * certified by 53 (when applicable)	P.E. State Reg. no.

69 CERTIFICATE OF COMPLIANCE	
We certify that the statements made in this report are correct and that this (these) conforms to the rules of construction of the ASME Code, Section III, Division 1.	
NPT Certificate of Authorization No.	Expires
Date Name (NPT Certificate Holder)	Signed (authorized representative)

68 CERTIFICATE OF INSPECTION	
I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of and employed by of have inspected these items described in this Data Report on , and state that to the best of my knowledge and belief, the Certificate Holder has fabricated these parts or appurtenances in accordance with the ASME Code, Section III, Division 1. Each part listed has been authorized for stamping on the date shown above.	
By signing this certificate, neither the inspector nor his employer makes any warranty, expressed or implied, concerning the equipment described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or loss of any kind arising from or connected with this inspection.	
Date Signed (Authorized Nuclear Inspector)	Commissions 67 (Nat'l. Bd. (incl. endorsements) and state or prov. and no. I

FORM N-2

Page 55

Pages 54-54

FORM N-3 OWNERS' DATA REPORT FOR NUCLEAR POWER PLANT COMPONENTS*
As Required by the Provisions of the ASME Code, Section III

Pg. 1 of 58

98

1. Name of Owner ^① _____
2. Address of Owner ^② _____
3. Name of power plant ^{⑤②} _____ ^{⑤③} _____ ^{⑤④} _____
(unit no.) (Nat'l. Bd. no.)
4. Location of power plant ^③ _____

5. NUCLEAR VESSELS (List all nuclear concrete and metallic vessels or core supports and attach copies of all N and NPT Certificate Holders' Data Reports, Forms N-1, N-1A, N-2, NCS-1, and C-1.)

Certificate Holder - and - Serial No.		State No. or CRN	Nat'l. Bd. No.	Year Built
^①	^⑥	^⑦	^⑧	^⑩
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____

Attach supplemental pages as required.

6. NUCLEAR PIPING (Identify all nuclear piping by listing system identification appearing on Form N-5 and attach copies of all N-5 Data Reports for nuclear piping.)

Certificate Holder - and - Serial No.		Piping System Identification	Nat'l. Bd. No.	Year Built
^①	^⑥	^{⑤①}	^⑧	^⑩
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____

Attach supplemental pages as required.

* Supplemental information in the form of lists, sketches, or drawings may be used provided (1) size is 8 1/2 x 11, (2) information in items 1 through 4 on this Data Report is included on each sheet, (3) each sheet is numbered and the number of sheets is recorded at the top of this form.

This form (E00024) may be obtained from the Order Dept., ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

[98]

FORM N-3 OWNERS' DATA REPORT FOR NUCLEAR POWER PLANT COMPONENTS*
As Required by the Provisions of the ASME Code, Section III

Page 54

FORM N-3 (Back — Pg. 2 of 55)

Unit No. 53

7. NUCLEAR PUMPS & VALVES (List and identify all nuclear pumps and valves and attach copies of all N Certificate Holders' Data Reports, Forms NV-1 and NPV-1.)

Certificate Holder	Pump	Valve	Cert. Holder's Serial No.	Nat'l. Bd. No.	Year Built
1	54	54	8	9	10

Attach supplemental pages as required.

8. Remarks: 46

66 OWNERS' CERTIFICATE OF COMPLETED INSTALLATION	
I, the undersigned, certify that the statements made in this report are correct and have checked all nuclear components coming under the scope of the ASME Code, Section III, and state that to the best of my knowledge and belief, each Certificate Holder has met all the rules for construction of the ASME Code, Section III. Attached are copies of Certificate Holders' Data Reports covering all nuclear components.	
Owners' Certificate of Authorization No. _____	Expires _____
Date _____ Signature _____	(authorized representative)
69 CERTIFICATE OF INSPECTION	
I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of _____ and employed by _____, based on audits of the owners' quality assurance program and supporting documentation for components and/or appurtenances and installation of same described in this Data Report on _____, state that to the best of my knowledge and belief, the owner, or his designee, as applicable, has complied with the requirements of the ASME Code, Section III. By signing this certificate, neither the inspector nor his employer makes any warranty, expressed or implied, concerning the components and/or appurtenances and installation of same described in this owners' Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this audit activity.	
Date _____ Signed _____	Commissions _____ (Authorized Nuclear Inspector) (Nat'l. Bd. (incl. endorsements) and state or prov. and no.)

**FORM N-5 CERTIFICATE HOLDERS' DATA REPORT FOR INSTALLATION OR SHOP ASSEMBLY OF
NUCLEAR POWER PLANT COMPONENTS, SUPPORTS, AND APPURTENANCES***
As Required by the Provisions of the ASME Code, Section III, Division 1

98

Pg. 1 of 60

1. Installed and certified by 1 (name and address of N or NA Certificate Holder)
2. Installed for 2 (name and address of Purchaser)
3. Location of installation 3 (name and address)
4. System identification 5 (system name) 6 (Cert. Holder's serial no.) 8 (drawing no.) 7 (CRN) 9 (Nat'l. Bd. no.) 10 (year installed)
5. ASME Code, Section III, Division 1: 11 (edition) 12 (addenda date) 13 (class) 14 (Code Case no.)
6. N Certificate Holder having overall responsibility 1 (name and address)

7. Nuclear components, parts, appurtenances, and supports installed (List each item and attach copies of N Certificate Holders' Data Reports and NPT Certificate Holders' Data Reports.):

Components:

(a) Comp. or Appurt.	(b) Name of Certificate Holder	(c) Serial No.	(d) CRN No.	(e) Nat'l. Bd. No.	(f) Year Built
<u>62</u>	<u>1</u>	<u>6</u>	<u>7</u>	<u>9</u>	<u>10</u>

Piping and part installation:

(a) Piping or Part Subassembly	(b) Name of Certificate Holder	(c) Serial No.	(d) CRN No.	(e) Nat'l. Bd. No.	(f) Year Built -- Parts Only
<u>63</u>	<u>1</u>	<u>6</u>	<u>7</u>	<u>9</u>	<u>10</u>

Support installation:

(a) Support No.	(b) Name of Certificate Holder	(c) Serial No.	(d) Design Rept./Load Capac. Data Sheet	(e) CRN No.	(f) Nat'l. Bd. No.	(g) Year Built
<u>64</u>	<u>1</u>	<u>6</u>	<u>61</u>	<u>7</u>	<u>9</u>	<u>10</u>

Additional material excluding welding material:

(a) Name of Mfr.	(b) Material Spec. No.	(c) Dimensions -- Overall
<u>65</u>	<u>15</u>	<u>20</u>

8. Installation in accordance with:

Procedure or Drawing No.	Prepared by
<u>8</u>	<u>66</u>

9. Hydrostatic test pressure 24 psi at temp. 33 °F. System design pressure 31 psi at temp. 32 °F.

10. Remarks:

46

*Supplemental information in form of lists, sketches, or drawings may be used provided (1) size is 8 1/2 x 11, (2) information in items 1 through 4 on this Data Report is included on each sheet, (3) each sheet is numbered and the number of sheets is recorded at the top of this form.

This form (E00025) may be obtained from the Order Dept., ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

[98]

FORM N-5 CERTIFICATE HOLDERS' DATA REPORT FOR INSTALLATION OR SHOP ASSEMBLY OF NUCLEAR POWER PLANT COMPONENTS, SUPPORTS, AND APPURTENANCES*

As Required by the Provisions of the ASME Code, Section III, Division 1

Page 56

FORM N-5 (Back — Pg. 2 of 59)

Certificate Holder's Serial No. 6

CERTIFICATION OF DESIGN FOR PIPING SYSTEM	
Design information on file at 47 _____	
Design report on file at 48 _____	
Design specification certified by 49 _____	P.E. State _____ Reg. no. _____
Design report certified by 50 _____	P.E. State _____ Reg. no. _____
Design conditions of pressure piping 51 _____ psi. Temp. 52 _____ °F.	
70 CERTIFICATE OF INSTALLATION COMPLIANCE	
We certify that the statements made in this report are correct and that this installation conforms to the rules for construction of the ASME Code, Section III, Division 1, and was performed in accordance with the documents listed in 8 above.	
N or NA Certificate of Authorization No. _____ Expires _____	
Date _____	Name _____ (N or NA Certificate Holder)
Signed _____ (authorized representative)	
71 CERTIFICATE OF INSTALLATION INSPECTION	
I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of _____ and employed by _____	
of _____ have inspected the installation of the items described in this Data Report on _____ and state that to the best of my knowledge and belief, the Certificate of Authorization Holder has performed this installation in accordance with the ASME Code, Section III, Division 1.	
By signing this certificate, neither the inspector nor his employer makes any warranty, expressed or implied, concerning the installation described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.	
Date _____	Signed _____ (Authorized Nuclear Inspector)
Commissions 67 _____ (Nat'l. Bd. (incl. endorsements) and state or prov. and no. 1)	
69 CERTIFICATE OF COMPLIANCE FOR OVERALL RESPONSIBILITY	
Following completion of the above, the Certificate of Authorization Holder accepting overall responsibility for the piping system shall complete the following statement:	
We certify that the statements made by this report are correct and that the piping system conforms to the rules for construction of the ASME Code, Section III, Division 1.	
N Certificate of Authorization No. _____ Expires _____	
Date _____	Name _____ (N Certificate Holder)
Signed _____ (authorized representative)	
68 CERTIFICATE OF INSPECTION	
I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of _____ and employed by _____	
of _____ have inspected the piping system described in this Data Report on _____ and state that to the best of my knowledge and belief, the Certificate Holder has constructed this piping system in accordance with the ASME Code, Section III, Division 1.	
By signing this certificate, neither the inspector nor his employer makes any warranty, expressed or implied, concerning the piping system described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.	
Date _____	Signed _____ (Authorized Nuclear Inspector)
Commissions 67 _____ (Nat'l. Bd. (incl. endorsements) and state or prov. and no. 1)	

[98]

FORM N-6 CERTIFICATE HOLDERS' DATA REPORT FOR STORAGE TANKS*
As Required by the Provisions of the ASME Code, Section III, Division 1

Page 58

FORM N-6 (Back — Pg. 2 of 69)

Certificate Holder's Serial No. 69

CERTIFICATION OF DESIGN	
Design specifications certified by 46	P.E. State _____ Reg. no. _____
Design information on file at 42	

CERTIFICATE OF SHOP COMPLIANCE	
We certify that the statements made in this report are correct and that this storage tank conforms to the rules for construction of the ASME Code, Section III, Division 1.	
N Certificate of Authorization No. _____	Expires _____
Date _____ Name _____ (N Certificate Holder)	Signed _____ (authorized representative)

CERTIFICATE OF SHOP INSPECTION	
I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of _____ and employed by _____ of _____ have inspected the storage tank described in this Data Report on _____, and state that to the best of my knowledge and belief, the Certificate Holder has constructed this storage tank in accordance with the ASME Code, Section III, Division 1.	
By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied, concerning the storage tank described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.	
Date _____ Signed _____ (Authorized Nuclear Inspector)	Commissions 67 (Nat'l. Bd. (incl. endorsements) and state or prov. and no.)

CERTIFICATE OF FIELD ASSEMBLY COMPLIANCE	
We certify that the statements on this report are correct and that the field assembly construction of all parts of this storage tank conforms to the rules of construction of the ASME Code, Section III, Division 1.	
N Certificate of Authorization No. _____	Expires _____
Date _____ Name _____ (N Certificate Holder)	Signed _____ (authorized representative)

CERTIFICATE OF FIELD ASSEMBLY INSPECTION	
I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of _____ and employed by _____ of _____ have compared the statements in this Data Report with the described storage tank and state that parts referred to as data items _____, not included in the Certificate of Shop Inspection, have been inspected by me on _____ and that to the best of my knowledge and belief the Certificate Holder has constructed and assembled this storage tank in accordance with the ASME Code, Section III, Division 1.	
By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied, concerning the storage tank described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.	
Date _____ Signed _____ (Authorized Nuclear Inspector)	Commissions 67 (Nat'l. Bd. (incl. endorsements) and state or prov. and no.)

FORM N-6

Page 61

Pages 60-60

**FORM NPP-1 CERTIFICATE HOLDERS' DATA REPORT FOR FABRICATED
NUCLEAR PIPING SUBASSEMBLIES***

98

As Required by the Provisions of the ASME Code, Section III, Division 1 Pg. 1 of 59

1. Fabricated and certified by ①
(name and address of NPT Certificate Holder)

2. Fabricated for ②
(name and address)

3. Location of installation ③
(name and address of Purchaser)

4. Type ⑥ ⑦ ⑧ ⑨ ⑩
(Cert. Holder's serial no.) (CRN) (drawing no.) (Nat'l. Bd. no.) (year built)

5. ASME Code, Section III, Division 1: ⑪ ⑫ ⑬ ⑭
(edition) (addenda date) (class) (Code Case no.)

6. Shop hydrostatic test ③⁹ psi at ③³ °F (if performed)

7. Description of piping ⑤¹ ⑤⁵ ①⁵

8. Certificate Holders' Data Reports properly identified and signed by commissioned inspectors have been furnished for the following items of this report: ⑥⁹

9. Remarks: ④⁹

⑥⁹	CERTIFICATE OF SHOP COMPLIANCE
We certify that the statements made in this report are correct and that the fabrication of the described piping subassembly conforms to the rules for construction of the ASME Code, Section III, Division 1.	
NPT Certificate of Authorization No. _____ Expires _____	
Date _____	Name _____ (NPT Certificate Holder)
Signed _____ (authorized representative)	
⑥⁹	CERTIFICATE OF SHOP INSPECTION
I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of _____ and employed by _____	
of _____ have inspected the piping subassembly described in this Data Report on _____, and state that to the best of my knowledge and belief, the Certificate Holder has fabricated this piping subassembly in accordance with the ASME Code, Section III, Division 1.	
By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied, concerning the piping subassembly described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.	
Date _____	Signed _____ (Authorized Nuclear Inspector)
Commissions _____ (Nat'l. Bd. (incl. endorsements) and state or prov. and no.)	

* Supplemental information in form of lists, sketches, or drawings may be used provided (1) size is 8½ × 11, (2) information in items 1 through 4 on this Data Report is included on each sheet, (3) each sheet is numbered and the number of sheets is recorded at the top of this form.

This form (E00062) may be obtained from the Order Dept., ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

[98]

FORM NPP-1 CERTIFICATE HOLDERS' DATA REPORT FOR FABRICATED NUCLEAR PIPING SUBASSEMBLIES*
As Required by the Provisions of the ASME Code, Section III, Division 1

Page 60

FORM NPP-1 (Back — Pg. 2 of 62)

Certificate Holder's Serial No. 6

10. Description of field fabrication 51 55

11. Pneu., hydro., or comb. test pressure 54 psi at temp. 53 °F (if performed)

70		CERTIFICATE OF FIELD FABRICATION COMPLIANCE	
We certify that the statements on this report are correct and that the field fabrication of the described piping subassembly conforms with the rules for construction of the ASME Code, Section III, Division 1.			
NPT Certificate of Authorization No. _____		Expires _____	
Date _____	Name _____	Signed _____	
	(Certificate Holder)	(authorized representative)	

71		CERTIFICATE OF FIELD FABRICATION INSPECTION	
I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of _____ and employed by _____			
_____ of _____ have compared the statements in this Data Report with the described piping subassembly and state that parts referred to as data items _____, not included in the Certificate of Shop Inspection, have been inspected by me on _____ and that to the best of my knowledge and belief the Certificate Holder has fabricated this piping subassembly in accordance with the ASME Code, Section III, Division 1.			
By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied, concerning the piping subassembly described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.			
Date _____	Signed _____	Commissions _____	
	(Authorized Nuclear Inspector)	(Nat'l. Bd. incl. endorsements) and state or prov. and no. 1	

FORM NPP-1

[98]

FORM NPV-1 CERTIFICATE HOLDERS' DATA REPORT FOR NUCLEAR PUMPS OR VALVES*
As Required by the Provisions of the ASME Code, Section III, Division 1

Page 62

FORM NPV-1 (Back — Pg. 2 of 56)

Certificate Holder's Serial No. ⑥

8. Design conditions ⑩⑤ psi ⑩⑤ °F or valve pressure class ⑥⑦ (1)
(pressure) (temperature)

9. Cold working pressure ⑩③ psi at 100°F

10. Hydrostatic test ⑩⑤ psi. Disk differential test pressure ⑥③ psi

11. Remarks: ④⑨

CERTIFICATION OF DESIGN

Design Specification certified by ④⑨ P.E. State _____ Reg. no. _____
Design Report certified by ⑤⑨ P.E. State _____ Reg. no. _____

⑤⑨

CERTIFICATE OF COMPLIANCE

We certify that the statements made in this report are correct and that this pump or valve conforms to the rules for construction of the ASME Code, Section III, Division 1.

N Certificate of Authorization No. _____ Expires _____

Date _____ Name _____ Signed _____
(N Certificate Holder) (authorized representative)

⑤⑩

CERTIFICATE OF INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of _____ and employed by _____ of _____ have inspected the pump, or valve, described in this Data Report on _____, and state that to the best of my knowledge and belief, the Certificate Holder has constructed this pump, or valve, in accordance with the ASME Code, Section III, Division 1.

By signing this certificate, neither the inspector nor his employer makes any warranty, expressed or implied, concerning the component described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date _____ Signed _____ Commissions ⑥⑦
(Authorized Nuclear Inspector) [Nat'l. Bd. (incl. endorsements) and state or prov. and no.]

(1) For manually operated valves only.

1. Manufactured and certified by _____⁽¹⁾
(name and address of NV Certificate Holder)

2. Manufactured for _____⁽²⁾
(name and address of Purchaser)

3. Location of installation _____⁽³⁾
(name and address)

4. Valve _____^(10A) Orifice size _____⁽⁸²⁾ Nom. inlet size _____⁽⁸³⁾ Outlet size _____⁽⁸³⁾
(model no., series no.) (in.) (in.) (in.)

5. ASME Code, Section III, Division 1: _____⁽¹¹⁾ _____⁽¹²⁾ _____⁽¹³⁾ _____⁽¹⁴⁾
(edition) (addenda date) (class) (Code Case no.)

6. Type _____⁽⁸⁴⁾ _____⁽⁸⁵⁾ _____⁽⁸⁶⁾ _____⁽⁸⁷⁾ _____⁽⁸⁴⁾ at _____⁽⁸³⁾ °F
(spring, pilot or power operated) (set pressure, psig) (blowdown, psi) (rated temp.) (hydro. test, psig, inlet)

7. Identification _____⁽⁶⁾ _____⁽⁷⁾ _____⁽⁸⁾ _____⁽⁹⁾ _____⁽¹⁰⁾
(Cert. Holder's serial no.) (CRN) (drawing no.) (Nat'l. Bd. no.) (year built)

8. Control ring settings _____^(10B)

9. Pressure retaining items:

	Serial No. or Identification	Mat'l. Spec., Including Type or Grade	Tensile Strength
Body	_____ ⁽⁶⁾ _____	_____ ⁽¹⁵⁾ _____	_____ ⁽¹⁶⁾ _____
Bonnet or Yoke	_____	_____	_____
Support Rods	_____	_____	_____
Nozzle	_____	_____	_____
Disk	_____	_____	_____
Spring Washers	_____	_____	_____
Adjusting Screws	_____	_____	_____
Spindle	_____	_____	_____
Spring	_____	_____	_____
Bolting	_____	_____	_____
Other Items	_____	_____	_____

10. Relieving capacity _____⁽⁸⁶⁾ @ _____⁽⁸⁵⁾ overpressure as certified by the National Board _____⁽⁸⁶⁾
(steam or fluid, lb/hr) (psi) (date)

11. Remarks: _____⁽⁴⁶⁾

	CERTIFICATION OF DESIGN	
Design Specification certified by _____	P.E. State _____	Reg. no. _____
Design Report certified by _____	P.E. State _____	Reg. no. _____

* Supplemental information in form of lists, sketches, or drawings may be used provided (1) size is 8½ x 11, (2) information in items 1 through 4 on this Data Report is included on each sheet, (3) each sheet is numbered and the number of sheets is recorded at the top of this form.

This form (E00042) may be obtained from the Order Dept., ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

FORM NV-1 CERTIFICATE HOLDERS' DATA REPORT FOR PRESSURE OR VACUUM RELIEF VALVES*
As Required by the Provisions of the ASME Code, Section III, Division 1

FORM NV-1 (Back — Pg. 2 of 58)

66	CERTIFICATE OF INSPECTION	67
I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of _____ and employed by _____ of _____ have inspected the valve described in this Data Report on _____, and state that to the best of my knowledge and belief, the Certificate Holder has constructed this valve in accordance with the ASME Code, Section III, Division 1.		
By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied, concerning the component described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.		
Date _____	Signed _____ (Authorized Nuclear Inspector)	Commissions _____ (Nat'l. Bd. (incl. endorsements) and state or prov. and no.)

Page 67

As Required by the Provisions of the ASME Code, Section III, Division 1 Pg. 1 of 2

Design Specification certified by _____		CERTIFICATION OF DESIGN	Reg. no. _____
Design Report certified by _____		P. E. State _____	Reg. no. _____

CERTIFICATE OF INTERNAL STRUCTURES	
The undersigned, having a valid Certificate of Authorization, certify that the construction of the internal structures will not adversely affect the integrity of the core support structures.	
N Certificate of Authorization No. _____	Expires _____
Date _____ Name _____	Signed _____ (In Certificate Holder) (Authorized Representative)

CERTIFICATE OF COMPLIANCE	
We certify that the statements made in this report are correct and that this set of core support structures conforms to the rules for construction of the ASME Code, Section III, Division 1.	
N Certificate of Authorization No. _____	Expires _____
Date _____ Name _____	Signed _____ (In Certificate Holder) (Authorized Representative)

CERTIFICATE OF INSPECTION	
I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of _____, and employed by _____, inspected the core support structure described in this Data Report on _____, 10 _____ and state that to the best of my knowledge and belief, the Certificate Holder has constructed this item in accordance with the ASME Code, Section III, Division 1. By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied, concerning the item described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.	
Date _____ Signed _____	Commissions _____ (Not to be filled in by inspectors who are not members of the National Board of Boiler and Pressure Vessel Inspectors)

*Supplemental sheets in form of lists, sketches, or drawings may be used provided (1) size is 8 1/2 x 11, (2) information in items 1 through 4 on this Data Report is included on each sheet, (3) each sheet is numbered and the number of sheets is recorded at the top of this form.

FORM NCS-1 CERTIFICATE HOLDERS' DATA REPORT FOR CORE SUPPORT STRUCTURES*
As Required by the Provisions of the ASME Code, Section III, Division 1

1. Manufactured by _____	(name and address of NPT Certificate Holder)					
2. Manufactured for _____	(name and address of Purchaser)					
3. Location of installation _____	(name and address)					
4. Type: _____	(Design Report or Load Capacity Data Sheet)					
5. ASME Code, Section III, Division 1: _____	(Code Case no.)					
<table border="0" style="width: 100%;"> <tr> <td style="width: 20%;">(a) Support I.D. No.</td> <td style="width: 20%;">(b) Material Specification No.</td> <td style="width: 20%;">(c) Canadian Registration No.</td> <td style="width: 20%;">(d) Applicable Drawings With Last Rev. & Date</td> <td style="width: 20%;">(e) National Board No.</td> </tr> </table>		(a) Support I.D. No.	(b) Material Specification No.	(c) Canadian Registration No.	(d) Applicable Drawings With Last Rev. & Date	(e) National Board No.
(a) Support I.D. No.	(b) Material Specification No.	(c) Canadian Registration No.	(d) Applicable Drawings With Last Rev. & Date	(e) National Board No.		
(1) _____	(2) _____					
(3) _____	(4) _____					
(5) _____	(6) _____					
(7) _____	(8) _____					
(9) _____	(10) _____					
7. Remarks: _____						

This form (E00075) may be obtained from the Order Dept., ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

[98]

FORM NF-1 CERTIFICATE HOLDERS' DATA REPORT FOR SUPPORTS*

As Required by the Provisions of the ASME Code, Section III, Division 1

Page 68

FORM NF-1 (Back — Pg. 2 of 60)

Support I.D. Nos. 64 through

CERTIFICATION OF DESIGN

Design Specification certified by 49 P.E. State Reg. no.
Design Report certified by 60 P.E. State Reg. no.

CERTIFICATE OF COMPLIANCE

We certify that the statements made in this report are correct and that these supports conform to the rules for construction of the ASME Code, Section III, Division 1.

NPT Certificate of Authorization No. Expires

Date Name Signed
(NPT Certificate Holder) (authorized representative)

CERTIFICATE OF INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of and employed by of have inspected the supports described in this Data Report on, and state that to the best of my knowledge and belief, the Certificate Holder has constructed these supports in accordance with the ASME Code, Section III, Division 1.

By signing this certificate, neither the inspector nor his employer makes any warranty, expressed or implied, concerning the component supports described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date Signed Commissions 67
(Authorized Nuclear Inspector) [Nat'l. Bd. (incl. endorsements) and state or prov. and no.]

FORM NF-1

Page 71

**FORM NM-1 CERTIFICATE HOLDERS' DATA REPORT FOR
TUBULAR PRODUCTS AND FITTINGS WELDED WITH FILLER METAL***

As Required by the Provisions of the ASME Code, Section III, Division 1 **Pg. 1 of 58**

98

1. Manufactured and certified by	①		(name and address of NPT Certificate Holder)
2. Manufactured for	②		(name and address of Purchaser)
3. Location of installation	③		(name and address)
4. Identification	⑦⑧	⑧	⑨
	(lot, etc.)	(drawing no.)	(Nat'l. Bd. no.)
5. ASME Code, Section III, Division 1:	⑪	⑫	⑬
	(edition)	(addenda date)	(class)
6. Mat'l. Spec.	⑮	⑯	⑰
	(SA or SB and no.)	(tensile strength)	(nom. thickness)
7. Shop hydrostatic test pressure	⑤④	psi at	⑤③
			°F (if performed)
8. Remarks:	④⑥		

⑤⑨	CERTIFICATE OF COMPLIANCE
We certify that the statements made in this report are correct and that the products defined in this report conform to the rules for construction of the ASME Code, Section III, Division 1. The radiographic film and a radiographic report showing film locations are attached to the Certified Material Test Reports provided for the material covered by this report.	
NPT Certificate of Authorization No. _____ Expires _____	
Date _____ Name _____	Signed _____
(NPT Certificate Holder)	(authorized representative)
⑤⑩	
CERTIFICATE OF INSPECTION	
I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of _____ and employed by _____ have inspected the products described in this Data Report on _____, and state that to the best of my knowledge and belief, the Certificate Holder has constructed this product in accordance with the ASME Code, Section III, Division 1.	
By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied, concerning the products described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.	
Date _____ Signed _____	Commissions _____
(Authorized Nuclear Inspector)	(Nat'l. Bd. (incl. endorsements) and state or prov. and no.)

* Supplemental information in form of lists, sketches, or drawings may be used provided (1) size is 8 1/2 x 11, (2) information in items 1 through 4 on this Data Report is included on each sheet, (3) each sheet is numbered and the number of sheets is recorded at the top of this form.

This form (E00080) may be obtained from the Order Dept., ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

[98]

FORM NM-1 CERTIFICATE HOLDERS' DATA REPORT FOR TUBULAR PRODUCTS AND FITTINGS WELDED WITH FILLER METAL*

As Required by the Provisions of the ASME Code, Section III, Division 1

[98]

FORM C-1 CERTIFICATE HOLDERS' DATA REPORT FOR CONCRETE REACTOR VESSELS AND CONTAINMENTS*

As Required by the Provisions of the ASME Code, Section III, Division 2

Page 72

FORM C-1 (Back — Pg. 2 of 5)

Certificate Holders' Serial No. 6

13. Construction Report No. 53 Date

14. List of Penetrations 54

Attach a complete list of penetrations (i.e., personnel locks, equipment hatch, electrical, etc.) to this report. State the type, size, manufacturer, and serial no.

15. Test Pressure 54 psi Date tested

16. Remarks: 48

CERTIFICATION OF DESIGN

Design Specification on file at 109

Design Specification certified by 48 P.E. State Reg. no.

Design Report on file at 48

Design Report certified by 50 P.E. State Reg. no.

59

DESIGNER'S REPORT OF CERTIFICATION

I, the undersigned, representing the Designer and employed by have examined and evaluated the Construction Report for the component described in this Data Report. Following evaluation, the Construction Report has been certified and to the best of my knowledge and belief the Constructor has constructed this component in accordance with the rules of the ASME Code, Section III, Division 2, and the construction specifications listed herein, and these construction specifications meet the requirements of the Design Specification.

Date Signed (authorized representative)

P.E. State Reg. no.

70

CERTIFICATE OF CONSTRUCTION COMPLIANCE

We certify that the statements made in this report are correct and that all details of materials, construction, and workmanship of this component conform to the rules for construction of the ASME Code, Section III, Division 2, and the Construction Specifications listed herein.

Certificate of Authorization No. Expires

Date Constructor (In Certificate Holder) Signed (authorized representative)

71

CERTIFICATE OF INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of and employed by of have inspected the concrete reactor vessel or containment described in this Constructor's Data Report and state that to the best of my knowledge and belief this component has been constructed in accordance with the ASME Code, Section III, Division 2.

By signing this certificate neither the Authorized Inspector nor his employer makes any warranty, expressed or implied, concerning the component described in this report. Furthermore, neither the Authorized Inspector nor his employer shall be liable in any manner for any personal injury or property damage or loss of any kind arising from or connected with this inspection.

Date Signed (Authorized Nuclear Inspector) Commissions 67 (Nat'l. Bd. (incl. endorsements) and state or province and no.)

Table V-1000

Guide for Preparation of Data Report Forms

Begins on following page

TABLE V-1000
GUIDE FOR PREPARATION OF DATA REPORT FORMS

Applies to Form										Note	Instructions for Completion	
N-1	N-1A	N-2	N-3	N-5	N-6	NPP-1	NPV-1	NCS-1	NF-1	MM-1	C-1	Number
X	X	X	X	X	X	X	X	X	X	X	X	①
X	X	X	X	X	X	X	X	X	X	X	X	②
X	X	X	X	X	X	X	X	X	X	X	X	③
X	X	...	...	...	...	...	...	...	...	...	...	④
X	...	...	...	...	...	...	...	...	...	...	...	⑤
X	X	X	X	X	X	X	X	X	...	...	...	⑥
X	X	X	X	X	X	X	X	X	X	...	...	⑦
X	X	X	...	X	X	X	X	X	X	X	X	⑧
X	X	X	X	X	X	X	X	X	X	X	X	⑨
X	X	X	X	X	X	X	X	X	X	X	X	⑩
X	X	X	...	X	X	X	X	X	X	X	X	⑪
X	X	X	...	X	X	X	X	X	X	X	X	⑫
X	X	X	...	X	X	X	X	X	X	X	X	⑬
X	X	X	...	X	X	X	X	X	X	X	X	⑭
X	X	X	...	X	X	X	X	...	X	X	X	⑮
X	X	X	...	X	...	...	...	...	...	...	...	⑯

[SEC III D1 MA APP V] Copyright by American Society Of Mechanical Engineers (Thu Jan 30 11:17:08 2003)

TABLE V-1000

TABLE V-1000 (CONT'D)
GUIDE FOR PREPARATION OF DATA REPORT FORMS

Applies to Form												Note	Instructions for Completion	
N-1	N-1A	N-2	N-3	N-5	N-6	NPP-1	NPV-1	NCS-1	NF-1	NM-1	C-1	Number		
...	...	...	...	...	...	...	...	...	X	...	...	...	(39)	Describe type of core support structure component (e.g., bottom grid, fuel support, top guide, etc.).
X	...	...	...	...	...	...	...	...	...	...	...	...	(40)	Nominal outside diameter of tubes, in.
X	...	...	...	...	...	...	...	...	...	...	...	...	(41)	Nominal wall thickness of tubes or gage size, in.
X	...	...	...	...	X	...	...	...	...	...	...	...	(42)	Number of tubes.
X	...	...	...	...	...	...	...	...	...	...	...	...	(43)	Actual tube configuration (straight or U-tube, etc.).
X	X	...	...	...	X	...	...	...	...	...	...	...	(44)	Nozzles, inspection, and safety valve openings; list all openings, regardless of size, penetrating pressure boundary.
X	X	...	...	...	X	...	...	...	...	...	...	...	(45)	Describe: (a) type of support (skirt, lugs, legs, etc.); (b) location of support (top, bottom, side, etc.); (c) method of attachment (bolted, welded, etc.).
X	X	X	X	X	X	X	X	X	X	X	X	X	(46)	Describe any additional Code requirements, restrictions or additional information, including marking in lieu of stamping, not otherwise covered in Data Report. Include any required tests or examination not performed when Data Report is completed.
...	...	...	...	X	...	...	...	...	...	...	...	...	(47)	Specify the name and address of the organization where design information is on file.
...	...	...	...	X	...	...	...	...	...	...	X	...	(48)	Specify the name and address of the organization where Design Report or Design Specification is on file.
X	X	X	...	X	X	...	X	X	X	X	...	X	(49)	Enter the name of engineer who certified the Design Specification. Show state of registration and number. List name of individual only, signature not required. (Applies to Form N-2 only when Design Specification is required.)
X	X	X	...	X	...	...	X	X	X	X	...	X	(50)	Enter name of engineer who certified the Design Report. Show state of registration and number. List name of individual only, signature not required in space provided. (Applies to Form N-2 only when Design Report is required.)
...	...	...	X	X	...	X	...	...	...	...	...	...	(51)	System name is identified in the Design Specification (main steam, feedwater, safety injection, etc.).
...	...	...	X	...	...	...	...	...	...	...	...	...	(52)	Name of power plant designated by utility.
...	...	...	X	...	...	...	...	...	...	...	...	...	(53)	Number designation of unit.
...	...	...	X	...	...	...	...	...	...	...	...	...	(54)	Specify whether pump, valve, or safety relief valve.
...	...	...	...	...	...	X	...	...	...	...	...	...	(55)	Describe the piping, flanges, and fittings assembled and covered by Data Report including material specification (see Note 13) or as an alternative, reference applicable sketch or drawing and attach to the Data Re

SEC III D1 MA APP V] Copyright by American Society Of Mechanical Engineers (Thu Jan 30 11:17:11 2003)

X	X	X	X	X	X	X	X	X	X		(56)	When supplemental sheets are attached to the Data Report, each page is sequentially numbered and the total number of sheets is identified on the top right hand corner of the Data Report in the space provided.
.	.	.	.	.	.	.	.	.	.	.	(57)	Actual operating pressure for the system, psi. (This may differ from the Design Pressure in the design certification block on back of Form N-5.)
.	.	.	.	.	.	.	.	.	.	.	(58)	Actual operating temperature for the system, °F. (This may differ from the Design Pressure in the design certification block on back of Form N-5.)
.	.	.	.	.X	.	.	.	.	.	.X	(59)	Name of Material Manufacturer.
.	.	.	.	.X	.	.	.	.	.	.	(60)	Name of person approving drawing or procedure.
.	.	.	.	.X	.	.	.	.	.	.	(61)	List report or data sheet number as applicable.
.	.	.	.	.X	.	.	.	.	.	.	(62)	Indicate valve, vessel, pump, or appurtenance.
.	.	.	.	.X	.	.	.	.	.	.X	(63)	Indicate piping subassembly or part.
.	.	.	.	.X	.	.	.	.	.X	.	(64)	List support identification number, model, or catalog item.
.	.	.	.	.	.	.	.	.X	.	.	(65)	Indicate fluid used for National Board capacity test; the certified relieving capacity, lb/hr; and the percent overpressure used during the capacity test or psi differential for vacuum relief valves.
.	.	.	.	.	.	.	.	.X	.	.	(66)	Date of National Board capacity test certification.
X	X	X	X	X	X	X	X	X	X	X	(67)	The Authorized Nuclear Inspector's National Board Commission No. and province commission, must be shown when the completed component, part, support, or appurtenance is stamped "National Board." Otherwise, show only his state or province commission number.
X	X	X	X	X	X	X	X	X	X	X	(68)	This certificate is to be completed by the Certificate Holder and signed by the Authorized Nuclear Inspector who performs the inspection.
X	X	X	X	X	X	X	X	X	X	X	(69)	Certificate of Compliance block is to show the name of the responsible Certificate Holder as shown on his ASME Code Certificate of Authorization. This should be signed in accordance with the organizational authority defined in the Quality Assurance Program.
X	.	.	.	.X	.X	.	.	.	.	.X	(70)	Certificate of Compliance block for field installation work or assembly is to be signed by the Certificate Holder's representative in charge of field fabrication. This should be signed in accordance with organizational authority defined in the Quality Assurance Program.
X	.	.	.	.X	.X	.	.	.	.	.X	(71)	This certificate block is for the Authorized Inspector to sign for any field construction or assembly work. See (67) for National Board Commission Number requirements.
.	.	.	.	.X	.	.	.	.	.	.	(72)	Specific gravity (density of fluid in relation to water, water being 1.0).

TABLE V-1000 (CONT'D)

TABLE V-1000 (CONT'D)
GUIDE FOR PREPARATION OF DATA REPORT FORMS

Applies to Form													Note	Instructions for Completion
N-1	N-1A	N-2	N-3	N-5	N-6	NPP-1	NPV-1	NV-1	NCS-1	NF-1	NM-1	C-1	Number	
...	...	...	...	...	X	...	...	...	...	...	...	...	(73)	Maximum height of fluid in tank, ft.
...	...	...	...	...	X	...	...	...	...	...	...	...	(74)	Temperature of test, °F.
...	...	...	...	...	X	...	...	...	...	...	...	...	(75)	Impact test lateral expansion, mil.
...	...	...	...	...	X	...	...	...	...	...	...	...	(76)	Minimum temperature (only when below -20°F) for design.
...	...	X	...	...	...	...	...	...	...	...	...	X	(77)	Identification number and title of Division 2 Construction Specification, including applicable revision number and the date of the revision (applies to Division 2 items only).
...	...	...	...	...	...	...	...	...	X	...	...	X	(78)	Design Specification identifying number, including applicable revision number and the date of the revision.
...	...	...	...	...	...	...	...	...	...	...	X	...	(79)	Heat or lot identification number of material used for fabrication.
...	...	...	...	...	...	X	...	...	...	...	...	...	(80)	List items included in the piping subassembly for which Certificate Holder's Data Reports have been completed, including serial number or National Board number and brief identifying description.
...	...	...	...	...	...	...	X	...	...	...	...	...	(81)	Valve pressure class designation per ANSI B16.34.
...	...	...	...	...	...	...	...	X	...	...	...	...	(82)	Diameter of orifice opening, in.
...	...	...	...	...	...	...	X	X	...	...	...	X	(83)	Enter the nominal pipe size of inlet or outlet opening, in.
...	...	...	...	...	...	...	...	X	...	...	...	...	(84)	Indicate method of valve operation (spring, pilot operated, or power operated).
...	...	...	...	...	...	...	...	X	...	...	...	...	(85)	Set opening pressure of valve, psig.
...	...	...	...	...	...	...	...	X	...	...	...	...	(86)	Difference between opening and reseating pressure, psi.
...	...	...	...	...	...	...	...	X	...	...	...	...	(87)	Temperature rating of valve at the rated relieving capacity.
...	...	...	...	...	...	...	...	...	...	...	...	X	(88)	Concrete construction type (reinforced or prestressed).
...	...	...	...	...	...	...	...	...	...	...	...	X	(89)	Height of dome above springline, ft and in.
...	...	...	...	...	...	...	...	...	...	...	...	X	(90)	Geometry of dome (spherical, ellipsoidal, conical, flat, etc.).
...	...	...	...	...	...	...	...	...	...	...	...	X	(91)	Foundation type and underlying substrata.
...	...	...	...	...	...	...	...	...	...	...	...	...	(92)	Date Design Report certified.

TABLE V-1000 (CONT'D) GUIDE FOR PREPARATION OF DATA REPORT FORMS

										X	(93)	Construction report identification number and certification date.
										X	(94)	Describe corrosion protection and coatings for post-tensioning tendons.
										...	(95)	List all penetrations (openings), regardless of size, passing through the pressure boundary. State type (name), size (in. or ft and in.), shape (circular, rectangular, etc.), and serial number.
									X	...	(96)	Type of support (plate and shell, linear, standard support).
									X	...	(97)	Design Report or load capacity data sheet (indicate which).
						X			...	...	(98)	Disk differential pressure. A pressure equal to 110% of the valve pressure rating at 100°F.
									...	...	(99)	Description of part (support) (snubber, sway brace, clevis, U-bolt, threaded rod with fastener, etc.).
						X			...	...	(100)	Pump or valve (indicate which).
									...	...	(101)	Brief description of service (feedwater, reactor cooling, safety injection, component cooling, etc.).
						X			...	...	(102)	Mark number (the unique identification assigned by the Material Manufacturer to provide traceability to the CMTR).
						X			...	...	(103)	Cold working pressure: the pressure at 100°F as established by the pressure-temperature tables in ANSI B16.34 (valves only).
						X	X		...	...	(104)	Model number, series number, type (either a number traceable to the type or a description of the type for example gate, globe, butterfly, etc.).
						X			...	...	(105)	Pressure equal to or greater than the Design Pressure specified in the Design Specification.
						X			...	...	(106)	Coincident temperature per ANSI B16.34 to pressure listed in (103). This temperature shall be equal to or greater than the Design Temperature specified in the Design Specification.
									...	...	(107)	Minimum allowable yield strength specified in the appropriate Material Specification.
							X		...	...	(108)	Indicate final ring position(s) with respect to an indicated reference point.
									...	...	(109)	Name of certifying Professional Engineer. Show state of registration and registration number.

GENERAL NOTES:

- GENERAL NOTES:
(a) All blanks on the Data Report must contain an entry. If an entry is not applicable, enter "N/A" into the blank.
(b) If space on Data Report is not sufficient for required information, either the remarks section is used or a supplementary sheet shall be attached and information listed by line number.
(c) These instructions constitute a nonmandatory guide for completion of Data Reports for items constructed to Section III Editions and Addenda prior to the Winter 1984 Addenda.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 MA APP VI

APPENDIX VI ROUNDED INDICATIONS

Page 81

ARTICLE VI-1000 ROUNDED INDICATIONS

VI-1100 ACCEPTANCE STANDARDS FOR RADIOGRAPHICALLY DETERMINED ROUNDED INDICATIONS IN WELDS

VI-1110 APPLICABILITY OF THESE STANDARDS

These standards are applicable to ferritic, austenitic, and nonferrous material.

VI-1120 TERMINOLOGY

VI-1121 Rounded Indications

Indications with a maximum length of three times the width or less on the radiograph are defined as rounded indications. These indications may be circular, elliptical, conical, or irregular in shape and may have tails. When evaluating the size of an indication, the tail shall be included. The indication may be from any source in the weld, such as porosity, slag, or tungsten.

VI-1122 Aligned Indications

A sequence of four or more rounded indications shall be considered to be aligned when they touch a line parallel to the length of the weld drawn through the center of the two outer rounded indications.

VI-1123 Thickness t

t is the thickness of the weld, of the pressure retaining material, or of the thinner of the sections being joined, whichever is least. If a full penetration weld includes a fillet weld, the thickness of the fillet weld throat shall be included in t .

**TABLE VI-1132-1
MAXIMUM SIZE OF NONRELEVANT INDICATIONS
AND ACCEPTABLE ROUNDED INDICATIONS —
EXAMPLES ONLY**

Thickness t , in.	Maximum Size of Acceptable Rounded Indication, in.		Maximum Size of Nonrelevant Indication, in.
	Random	Isolated	
$< \frac{1}{8}$	$\frac{1}{4}t$	$\frac{1}{3}t$	$\frac{1}{10}t$
$\frac{1}{8}$	0.031	0.042	0.015
$\frac{3}{16}$	0.047	0.063	0.015
$\frac{1}{4}$	0.063	0.083	0.015
$\frac{5}{16}$	0.078	0.104	0.031
$\frac{3}{8}$	0.091	0.125	0.031
$\frac{7}{16}$	0.109	0.146	0.031
$\frac{1}{2}$	0.125	0.168	0.031
$\frac{9}{16}$	0.142	0.188	0.031
$\frac{5}{8}$	0.156	0.210	0.031
$\frac{11}{16}$	0.156	0.230	0.031
$\frac{3}{4}$ –2, incl.	0.156	0.250	0.031
> 2	0.156	0.375	0.063

TABLE VI-1132-1 MAXIMUM SIZE OF NONRELEVANT INDICATIONS AND ACCEPTABLE ROUNDED INDICATIONS - EXAMPLES ONLY

VI-1130 ACCEPTANCE CRITERIA

VI-1131 Image Density

Density within the image of the indication may vary and is not a criterion for acceptance or rejection.

VI-1132 Relevant Indications

(See Table VI-1132-1 for Examples)

Only those rounded indications which exceed the following dimensions shall be considered relevant:

$\frac{1}{10}t$ for t less than $\frac{1}{8}$ in. (3.2 mm);

$\frac{1}{64}$ in. (0.4 mm) for t equal to $\frac{1}{8}$ - $\frac{1}{4}$ in. (3.2-6 mm), inclusive;

$\frac{1}{32}$ in. (0.8 mm) for t greater than $\frac{1}{4}$ -2 in. (6-51 mm), inclusive;

$\frac{1}{16}$ in. (1.6 mm) for t greater than 2 in. (51 mm).

Page 84

VI-1133 Maximum Size of Rounded Indication

(See Table VI-1132-1 for Examples)

The maximum permissible size of any indication shall be $\frac{1}{4}t$ or $\frac{5}{32}$ in. (4 mm), whichever is less, except that an isolated indication separated from an adjacent indication by 1 in. (25 mm) or more may be $\frac{1}{3}t$ or $\frac{1}{4}$ in. (6 mm), whichever is less. For t greater than 2 in. (51 mm), the maximum permissible size of an isolated indication shall be increased to $\frac{3}{8}$ in. (10 mm).

VI-1134 Aligned Rounded Indications

Aligned rounded indications are acceptable when the summation of the diameters of the indications is less than t in a length of $12t$ (see Fig. VI-1134-1). The length of groups of aligned rounded indications and the spacing between the groups shall meet the requirements of Fig. VI-1134-2.

VI-1135 Spacing

The distance between adjacent rounded indications is not a factor in determining acceptance or rejection, except as required for isolated indications or groups of aligned indications.

VI-1136 Rounded Indication Charts

(a) The rounded indications as determined from the radiographic film shall not exceed that shown in the charts.

(b) The charts in Figs. VI-1136-1 through VI-1136-6 illustrate various types of assorted, randomly dispersed, and clustered rounded indications for different weld thicknesses greater than $\frac{1}{8}$ in. (3.2 mm). These charts represent the maximum acceptable concentration limits for rounded indications.

(c) The chart for each thickness range represents full-scale 6 in. (152 mm) radiographs and shall not be enlarged or reduced. The distributions shown are not necessarily the patterns that may appear on the radiograph, but are typical of the concentration and size of indications permitted.

VI-1137 Weld Thickness t Less Than $\frac{1}{8}$ in. (3.2 mm)

For t less than $\frac{1}{8}$ in. (3.2 mm) the maximum number of rounded indications shall not exceed 12 in a 6 in. (152 mm) length of weld. A proportionally fewer number of indications shall be permitted in welds less than 6 in. (152 mm) in length.

VI-1138 Clustered Indications

The illustrations for clustered indications show up to four times as many indications in a local area, as that shown in the illustrations for random indications. The length of an acceptable cluster shall not exceed the lesser of 1 in. (25 mm) or $2t$. Where more than one cluster is present, the sum of the lengths of the clusters shall not exceed 1 in. (25 mm) in a 6 in. (152 mm) length of weld.

Page 85

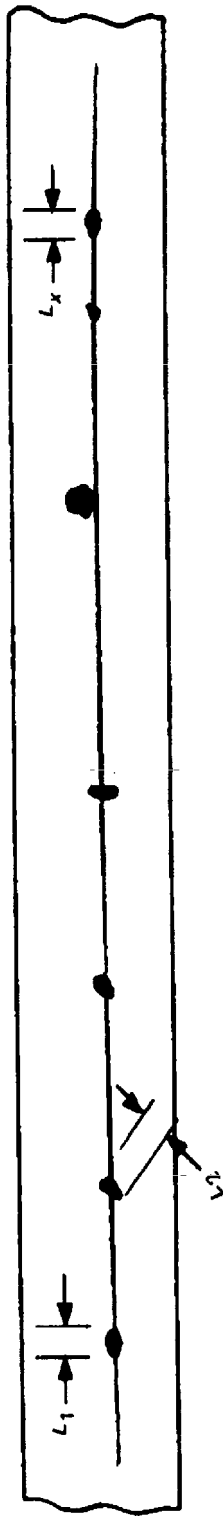
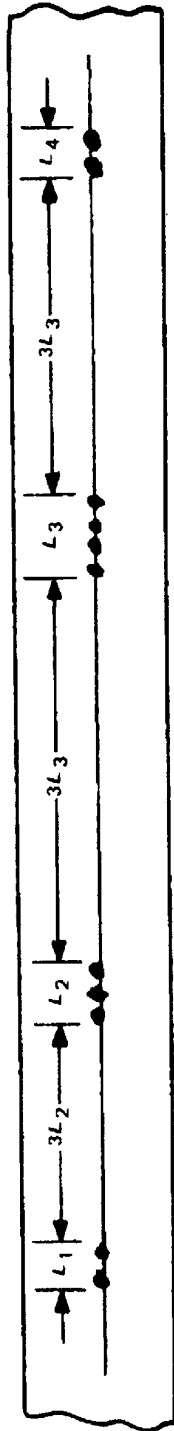


FIG. VI-1134-1 ALIGNED ROUNDED INDICATIONS



The sum of the group lengths shall be less than t in a length of $12 t$.

Maximum Group Length

$L = 1/4$ in. for t less than $3/4$ in.

$L = 1/3 t$ for t equal to $3/4$ in. to $2 1/4$ in.

$L = 3/4$ in. for t greater than $2 1/4$ in.

Minimum Group Spacing

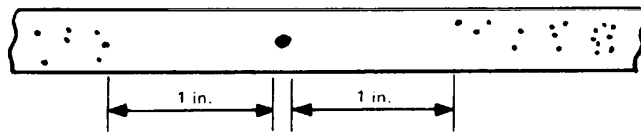
$3L$ where L is the length of the longest adjacent group being evaluated.

FIG. VI-1134-2 GROUPS OF ALIGNED ROUNDED INDICATIONS

FIG. VI-1134-2 GROUPS OF ALIGNED ROUNDED INDICATIONS



(a) Random Rounded Indications (Typical concentration and size permitted in any 6 in. length of weld.)



(b) Isolated Indication (Maximum size per Table VI-1132-1.)



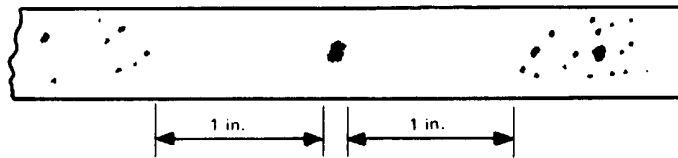
(c) Cluster

FIG. VI-1136-1 CHARTS FOR t EQUAL TO $\frac{1}{8}$ - $\frac{1}{4}$ in., INCLUSIVE

FIG. VI-1136-1 CHARTS FOR t EQUAL TO $\frac{1}{8}$ - $\frac{1}{4}$ in., INCLUSIVE



(a) Random Rounded Indications (Typical concentration and size permitted in any 6 in. length of weld.)



(b) Isolated Indication (Maximum size per Table VI-1132-1.)



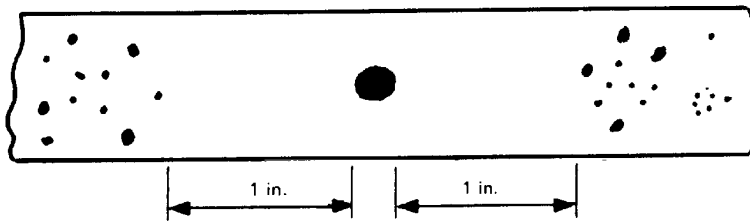
(c) Cluster

FIG. VI-1136-2 CHARTS FOR t OVER $\frac{1}{4}$ - $\frac{3}{8}$ in., INCLUSIVE

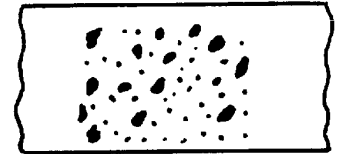
FIG. VI-1136-2 CHARTS FOR t OVER $\frac{1}{4}$ - $\frac{3}{8}$ in., INCLUSIVE



(a) Random Rounded Indications (Typical concentration and size permitted in any 6 in. length of weld.)



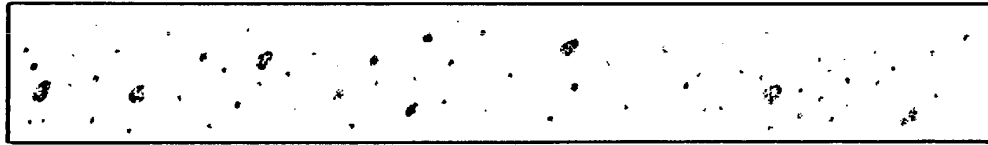
(b) Isolated Indication (Maximum size per Table VI-1132-1.)



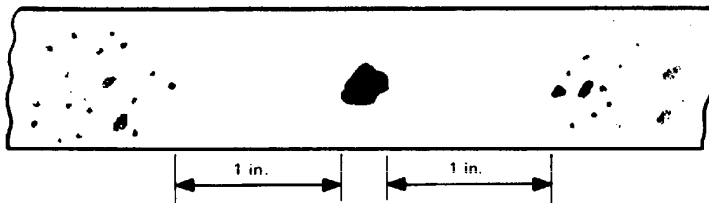
(c) Cluster

FIG. VI-1136-3 CHARTS FOR t OVER $\frac{3}{8}$ - $\frac{3}{4}$ in., INCLUSIVE

FIG. VI-1136-3 CHARTS FOR t OVER $\frac{3}{8}$ - $\frac{3}{4}$ in., INCLUSIVE



(a) Random Rounded Indications (Typical concentration and size permitted in any 6 in. length of weld.)



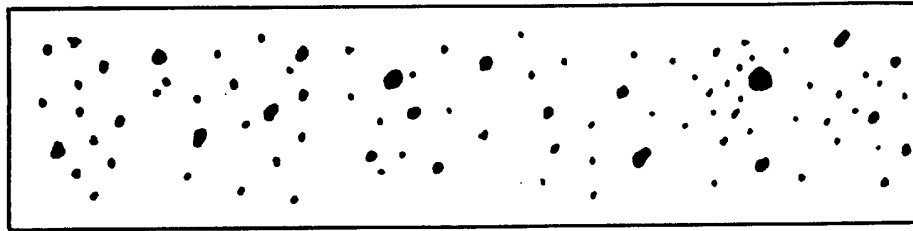
(b) Isolated Indication (Maximum size per Table VI-1132-1.)



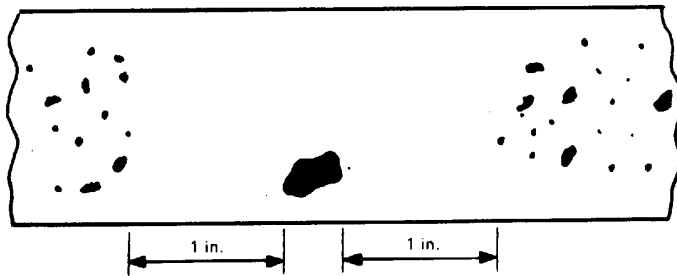
(c) Cluster

FIG. VI-1136-4 CHARTS FOR t OVER $\frac{3}{4}$ -2 in., INCLUSIVE

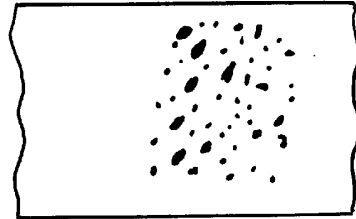
FIG. VI-1136-4 CHARTS FOR t OVER $\frac{3}{4}$ -2 in., INCLUSIVE



(a) Random Rounded Indications (Typical concentration and size permitted in any 6 in. length of weld.)



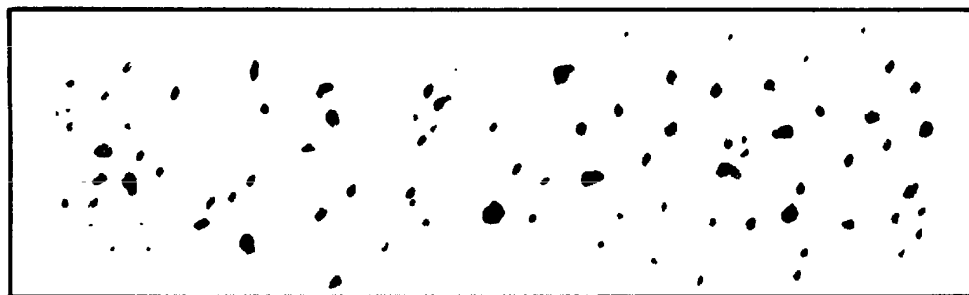
(b) Isolated Indication (Maximum size per Table VI-1132-1.)



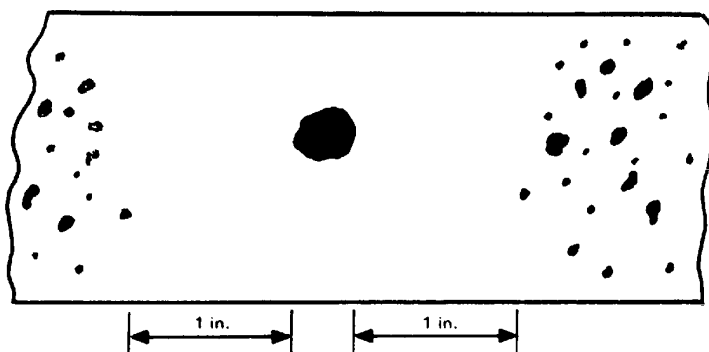
(c) Cluster

FIG. VI-1136-5 CHARTS FOR t OVER 2-4 in., INCLUSIVE

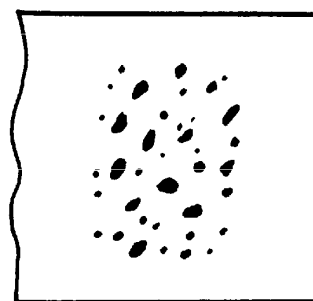
FIG. VI-1136-5 CHARTS FOR t OVER 2-4 in., INCLUSIVE



(a) Random Rounded Indications (Typical concentration and size permitted in any 6 in. length of weld.)



(b) Isolated Indication (Maximum size per Table VI-1132-1.)



(c) Cluster

FIG. VI-1136-6 CHARTS FOR t OVER 4 in.

FIG. VI-1136-6 CHARTS FOR t OVER 4 in.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 MA APP VII

APPENDIX VII CHARTS AND TABLES FOR DETERMINING
SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL
COMPONENTS UNDER EXTERNAL PRESSURE

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 MA APP XI

APPENDIX XI RULES FOR BOLTED FLANGE CONNECTIONS FOR CLASS 2 AND 3 COMPONENTS AND CLASS MC VESSELS

Page 93

Page 94

ARTICLE XI-1000 INTRODUCTION

XI-1100 GENERAL REQUIREMENTS

[98]

XI-1110 SCOPE

(a) The rules in Appendix XI apply specifically to the design of bolted flange connections for Class 2 and 3 components and Class MC vessels, and are to be used in conjunction with the applicable requirements in Subsections NC, ND, and NE. These rules provide only for hydrostatic end loads and gasket seating loads. For a discussion of design considerations for bolted flange connections, see Appendix XII.

(b) Only circular flanges designated Class RF are covered by the rules of Appendix XI. The design procedures for Class RF flanges, as defined in XI-3211, are given in XI-3200. For Class FF flanges, see Appendix L.

(c) The flange design methods stipulated in this Appendix are primarily applicable to circular flanges under internal pressure. However, Class RF flanges may be used under external pressure when designed in accordance with XI-3260.

[98]

XI-1120 ELEMENTS INVOLVED IN FLANGE DESIGN

XI-1121 General Considerations

This method of designing a flange involves the selection of the gasket material, type and dimensions, flange facing, bolting, hub proportions, flange width, and flange thickness (footnote 1, XI-3221.1). Flange dimensions shall be such that the stresses in the flange, calculated in accordance with XI-3240, do not exceed the allowable flange stresses specified in XI-3250 for Class RF flanges. All calculations shall use dimensions in the corroded condition.

XI-1122 Conditions for Which Design Calculations Shall Be Made

In the design of a bolted flange connection, complete calculations shall be made for two separate and independent sets of conditions which are defined in the following subparagraphs.

[98]

XI-1122.1 Design Conditions.

The Design Conditions are those required to resist the hydrostatic end force of the Design Pressure tending to part the joint and to maintain on the gasket or joint contact surface sufficient compression to assure a tight joint, all at the Design Temperature. The minimum load is a function of the Design Pressure, the gasket material, and the effective gasket or contact area to be kept tight under pressure [as calculated by Eq. (1) in XI-3221.1], and determines one of the two requirements for the amount of bolting A . This load is also used for the design of the flange in Eq. (3) in XI-3223.

[98]

XI-1122.2 Gasket Seating Conditions.

The gasket seating conditions are those existing when the gasket or joint contact surface is seated by applying initial load with the bolts when assembling the joint, at atmospheric temperature and pressure. The minimum initial load considered to be adequate for proper seating is a function of the gasket material and the effective gasket or contact area to be seated [as calculated by Eq. (2) in XI-3221.2], and determines the other of the two requirements for the amount of bolting A_{m2} . For the design of the flange, this load is modified in Eq. (4) in XI-3223 to take account of the Design Conditions when they govern the amount of bolting required A_m , as well as the amount of bolting actually provided A_b .

Page 96

XI-1123 Bolted Flange Connections to External Piping

It is recommended that bolted flange connections conforming to the standards¹ listed in NC-3362, ND-3362, and NE-3362, as applicable, be used for connections to external piping. These standards may be used for other bolted flange connections within the limits of size in the standards and the pressure-temperature ratings permitted in Subsections NC, ND, or NE.

¹ The ratings in these standards are based on the hub dimensions given or on the minimum specified thickness of flanged fittings of integral construction. Flanges fabricated from rings may be used in place of the hub flanges in these standards provided that their strength, calculated by the rules in this Appendix, is not less than that calculated for the corresponding size of hub flange.

Page 97

ARTICLE XI-2000 MATERIALS FOR BOLTED FLANGE CONNECTIONS

XI-2100 MATERIAL REQUIREMENTS

XI-2110 GENERAL REQUIREMENTS

Materials used in the construction of bolted flange connections shall comply with the material requirements given in Subsections NC, ND, or NE, as applicable.

XI-2120 HEAT TREATMENT OF FLANGES

Flanges made from ferritic steel and designed in accordance with this Appendix shall be given a normalizing or full annealing heat treatment when the thickness of the flange section exceeds 3 in. (76 mm).

XI-2130 WELDABILITY OF FLANGES AND POSTWELD HEAT TREATMENT

Material on which welding is to be performed shall be proved of good weldable quality. Satisfactory qualification of the welding procedure under Section IX is considered as proof. Welding shall not be performed on steel that has a carbon content greater than 0.35%. All welding on flange connections shall comply with the requirements for postweld heat treatment given in Subsections NC, ND, or NE, as applicable.

[98]

XI-2140 FABRICATED HUBBED FLANGES

Fabricated hubbed flanges shall be in accordance with (a) through (c) below.

(a) Hubbed flanges may be fabricated from a hot-rolled or -forged billet. The axis of the finished flange shall be parallel to the long axis of the original billet. (This is not intended to imply that the axis of the finished flange and the original billet must be concentric).

(b) Hubbed flanges, except as permitted in (a), shall not be machined from plate or bar stock material unless the material has been formed into a ring and, further, provided that:

(1) in a ring formed from plate, the original plate surfaces are parallel to the axis of the finished flange (this is not

intended to imply that the original plate surface be present in the finished flange);

(2) the joints in the ring are welded butt joints that conform to the requirements of the applicable Subsection. The thickness to be used to determine postweld heat treatment and radiography requirements shall be the lesser of t or $(A - B)/2$, when these symbols are as defined in XI-3130.

(c) The back of the flange and the outer surface of the hub shall be examined by the magnetic particle method (NC-2545) or the liquid penetrant method (NC-2546) to ensure that these surfaces are free from defects.

[98]

XI-2150 BOLTING MATERIALS

Bolts, studs, nuts, and washers shall comply with the requirements of the applicable Subsection. It is recommended that bolts and studs not be smaller than $\frac{1}{2}$ in. (13 mm). If bolts or studs smaller than $\frac{1}{2}$ in. (13 mm) are used, ferrous bolting material shall be of alloy steel. Precautions shall be taken to avoid overstressing small diameter bolts.

Page 98

ARTICLE XI-3000 DESIGN REQUIREMENTS

XI-3100 GENERAL REQUIREMENTS

XI-3110 SCOPE

(a) The rules of XI-3200 apply to Class RF flanges as defined in XI-3212.

(b) The flange design methods given in XI-3210 through XI-3250 apply to Class RF flanges under internal pressure. The flange design methods for Class RF flanges under external pressure or under both internal and external pressure are given in XI-3260.

XI-3120 TYPES OF FLANGES

For purposes of computation, there are three types as described in (a), (b), and (c) below.

(a) *Loose Type Flanges*. This type covers those designs in which the flange has no direct connection to the nozzle neck, vessel, or pipe wall and designs where the method of attachment is not considered to give the mechanical strength equivalent to integral attachment. Figure XI-3120-1 sketches (1), (1a), (2), (3), and (4) show typical loose type flanges and the location of the loads and moments; welds and other details of construction shall satisfy the dimensional requirements given in the referenced sketches.

(b) *Integral Type Flanges*. This type covers designs where the flange is cast or forged integrally with the nozzle neck, vessel, or pipe wall, butt welded thereto, or attached by other forms of arc or gas welding of such a nature that the flange and nozzle neck, vessel, or pipe wall is considered to be the equivalent of an integral structure. In welded construction, the nozzle neck, vessel, or pipe wall is considered to act as a hub. Figure XI-3120-1 sketches (5), (6), (6a), (6b), and (7) show typical integral type flanges and the location of the loads and moments; welds and other details of construction shall satisfy the dimensional requirements given in the referenced sketches.

(c) *Optional Type Flanges*. This type covers designs where the attachment of the flange to the nozzle neck, vessel, or pipe wall is such that the assembly is considered to act as a unit, which shall be calculated as an integral flange, except that for simplicity the designer may calculate the construction as a loose type flange provided none of the following values are exceeded:

$$g_0 = \frac{5}{8} \text{ in. (16 mm)}$$

$$B/g_0 = 300$$

$$P = 300 \text{ psi (2070 kPa)}$$

$$\text{Design Temperature} = 700^\circ\text{F (371}^\circ\text{C)}$$

Figure XI-3120-1 sketches (8), (8a), (8b), and (9) show typical optional type flanges. Welds and other details of construction shall satisfy the dimensional requirements given in those sketches.

[98]

XI-3130 NOMENCLATURE

The nomenclature defined below and shown in Fig. XI-3120-1 is used in the equations for the design of flanges.

A	= outside diameter of flange or, when slotted holes extend to the outside of the flange, the diameter to the bottom of the slots, in.
A_b	= actual total cross-sectional area of bolts at root of thread or section of least diameter under stress, sq in.
A_m	= total required cross-sectional area of bolts taken as the greater of A_{m1} and A_{m2} , sq in.
A_{m1}	= total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for the Design Conditions, sq in. = W_{m1}/S_b

Page 99

Page 101

A_{m2}	= total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for gasket seating, sq in. = W_{m2}/S_a
B	= inside diameter of flange, in. (when B is less than $20g_1$ it will be optional for the designer to substitute B_1 for B in the equation for longitudinal stress S_H)
B_1	= $B + g_1$, in., for loose type hub flanges and also for integral type flanges when f is less than 1 = $B + g_0$, in., for integral type flanges when f is equal to or greater than 1
b	= effective gasket or joint contact surface seating width, in. (footnote ¹ , 3221.1)
b_0	= basic gasket seating width, in. (Table XI-3221.1-2)
C	= bolt circle diameter, in.
c	= basic dimension used for the minimum sizing of welds, in.; equal to t_n or t_D , whichever is less
d	= factor, in. ³ , as follows:

$$= \frac{U}{V} h_0 g_0^2 \text{ for integral type flanges}$$

$$= \frac{U}{V_L} h_0 g_0^2 \text{ for loose type flanges}$$

e	= factor, in.⁻¹, as follows: = F/h_0 for integral type flanges = F_L/h_0 for loose type flanges
F	= factor for integral type flanges (Fig. XI-3240-2)
F_L	= factor for loose type flanges (Fig. XI-3240-4)
f	= hub stress correction factor for integral flanges from Fig. XI-3240-6 (when greater than 1, this is the ratio of the stress in the small end of hub to the stress in the large end; for values below limit of Figure use $f=1$)
G	= diameter at location of gasket load reaction; except as noted in sketch (1) of Fig. XI-3120-1, G is defined as follows for Class RF flanges (see Table XI-3221.1-2): (a) when $b_0 \leq \frac{1}{4}$ in., G is the mean diameter of gasket contact face, in.; (b) when $b_0 > \frac{1}{4}$ in., G is the outside diameter of gasket contact face less $2b$, in.
g_0	= thickness of hub at small end, in.
g_1	= thickness of hub at back of flange, in.
H	= total hydrostatic end force, lb = $0.785G^2P$
H_D	= hydrostatic end force on area inside of flange, lb = $0.785B^2P$
H_G	= gasket load (difference between flange design bolt load and total hydrostatic end force), lb = $W - H$
H_p	= total joint contact surface compression load, lb = $2b \times 3.14GmP$
H_T	= difference between total hydrostatic end force and the hydrostatic end force on area inside of flange, lb

	$= H - H_D$
h	= hub length, in.
h_D	= radial distance, in., from the bolt circle to the circle on which H_D acts, as prescribed in Table XI-3230-1
h_G	= radial distance, in., from gasket load reaction to the bolt circle
	$= (C - G)/2$
h_0	= factor equal to $\sqrt{B g_0}$ in.
h_T	= radial distance, in., from the bolt circle to the circle on which H_T acts, as prescribed in Table XI-3230-1
K	= ratio of outside diameter of flange to inside diameter of flange
	$= A/B$
L	= factor
	=

$$\frac{te + 1}{T} + \frac{t^3}{d}$$

M_D	= component of moment due to H_D in.-lb
	$= H_D h_D$
M_G	= component of moment due to H_G in.-lb
	$= H_G h_G$
M_0	= total moment acting upon the flange, for the Design Conditions or gasket seating, as may apply, in.-lb (XI-3230)
M_T	= component of moment due to H_T in.-lb
	$= H_T h_T$
m	= gasket factor obtained from Table XI-3221.1-1 (footnote ¹ , XI-3221.1)
N	= width, in., used to determine the basic gasket seating width b_0 based upon the possible contact width of the gasket (Table XI-3221.1-2)
P	= Design Pressure, psi (for flanges subject to external pressure see XI-3260 for Class RF flanges)

R	= radial distance from bolt circle to point of intersection of hub and back of flange (integral and hub flanges), in. = $(C - B)/2 - g_1$
S_a	= allowable bolt stress at atmospheric temperature, psi (given in Section II, Part D, Subpart 1, Table 3)

Page 102

S_b	= allowable bolt stress, psi, at Design Temperature (given in Section II, Part D, Subpart 1, Table 3)
S_f	= allowable design stress, psi, for material of flange at Design Temperature (Design Condition) or atmospheric temperature (gasket seating), as applicable (given in Section II, Part D, Subpart 1, Tables 1A and 1B, as applicable)
S_n	= allowable design stress, psi, for material of nozzle neck, vessel, or pipe wall at Design Temperature (Design Condition) or atmospheric temperature (gasket seating) as applicable (given in Section II, Part D, Subpart 1, Tables 1A and 1B, as applicable)
S_H	= calculated longitudinal stress in hub, psi
S_R	= calculated radial stress in flange, psi
S_T	= calculated tangential stress in flange, psi
T	= factor involving K (Fig. XI-3240-1)
t	= flange thickness, in.
t_D	= two times the thickness g_ϕ in., when the design is calculated as an integral flange, or two times the thickness, in., of shell or nozzle wall required for internal pressure when the design is calculated as loose flange, but not less than $1/4$ in.
t_n	= nominal thickness, in., of shell or nozzle wall to which flange or lap is attached, less corrosion allowance
U	= factor involving K (Fig. XI-3240-1)
V	= factor for integral type flanges (Fig. XI-3240-3)
V_L	= factor for loose type flanges (Fig. XI-3240-5)
W	= flange design bolt load, lb, for the Design Conditions or gasket seating as applicable (XI-3223)
W_{m1}	= minimum required bolt load, lb, for the Design Conditions (XI-3220)
W_{m2}	= minimum required bolt load, lb, for gasket seating (XI-3220)
w	= width, in., used to determine the basic gasket seating width b_ϕ based upon the contact width between the flange facing and the gasket (Table XI-3221.1-2)
Y	= factor involving K (Fig. XI-3240-1)

y

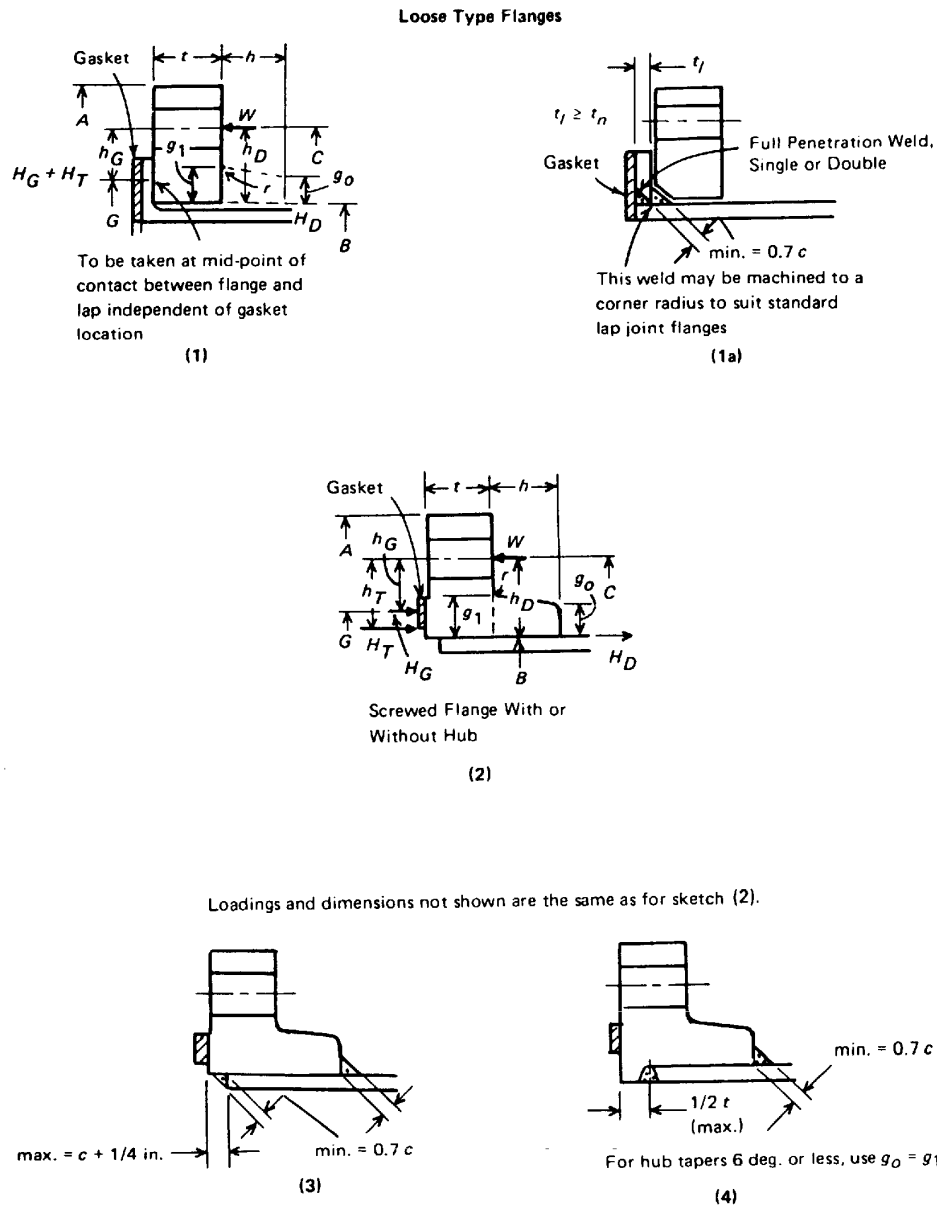
= gasket or joint contact surface unit seating load, psi
(footnote ¹, XI-3221.1)

Z

= factor involving K (Fig. XI-3240-1)

[98]

Pages 100-100



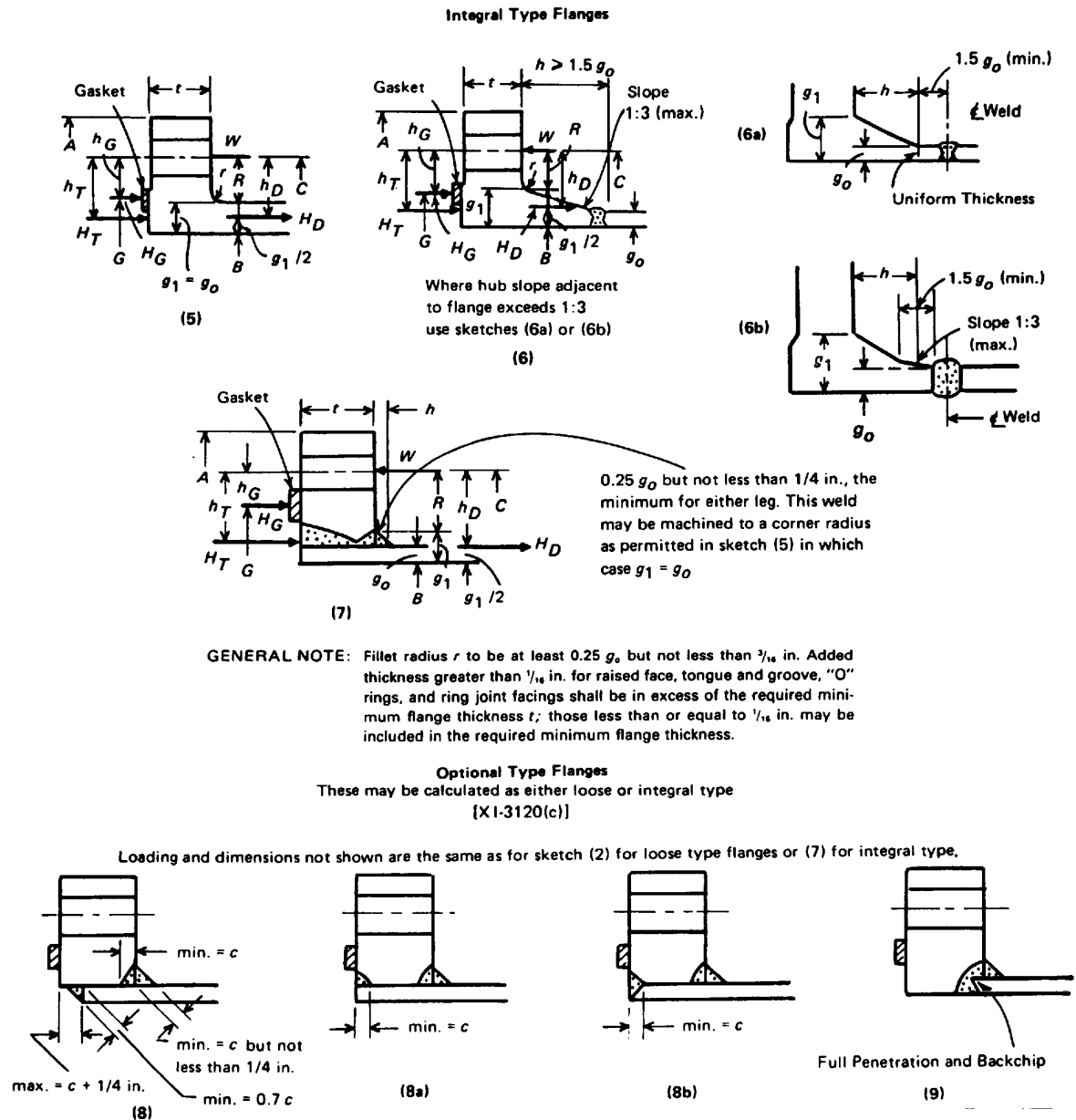


FIG. XI-3120-1 TYPES OF FLANGES (CONT'D)

FIG. XI-3120-1 TYPES OF FLANGES (CONT'D)

XI-3200 CLASS RF FLANGE DESIGN

XI-3210 GENERAL REQUIREMENTS

[98]

XI-3211 Definition of Class RF Flanges

Class RF flanges are circular flanges having gaskets which are entirely within the circle enclosed by the bolt holes and which have no contact outside this circle.

[98]

[98]

XI-3212 Acceptability

The requirements for acceptability of Class RF flange design are given in (a) and (b) below.

(a) The design shall be such that the general design requirements of NC-3100, ND-3100, or NE-3100, as appropriate, and the specific design requirements of this Subarticle are met.

(b) The designs shall be limited to the types of flanges defined in XI-3120.

[98]

XI-3220 BOLT LOADS AND BOLT AREAS

[98]

XI-3221 Determination of Bolt Loads

In the design of a bolted flange connection, calculations shall be made for each of the two conditions, namely, Design Loadings and gasket seating loads, and the more severe condition shall control. In the design of flange pairs used to contain a tubesheet of a heat exchanger, or any similar design where the flanges and/or gaskets may not be the same, loads shall be determined for the most severe condition of Design Loadings and/or gasket seating loads applied to each side at the same time. This most severe condition may be gasket seating on one flange with Design Loadings on the other, gasket seating on each flange at the same time, or Design Loadings on each flange at the same time.

[98]

XI-3221.1 Bolt Load for Design Conditions.

The required bolt load for the Design Conditions W_{m1} shall be sufficient to resist the hydrostatic end force H exerted by the Design Pressure on the area bounded by the diameter of gasket reaction and, in addition, to maintain on the gasket or joint contact surface a compression load H_p which experience has shown to be sufficient to ensure a tight joint. This compression load is expressed as a multiple m of the internal pressure. Its value is a function of the gasket material and construction.² The required bolt load for the Design Conditions W_{m1} is determined in accordance with Eq. (1):

$$(1) W_{m1} = H + H_p = 0.785G^2P + (2b \times 3.14GmP)$$

² Tables XI-3221.1-1 and XI-3221.1-2 give a list of many commonly used gasket materials and contact facings, with suggested values of m , b , and y that have proved satisfactory in actual service.

These values are suggested only and are not mandatory. Values that are too low may result in leakage at the joint, without affecting the safety of the design. The primary proof that the values are adequate is the hydrostatic test.

XI-3221.2 Bolt Load for Gasket Seating Condition.

Before a tight joint can be obtained, it is necessary to

Page 103

Page 105

Pages 104-104

TABLE XI-3221.1-1
GASKET MATERIALS AND CONTACT FACINGS¹
Gasket Factors m for Operating Conditions and Minimum Design Seating Stress y

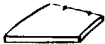
Gasket Material	Gasket Factor m	Min. Design Seating Stress y , psi	Sketches	Facing Sketch and Column in Table XI-3221.1-2
Self-energizing types (O rings, metallic, elastomer, other gasket types considered as self-sealing)	0	0	...	...
Elastomers without fabric or high percent of asbestos fiber:				
Below 75A Shore Durometer	0.50	0		(1a),(1b),(1c),(1d), (4),(5); Column II
75A or higher Shore Durometer	1.00	200		
Asbestos with suitable binder for operating conditions:				
1/8 in. thick	2.00	1600		(1a),(1b),(1c),(1d), (4),(5); Column II
1/16 in. thick	2.75	3700		
1/32 in. thick	3.50	6500		
Elastomers with cotton fabric insertion	1.25	400		(1a),(1b),(1c),(1d), (4),(5); Column II
Elastomers with asbestos fabric insertion (with or without wire reinforcement):				
3-ply	2.25	2200		
2-ply	2.50	2900		(1a),(1b),(1c),(1d), (4),(5); Column II
1-ply	2.75	3700		
Vegetable fiber	1.75	1100		(1a),(1b),(1c),(1d), (4),(5); Column II
Spiral-wound metal, asbestos filled:				
Carbon	2.50	10,000		(1a),(1b); Column II
Stainless or Monel	3.00	10,000		
Corrugated metal, asbestos inserted; or corrugated metal, jacketed asbestos filled:				
Soft aluminum	2.50	2900		
Soft copper or brass	2.75	3700		(1a),(1b); Column II
Iron or soft steel	3.00	4500		
Monel or 4-6% chrome	3.25	5500		
Stainless steels	3.50	6500		

TABLE XI-3221.1-1 GASKET MATERIALS AND CONTACT FACINGS¹

TABLE XI-3221.1-1 (CONT'D)
GASKET MATERIALS AND CONTACT FACINGS¹
Gasket Factors m for Operating Conditions and Minimum Design Seating Stress y

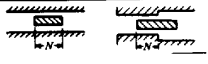
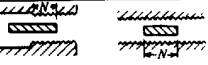
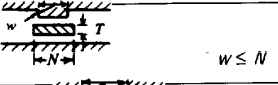
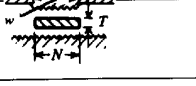
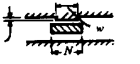
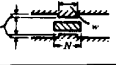
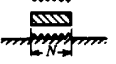
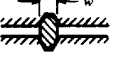
Gasket Material	Gasket Factor m	Min. Design Seating Stress y , psi	Sketches	Facing Sketch and Column in Table XI-3221.1-2
Corrugated metal:				
Soft aluminum	2.75	3700		(1a),(1b),(1c),(1d), Column II
Soft copper or brass	3.00	4500		
Iron or soft steel	3.25	5500		
Monel or 4-6% chrome	3.50	6500		
Stainless steels	3.75	7600		
Flat metal, jacketed asbestos filled:				
Soft aluminum	3.25	5500		(1a),(1b),(1c), ² (1d), ² (2) ² ; Column II
Soft copper or brass	3.50	6500		
Iron or soft steel	3.75	7600		
Monel	3.50	8000		
4-6% chrome	3.75	9000		
Stainless steels	3.75	9000		
Grooved metal:				
Soft aluminum	3.25	5500		(1a),(1b),(1c),(1d), (2),(3); Column II
Soft copper or brass	3.50	6500		
Iron or soft steel	3.75	7600		
Monel or 4-6% chrome	3.75	9000		
Stainless steels	4.25	10,100		
Solid flat metal:				
Soft aluminum	4.00	8800		(1a),(1b),(1c),(1d), (2),(3),(4),(5); Column I
Soft copper or brass	4.75	13,000		
Iron or soft steel	5.50	18,000		
Monel or 4-6% chrome	6.00	21,800		
Stainless steels	6.50	26,000		
Ring joint:				
Iron or soft steel	5.50	18,000		(6), Column I
Monel or 4-6% chrome	6.00	21,800		
Stainless steels	6.50	26,000		

NOTES:

- (1) This Table gives a list of many commonly used gasket materials and contact facings with suggested design values of m and y that have generally proved satisfactory in actual service when using effective gasket seating width b given in Table XI-3221.1-2. The design values and other details given in this Table are suggested only and are not mandatory.
- (2) The surface of a gasket having a lap should not be against the nubbin.

TABLE XI-3221.1-1 (CONT'D) GASKET MATERIALS AND CONTACT FACINGS¹

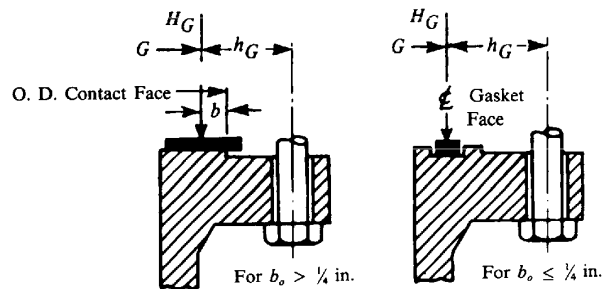
TABLE XI-3221.1-2
EFFECTIVE GASKET WIDTH²

Facing Stretch (Exaggerated)		Basic Gasket Seating Width, b_o	
		Column I	Column II
(1a)		$\frac{N}{2}$	$\frac{N}{2}$
(1b)			
(1c)		$\frac{w + T}{2}; \left(\frac{w + N}{4} \text{ max.} \right)$	$\frac{w + T}{2}; \left(\frac{w + N}{4} \text{ max.} \right)$
(1d)			
(2)		$\frac{w + N}{4}$	$\frac{w + 3N}{8}$
(3)		$\frac{N}{4}$	$\frac{3N}{8}$
(4)		$\frac{3N}{8}$	$\frac{7N}{16}$
(5)		$\frac{N}{4}$	$\frac{3N}{8}$
(6)		$\frac{w}{8}$	...

Effective Gasket Seating Width, b

$$b = b_o, \text{ when } b_o \leq \frac{1}{4} \text{ in.}; b = \sqrt{b_o}, \text{ when } b_o > \frac{1}{4} \text{ in.}$$

Location of Gasket Load Reaction



NOTES:

- (1) Where serrations do not exceed $\frac{1}{64}$ in. depth and $\frac{1}{32}$ in. width spacing, sketches (1b) and (1d) shall be used.
- (2) The gasket factors listed only apply to flanged joints in which the gasket is contained entirely within the inner edges of the bolt holes.

TABLE XI-3221.1-2 EFFECTIVE GASKET WIDTH²

seat the gasket or joint contact surface properly by applying a minimum initial load under atmospheric temperature conditions without the presence of internal pressure, which is a function of the gasket material and the effective gasket

area to be seated. The minimum initial bolt load W_{m2} required for this purpose shall be determined in accordance with Eq. (2):

$$(2) W_{m2} = 3.14bGy$$

98

**TABLE XI-3230-1
MOMENT ARMS FOR FLANGE LOADS**

Flange Type	h_D	h_T	h_G
Integral type flanges			
[see Fig. XI-3120-1 sketches (5), (6), (6a), (6b), (7), (8), (8a), (8b), and (9)]	$R + 0.5g_1$	$\frac{R + g_1 + h_G}{2}$	$\frac{C - G}{2}$
Loose type, except lap joint flanges [Fig. XI-3120-1 sketches (2), (3), and (4)]; and optional type flanges [Fig. XI-3120-1 sketches (8), (8a), (8b), and (9)]			
	$\frac{C - B}{2}$	$\frac{h_D + h_G}{2}$	$\frac{C - G}{2}$
Lap joint flanges [Fig. XI-3120-1 sketches (1) and (1a)]			
	$\frac{C - B}{2}$	$\frac{C - G}{2}$	$\frac{C - G}{2}$

[98]

TABLE XI-3230-1 MOMENT ARMS FOR FLANGE LOADS

The need for providing sufficient bolt load to seat the gasket or joint contact surfaces in accordance with Eq. (2) will prevail on many low pressure designs and with facings and materials that require a high seating load and where the bolt load computed by Eq. (1) for the Design Conditions is insufficient to seat the joint. Accordingly, it is necessary to furnish bolting and to pretighten the bolts to provide a bolt load sufficient to satisfy both of these requirements, each one

being individually investigated. When Eq. (2) governs, flange proportions will be a function of the bolting instead of internal pressure.

XI-3221.3 Bolt Load When Self-Energizing Gaskets Are Used.

Bolt loads for flanges using gaskets of the self-energizing type differ from those shown above as stipulated in (a) and (b) below.

(a) The required bolt load for the Design Conditions W_{m1} shall be sufficient to resist the hydrostatic end force H exerted by the Design Pressure on the area bounded by the outside diameter of the gasket. H_p is to be considered as zero for all self-energizing gaskets except certain seal configurations which generate axial loads which shall be considered.

(b) $W_{m2} = 0$. Self-energizing gaskets may be considered to require an inconsequential amount of bolting force to produce a seal. Bolting, however, shall be pretightened to provide a bolt load sufficient to withstand the hydrostatic end force H .

XI-3222 Total Required and Actual Bolt Areas A_m and A_b

The total cross-sectional area of bolts A_m required for both the Design Conditions and gasket seating is the greater of the values for A_{m1} and A_{m2} , where $A_{m1} = W_{m1}/S_b$ and $A_{m2} = W_{m2}/S_a$. A selection of bolts to be used shall be made such that the actual total cross-sectional areas of bolts A_b will not be less than A_m .

XI-3223 Flange Design Bolt Load W

The bolt loads used in the design of the flange shall be the values obtained from Eqs. (3) and (4). For Design Conditions,

$$(3) W = W_{m1}$$

For gasket seating,

$$W = \frac{(A_m + A_b) S_a}{2} \quad (4)$$

(4)

In addition to the minimum requirements for safety, Eq. (4) provides a margin against abuse of the flange from overbolting. Since margin against such abuse is needed primarily for the initial bolting up operation, which is done at atmospheric temperature and before application of internal pressure, the flange design is required to satisfy this loading only under such conditions.³

³ Where additional safety against abuse is desired, or where it is necessary that the flange be suitable to withstand the full available bolt load $A_b \times S_b$, the flange may be designed on the basis of this latter quantity.

XI-3230 FLANGE MOMENTS

(a) In the calculation of flange stresses, the moment of a loading acting on the flange is the product of the

Page 107

load and its moment arm. The moment arm is determined by the relative position of the bolt circle with respect to that of

the load producing the moment (Fig. XI-3120-1). No consideration shall be given to any possible reduction in moment arm due to cupping of the flanges or due to inward shifting of the line of action of the bolts as a result thereof.

(b) For the Design Conditions, the total flange moment M_0 is the sum of the three individual moments M_D , M_T , and M_G as defined in XI-3130, and based on the flange design bolt load of Eq. (3) with moment arms as given in Table XI-3230-1.

(c) For gasket seating, the total flange moment M_0 is based on the flange design bolt load of Eq. (4), which is opposed only by the gasket load, in which case:

$$M_0 = W \frac{(C - G)}{2} \quad (5)$$

(5)

XI-3240 CALCULATION OF FLANGE STRESSES

The stresses in the flange shall be determined for both the Design Conditions and gasket seating, whichever controls, in accordance with the equations in (a) or (b) below.

(a) For integral type flanges and all hub type flanges:

Longitudinal hub stress

$$(6) S_H = fM_0/Lg_1^2B$$

Radial flange stress

$$(7) S_R = [(1.33te + 1)M_0]/Lr^2B$$

Tangential flange stress

$$(8) S_T = (YM_0/r^2B) - ZS_R$$

(b) For loose type ring flanges including optional type calculated as loose type having a rectangular cross section:

$$(9) S_T = YM_0/r^2B$$

$$S_R = 0$$

$$S_H = 0$$

[98]

XI-3250 ALLOWABLE FLANGE DESIGN STRESSES

The flange stresses calculated by the equations in XI-3240 shall not exceed the values given in (a) through (f) below.

(a) The longitudinal hub stress S_H shall not be greater than the smaller of $1.5S_f$ or $1.5S_n$ for optional type flanges designed as integral [Fig. XI-3120-1 sketches (8), (8a), (8b), and (9)], and also for integral type flanges [Fig. XI-3120-1 sketch (7)] where the neck material constitutes the hub of the flange.

(b) The longitudinal hub stress S_H shall not be greater than the smaller of $1.5S_f$ or $1.5S_n$ for integral type flanges with hub welded to the neck, pipe, or vessel wall [Fig. XI-3120-1 sketches (6), (6a), and (6b)].

(c) The radial flange stress S_R shall not be greater than S_f .

(d) The tangential flange stress S_T shall not be greater than S_f .

(e) Also $(S_H + S_R)/2$ shall not be greater than S_f and $(S_H + S_P)/2$ shall not be greater than S_f .

(f) In the case of loose type flanges with laps, as shown in Fig. XI-3120-1 sketches (1) and (1a), where the gasket is so located that the lap is subjected to shear, the shearing stress shall not exceed $0.8S_n$ for the material of the lap, as defined in XI-3130. In the case of welded flanges, shown in Fig. XI-3120-1 sketches (3), (4), (7), (8), (8a), and (8b), where the nozzle neck, vessel, or pipe wall extends near to the flange face and may form the gasket contact face, the shearing stress carried by the welds shall not exceed $0.8S_n$. The shearing stress shall be calculated on the basis of W_{m1} or W_{m2} (as defined in XI-3130), whichever is greater. Similar cases where flange parts are subjected to shearing stress shall be governed by the same requirements.

[98]

XI-3260 FLANGES SUBJECT TO EXTERNAL PRESSURE

⁴ When internal pressure occurs only during the required pressure test, the design may be based on external pressure and auxiliary devices such as clamps may be used during the application of the required test pressure.

XI-3261 Flanges for External Pressure Only

The design of flanges for external pressure⁴ only shall be based on the equations given in XI-3240 for internal pressure except that for Design Conditions,

Page 108

Page 111

Pages 109-110

TABLE XI-3240-1
FLANGE FACTORS IN FORMULA FORM

Integral Flange	Loose Hub Flange
For f (Fig. XI-3240-2) use:	For f (Fig. XI-3240-4) use:
$F = -\frac{E_s}{\left(\frac{C}{2.73}\right)^{1/4} (1+A)^2} \frac{C}{C}$	$F_L = \frac{C_{10}\left(\frac{1}{2} + \frac{A}{6}\right) + C_{11}\left(\frac{1}{4} + \frac{11A}{84}\right) + C_{12}\left(\frac{1}{10} + \frac{A}{105}\right) - \left(\frac{1}{40} + \frac{A}{72}\right)}{\left(\frac{C}{2.73}\right)^{1/4} (1+A)^2} \frac{C}{C}$
For V (Fig. XI-3240-3) use:	For V_L (Fig. XI-3240-5) use:
$V = \frac{E_s}{\left(\frac{2.73}{C}\right)^{1/4} (1+A)^2}$	$V_L = \frac{\frac{1}{4} - \frac{C_{12}}{5} - \frac{3C_{11}}{2} - C_{10}}{\left(\frac{C}{2.73}\right)^{1/4} (1+A)^2}$
For f (Fig. XI-3240-6) use:	For f (Fig. XI-3240-6) use:
$f = C_{10}/(1+A)$	$f = 1$
NOTE: Except for the case where $g_s = g_h$, the values used in the formulas given above are determined by using Eqs. (1) through (65), given below, which are based on the definitions: $F_{10} = F_{10}$, $F_{11} = F_{11}$, $F_{12} = F_{12}$, $F_{13} = F_{13}$, $F_{14} = F_{14}$, $F_{15} = F_{15}$, $F_{16} = F_{16}$, $F_{17} = F_{17}$, $F_{18} = F_{18}$, $F_{19} = F_{19}$, $F_{20} = F_{20}$, $F_{21} = F_{21}$, $F_{22} = F_{22}$, $F_{23} = F_{23}$, $F_{24} = F_{24}$, $F_{25} = F_{25}$, $F_{26} = F_{26}$, $F_{27} = F_{27}$, $F_{28} = F_{28}$, $F_{29} = F_{29}$, $F_{30} = F_{30}$, $F_{31} = F_{31}$, $F_{32} = F_{32}$, $F_{33} = F_{33}$, $F_{34} = F_{34}$, $F_{35} = F_{35}$, $F_{36} = F_{36}$, $F_{37} = F_{37}$, $F_{38} = F_{38}$, $F_{39} = F_{39}$, $F_{40} = F_{40}$, $F_{41} = F_{41}$, $F_{42} = F_{42}$, $F_{43} = F_{43}$, $F_{44} = F_{44}$, $F_{45} = F_{45}$, $F_{46} = F_{46}$, $F_{47} = F_{47}$, $F_{48} = F_{48}$, $F_{49} = F_{49}$, $F_{50} = F_{50}$, $F_{51} = F_{51}$, $F_{52} = F_{52}$, $F_{53} = F_{53}$, $F_{54} = F_{54}$, $F_{55} = F_{55}$, $F_{56} = F_{56}$, $F_{57} = F_{57}$, $F_{58} = F_{58}$, $F_{59} = F_{59}$, $F_{60} = F_{60}$, $F_{61} = F_{61}$, $F_{62} = F_{62}$, $F_{63} = F_{63}$, $F_{64} = F_{64}$, $F_{65} = F_{65}$, $F_{66} = F_{66}$, $F_{67} = F_{67}$, $F_{68} = F_{68}$, $F_{69} = F_{69}$, $F_{70} = F_{70}$, $F_{71} = F_{71}$, $F_{72} = F_{72}$, $F_{73} = F_{73}$, $F_{74} = F_{74}$, $F_{75} = F_{75}$, $F_{76} = F_{76}$, $F_{77} = F_{77}$, $F_{78} = F_{78}$, $F_{79} = F_{79}$, $F_{80} = F_{80}$, $F_{81} = F_{81}$, $F_{82} = F_{82}$, $F_{83} = F_{83}$, $F_{84} = F_{84}$, $F_{85} = F_{85}$, $F_{86} = F_{86}$, $F_{87} = F_{87}$, $F_{88} = F_{88}$, $F_{89} = F_{89}$, $F_{90} = F_{90}$, $F_{91} = F_{91}$, $F_{92} = F_{92}$, $F_{93} = F_{93}$, $F_{94} = F_{94}$, $F_{95} = F_{95}$, $F_{96} = F_{96}$, $F_{97} = F_{97}$, $F_{98} = F_{98}$, $F_{99} = F_{99}$, $F_{100} = F_{100}$, $F_{101} = F_{101}$, $F_{102} = F_{102}$, $F_{103} = F_{103}$, $F_{104} = F_{104}$, $F_{105} = F_{105}$, $F_{106} = F_{106}$, $F_{107} = F_{107}$, $F_{108} = F_{108}$, $F_{109} = F_{109}$, $F_{110} = F_{110}$, $F_{111} = F_{111}$, $F_{112} = F_{112}$, $F_{113} = F_{113}$, $F_{114} = F_{114}$, $F_{115} = F_{115}$, $F_{116} = F_{116}$, $F_{117} = F_{117}$, $F_{118} = F_{118}$, $F_{119} = F_{119}$, $F_{120} = F_{120}$, $F_{121} = F_{121}$, $F_{122} = F_{122}$, $F_{123} = F_{123}$, $F_{124} = F_{124}$, $F_{125} = F_{125}$, $F_{126} = F_{126}$, $F_{127} = F_{127}$, $F_{128} = F_{128}$, $F_{129} = F_{129}$, $F_{130} = F_{130}$, $F_{131} = F_{131}$, $F_{132} = F_{132}$, $F_{133} = F_{133}$, $F_{134} = F_{134}$, $F_{135} = F_{135}$, $F_{136} = F_{136}$, $F_{137} = F_{137}$, $F_{138} = F_{138}$, $F_{139} = F_{139}$, $F_{140} = F_{140}$, $F_{141} = F_{141}$, $F_{142} = F_{142}$, $F_{143} = F_{143}$, $F_{144} = F_{144}$, $F_{145} = F_{145}$, $F_{146} = F_{146}$, $F_{147} = F_{147}$, $F_{148} = F_{148}$, $F_{149} = F_{149}$, $F_{150} = F_{150}$, $F_{151} = F_{151}$, $F_{152} = F_{152}$, $F_{153} = F_{153}$, $F_{154} = F_{154}$, $F_{155} = F_{155}$, $F_{156} = F_{156}$, $F_{157} = F_{157}$, $F_{158} = F_{158}$, $F_{159} = F_{159}$, $F_{160} = F_{160}$, $F_{161} = F_{161}$, $F_{162} = F_{162}$, $F_{163} = F_{163}$, $F_{164} = F_{164}$, $F_{165} = F_{165}$, $F_{166} = F_{166}$, $F_{167} = F_{167}$, $F_{168} = F_{168}$, $F_{169} = F_{169}$, $F_{170} = F_{170}$, $F_{171} = F_{171}$, $F_{172} = F_{172}$, $F_{173} = F_{173}$, $F_{174} = F_{174}$, $F_{175} = F_{175}$, $F_{176} = F_{176}$, $F_{177} = F_{177}$, $F_{178} = F_{178}$, $F_{179} = F_{179}$, $F_{180} = F_{180}$, $F_{181} = F_{181}$, $F_{182} = F_{182}$, $F_{183} = F_{183}$, $F_{184} = F_{184}$, $F_{185} = F_{185}$, $F_{186} = F_{186}$, $F_{187} = F_{187}$, $F_{188} = F_{188}$, $F_{189} = F_{189}$, $F_{190} = F_{190}$, $F_{191} = F_{191}$, $F_{192} = F_{192}$, $F_{193} = F_{193}$, $F_{194} = F_{194}$, $F_{195} = F_{195}$, $F_{196} = F_{196}$, $F_{197} = F_{197}$, $F_{198} = F_{198}$, $F_{199} = F_{199}$, $F_{200} = F_{200}$, $F_{201} = F_{201}$, $F_{202} = F_{202}$, $F_{203} = F_{203}$, $F_{204} = F_{204}$, $F_{205} = F_{205}$, $F_{206} = F_{206}$, $F_{207} = F_{207}$, $F_{208} = F_{208}$, $F_{209} = F_{209}$, $F_{210} = F_{210}$, $F_{211} = F_{211}$, $F_{212} = F_{212}$, $F_{213} = F_{213}$, $F_{214} = F_{214}$, $F_{215} = F_{215}$, $F_{216} = F_{216}$, $F_{217} = F_{217}$, $F_{218} = F_{218}$, $F_{219} = F_{219}$, $F_{220} = F_{220}$, $F_{221} = F_{221}$, $F_{222} = F_{222}$, $F_{223} = F_{223}$, $F_{224} = F_{224}$, $F_{225} = F_{225}$, $F_{226} = F_{226}$, $F_{227} = F_{227}$, $F_{228} = F_{228}$, $F_{229} = F_{229}$, $F_{230} = F_{230}$, $F_{231} = F_{231}$, $F_{232} = F_{232}$, $F_{233} = F_{233}$, $F_{234} = F_{234}$, $F_{235} = F_{235}$, $F_{236} = F_{236}$, $F_{237} = F_{237}$, $F_{238} = F_{238}$, $F_{239} = F_{239}$, $F_{240} = F_{240}$, $F_{241} = F_{241}$, $F_{242} = F_{242}$, $F_{243} = F_{243}$, $F_{244} = F_{244}$, $F_{245} = F_{245}$, $F_{246} = F_{246}$, $F_{247} = F_{247}$, $F_{248} = F_{248}$, $F_{249} = F_{249}$, $F_{250} = F_{250}$, $F_{251} = F_{251}$, $F_{252} = F_{252}$, $F_{253} = F_{253}$, $F_{254} = F_{254}$, $F_{255} = F_{255}$, $F_{256} = F_{256}$, $F_{257} = F_{257}$, $F_{258} = F_{258}$, $F_{259} = F_{259}$, $F_{260} = F_{260}$, $F_{261} = F_{261}$, $F_{262} = F_{262}$, $F_{263} = F_{263}$, $F_{264} = F_{264}$, $F_{265} = F_{265}$, $F_{266} = F_{266}$, $F_{267} = F_{267}$, $F_{268} = F_{268}$, $F_{269} = F_{269}$, $F_{270} = F_{270}$, $F_{271} = F_{271}$, $F_{272} = F_{272}$, $F_{273} = F_{273}$, $F_{274} = F_{274}$, $F_{275} = F_{275}$, $F_{276} = F_{276}$, $F_{277} = F_{277}$, $F_{278} = F_{278}$, $F_{279} = F_{279}$, $F_{280} = F_{280}$, $F_{281} = F_{281}$, $F_{282} = F_{282}$, $F_{283} = F_{283}$, $F_{284} = F_{284}$, $F_{285} = F_{285}$, $F_{286} = F_{286}$, $F_{287} = F_{287}$, $F_{288} = F_{288}$, $F_{289} = F_{289}$, $F_{290} = F_{290}$, $F_{291} = F_{291}$, $F_{292} = F_{292}$, $F_{293} = F_{293}$, $F_{294} = F_{294}$, $F_{295} = F_{295}$, $F_{296} = F_{296}$, $F_{297} = F_{297}$, $F_{298} = F_{298}$, $F_{299} = F_{299}$, $F_{300} = F_{300}$, $F_{301} = F_{301}$, $F_{302} = F_{302}$, $F_{303} = F_{303}$, $F_{304} = F_{304}$, $F_{305} = F_{305}$, $F_{306} = F_{306}$, $F_{307} = F_{307}$, $F_{308} = F_{308}$, $F_{309} = F_{309}$, $F_{310} = F_{310}$, $F_{311} = F_{311}$, $F_{312} = F_{312}$, $F_{313} = F_{313}$, $F_{314} = F_{314}$, $F_{315} = F_{315}$, $F_{316} = F_{316}$, $F_{317} = F_{317}$, $F_{318} = F_{318}$, $F_{319} = F_{319}$, $F_{320} = F_{320}$, $F_{321} = F_{321}$, $F_{322} = F_{322}$, $F_{323} = F_{323}$, $F_{324} = F_{324}$, $F_{325} = F_{325}$, $F_{326} = F_{326}$, $F_{327} = F_{327}$, $F_{328} = F_{328}$, $F_{329} = F_{329}$, $F_{330} = F_{330}$, $F_{331} = F_{331}$, $F_{332} = F_{332}$, $F_{333} = F_{333}$, $F_{334} = F_{334}$, $F_{335} = F_{335}$, $F_{336} = F_{336}$, $F_{337} = F_{337}$, $F_{338} = F_{338}$, $F_{339} = F_{339}$, $F_{340} = F_{340}$, $F_{341} = F_{341}$, $F_{342} = F_{342}$, $F_{343} = F_{343}$, $F_{344} = F_{344}$, $F_{345} = F_{345}$, $F_{346} = F_{346}$, $F_{347} = F_{347}$, $F_{348} = F_{348}$, $F_{349} = F_{349}$, $F_{350} = F_{350}$, $F_{351} = F_{351}$, $F_{352} = F_{352}$, $F_{353} = F_{353}$, $F_{354} = F_{354}$, $F_{355} = F_{355}$, $F_{356} = F_{356}$, $F_{357} = F_{357}$, $F_{358} = F_{358}$, $F_{359} = F_{359}$, $F_{360} = F_{360}$, $F_{361} = F_{361}$, $F_{362} = F_{362}$, $F_{363} = F_{363}$, $F_{364} = F_{364}$, $F_{365} = F_{365}$, $F_{366} = F_{366}$, $F_{367} = F_{367}$, $F_{368} = F_{368}$, $F_{369} = F_{369}$, $F_{370} = F_{370}$, $F_{371} = F_{371}$, $F_{372} = F_{372}$, $F_{373} = F_{373}$, $F_{374} = F_{374}$, $F_{375} = F_{375}$, $F_{376} = F_{376}$, $F_{377} = F_{377}$, $F_{378} = F_{378}$, $F_{379} = F_{379}$, $F_{380} = F_{380}$, $F_{381} = F_{381}$, $F_{382} = F_{382}$, $F_{383} = F_{383}$, $F_{384} = F_{384}$, $F_{385} = F_{385}$, $F_{386} = F_{386}$, $F_{387} = F_{387}$, $F_{388} = F_{388}$, $F_{389} = F_{389}$, $F_{390} = F_{390}$, $F_{391} = F_{391}$, $F_{392} = F_{392}$, $F_{393} = F_{393}$, $F_{394} = F_{394}$, $F_{395} = F_{395}$, $F_{396} = F_{396}$, $F_{397} = F_{397}$, $F_{398} = F_{398}$, $F_{399} = F_{399}$, $F_{400} = F_{400}$, $F_{401} = F_{401}$, $F_{402} = F_{402}$, $F_{403} = F_{403}$, $F_{404} = F_{404}$, $F_{405} = F_{405}$, $F_{406} = F_{406}$, $F_{407} = F_{407}$, $F_{408} = F_{408}$, $F_{409} = F_{409}$, $F_{410} = F_{410}$, $F_{411} = F_{411}$, $F_{412} = F_{412}$, $F_{413} = F_{413}$, $F_{414} = F_{414}$, $F_{415} = F_{415}$, $F_{416} = F_{416}$, $F_{417} = F_{417}$, $F_{418} = F_{418}$, $F_{419} = F_{419}$, $F_{420} = F_{420}$, $F_{421} = F_{421}$, $F_{422} = F_{422}$, $F_{423} = F_{423}$, $F_{424} = F_{424}$, $F_{425} = F_{425}$, $F_{426} = F_{426}$, $F_{427} = F_{427}$, $F_{428} = F_{428}$, $F_{429} = F_{429}$, $F_{430} = F_{430}$, $F_{431} = F_{431}$, $F_{432} = F_{432}$, $F_{433} = F_{433}$, $F_{434} = F_{434}$, $F_{435} = F_{435}$, $F_{436} = F_{436}$, $F_{437} = F_{437}$, $F_{438} = F_{438}$, $F_{439} = F_{439}$, $F_{440} = F_{440}$, $F_{441} = F_{441}$, $F_{442} = F_{442}$, $F_{443} = F_{443}$, $F_{444} = F_{444}$, $F_{445} = F_{445}$, $F_{446} = F_{446}$, $F_{447} = F_{447}$, $F_{448} = F_{448}$, $F_{449} = F_{449}$, $F_{450} = F_{450}$, $F_{451} = F_{451}$, $F_{452} = F_{452}$, $F_{453} = F_{453}$, $F_{454} = F_{454}$, $F_{455} = F_{455}$, $F_{456} = F_{456}$, $F_{457} = F_{457}$, $F_{458} = F_{458}$, $F_{459} = F_{459}$, $F_{460} = F_{460}$, $F_{461} = F_{461}$, $F_{462} = F_{462}$, $F_{463} = F_{463}$, $F_{464} = F_{464}$, $F_{465} = F_{465}$, $F_{466} = F_{466}$, $F_{467} = F_{467}$, $F_{468} = F_{468}$, $F_{469} = F_{469}$, $F_{470} = F_{470}$, $F_{471} = F_{471}$, $F_{472} = F_{472}$, $F_{473} = F_{473}$, $F_{474} = F_{474}$, $F_{475} = F_{475}$, $F_{476} = F_{476}$, $F_{477} = F_{477}$, $F_{478} = F_{478}$, $F_{479} = F_{479}$, $F_{480} = F_{480}$, $F_{481} = F_{481}$, $F_{482} = F_{482}$, $F_{483} = F_{483}$, $F_{484} = F_{484}$, $F_{485} = F_{485}$, $F_{486} = F_{486}$, $F_{487} = F_{487}$, $F_{488} = F_{488}$, $F_{489} = F_{489}$, $F_{490} = F_{490}$, $F_{491} = F_{491}$, $F_{492} = F_{492}$, $F_{493} = F_{493}$, $F_{494} = F_{494}$, $F_{495} = F_{495}$, $F_{496} = F_{496}$, $F_{497} = F_{497}$, $F_{498} = F_{498}$, $F_{499} = F_{499}$, $F_{500} = F_{500}$, $F_{501} = F_{501}$, $F_{502} = F_{502}$, $F_{503} = F_{503}$, $F_{504} = F_{504}$, $F_{505} = F_{505}$, $F_{506} = F_{506}$, $F_{507} = F_{507}$, $F_{508} = F_{508}$, $F_{509} = F_{509}$, $F_{510} = F_{510}$, $F_{511} = F_{511}$, $F_{512} = F_{512}$, $F_{513} = F_{513}$, $F_{514} = F_{514}$, $F_{515} = F_{515}$, $F_{516} = F_{516}$, $F_{517} = F_{517}$, $F_{518} = F_{518}$, $F_{519} = F_{519}$, $F_{520} = F_{520}$, $F_{521} = F_{521}$, $F_{522} = F_{522}$, $F_{523} = F_{523}$, $F_{524} = F_{524}$, $F_{525} = F_{525}$, $F_{526} = F_{526}$, $F_{527} = F_{527}$, $F_{528} = F_{528}$, $F_{529} = F_{529}$, $F_{530} = F_{530}$, $F_{531} = F_{531}$, $F_{532} = F_{532}$, $F_{533} = F_{533}$, $F_{534} = F_{534}$, $F_{535} = F_{535}$, $F_{536} = F_{536}$, $F_{537} = F_{537}$, $F_{538} = F_{538}$, $F_{539} = F_{539}$, $F_{540} = F_{540}$, $F_{541} = F_{541}$, $F_{542} = F_{542}$, $F_{543} = F_{543}$, $F_{544} = F_{544}$, $F_{545} = F_{545}$, $F_{546} = F_{546}$, $F_{547} = F_{547}$, $F_{548} = F_{548}$, $F_{549} = F_{549}$, $F_{550} = F_{550}$, $F_{551} = F_{551}$, $F_{552} = F_{552}$, $F_{553} = F_{553}$, $F_{554} = F_{554}$, $F_{555} = F_{555}$, $F_{556} = F_{556}$, $F_{557} = F_{557}$, $F_{558} = F_{558}$, $F_{559} = F_{559}$, $F_{560} = F_{560}$, $F_{561} = F_{561}$, $F_{562} = F_{562}$, $F_{563} = F_{563}$, $F_{564} = F_{564}$, $F_{565} = F_{565}$, $F_{566} = F_{566}$, $F_{567} = F_{567}$, $F_{568} = F_{568}$, $F_{569} = F_{569}$, $F_{570} = F_{570}$, $F_{571} = F_{571}$, $F_{572} = F_{572}$, $F_{573} = F_{573}$, $F_{574} = F_{574}$, $F_{575} = F_{575}$, $F_{576} = F_{576}$, $F_{577} = F_{577}$, $F_{578} = F_{578}$, $F_{579} = F_{579}$, $F_{580} = F_{580}$, $F_{581} = F_{581}$, $F_{582} = F_{582}$, $F_{583} = F_{583}$, $F_{584} = F_{584}$, $F_{585} = F_{585}$, $F_{586} = F_{586}$, $F_{587} = F_{587}$, $F_{588} = F_{588}$, $F_{589} = F_{589}$, $F_{590} = F_{590}$, $F_{591} = F_{591}$, $F_{592} = F_{592}$, $F_{593} = F_{593}$, $F_{594} = F_{594}$, $F_{595} = F_{595}$, $F_{596} = F_{596}$, $F_{597} = F_{597}$, $F_{598} = F_{598}$, $F_{599} = F_{599}$, $F_{600} = F_{600}$, $F_{601} = F_{601}$, $F_{602} = F_{602}$, $F_{603} = F_{603}$, $F_{604} = F_{604}$, $F_{605} = F_{605}$, $F_{606} = F_{606}$, $F_{607} = F_{607}$, $F_{608} = F_{608}$, $F_{609} = F_{609}$, $F_{610} = F_{610}$, $F_{611} = F_{611}$, $F_{612} = F_{612}$, $F_{613} = F_{613}$, $F_{614} = F_{614}$, $F_{615} = F_{615}$, $F_{616} = F_{616}$, $F_{617} = F_{617}$, $F_{618} = F_{618}$, $F_{619} = F_{619}$, $F_{620} = F_{620}$, $F_{621} = F_{621}$, $F_{622} = F_{622}$, $F_{623} = F_{623}$, $F_{624} = F_{624}$, $F_{625} = F_{625}$, $F_{626} = F_{626}$, $F_{627} = F_{627}$, $F_{628} = F_{628}$, $F_{629} = F_{629}$, $F_{630} = F_{630}$, $F_{631} = F_{631}$, $F_{632} = F_{632}$, $F_{633} = F_{633}$, $F_{634} = F_{634}$, $F_{635} = F_{635}$, $F_{636} = F_{636}$, $F_{637} = F_{637}$, $F_{638} = F_{638}$, $F_{639} = F_{639}$, $F_{640} = F_{640}$, $F_{641} = F_{641}$, $F_{642} = F_{642}$, $F_{643} = F_{643}$, $F_{644} = F_{644}$, $F_{645} = F_{645}$, $F_{646} = F_{646}$, $F_{647} = F_{647}$, $F_{648} = F_{648}$, $F_{649} = F_{649}$, $F_{650} = F_{650}$, $F_{651} = F_{651}$, $F_{652} = F_{652}$, $F_{653} = F_{653}$, $F_{654} = F_{654}$, $F_{655} = F_{655}$, $F_{656} = F_{656}$, $F_{657} = F_{657}$, $F_{658} = F_{658}$, $F_{659} = F_{659}$, $F_{660} = F_{660}$, $F_{661} = F_{661}$, $F_{662} = F_{662}$, $F_{663} = F_{663}$, $F_{664} = F_{664}$, $F_{665} = F_{665}$, $F_{666} = F_{666}$, $F_{667} = F_{667}$, $F_{668} = F_{668}$, $F_{669} = F_{669}$, $F_{670} = F_{670}$, $F_{671} = F_{671}$, $F_{672} = F_{672}$, $F_{673} = F_{673}$, $F_{674} = F_{674}$, $F_{675} = F_{675}$, $F_{676} = F_{676}$, $F_{677} = F_{677}$, $F_{678} = F_{678}$, $F_{679} = F_{679}$, $F_{680} = F_{680}$, $F_{681} = F_{681}$, $F_{682} = F_{682}$, $F_{683} = F_{683}$, $F_{684} = F_{684}$, $F_{685} = F_{685}$, $F_{686} = F_{686}$, $F_{687} = F_{687}$, $F_{688} = F_{688}$, $F_{689} = F_{689}$, $F_{690} = F_{690}$, $F_{691} = F_{691}$, $F_{692} = F_{692}$, $F_{693} = F_{693}$, $F_{694} = F_{694}$, $F_{695} = F_{695}$, $F_{696} = F_{696}$, $F_{697} = F_{697}$, $F_{698} = F_{698}$, $F_{699} = F_{699}$, $F_{700} = F_{700}$, $F_{701} = F_{701}$, $F_{702} = F_{702}$, $F_{703} = F_{703}$, $F_{704} = F_{704}$, $F_{705} = F_{705}$, $F_{706} = F_{706}$, $F_{707} = F_{707}$, $F_{708} = F_{708}$, $F_{709} = F_{709}$, $F_{710} = F_{710}$, $F_{711} = F_{711}$, $F_{712} = F$	

TABLE XI-3240-1 (CONT'D)
FLANGE FACTORS IN FORMULA FORM

(7) $C_5 = 1/90 + 5A/1008 - (1 + A)^3/C$	(8) $C_6 = 1/120 + 17A/5040 + 1/C$
(9) $C_7 = 215/2772 + 51A/1232 + (607 + 225A/14 + 75A^2/7 + 5A^3/2)/C$	(10) $C_8 = 31/6930 + 128A/45,045 + (6/7 + 15A/7 + 12A^2/7 + 5A^3/11)/C$
(11) $C_9 = 533/30,240 + 653A/73,920 + (1/2 + 33A/14 + 39A^2/28 + 25A^3/84)/C$	(12) $C_{10} = 29/3780 + 3A/704 - (1/2 + 33A/14 + 81A^2/28 + 13A^3/12)/C$
(13) $C_{11} = 31/6048 + 1763A/665,280 + (1/2 + 6A/7 + 15A^2/28 + 5A^3/42)/C$	(14) $C_{12} = 1/2925 + 71A/300,300 + (8/35 + 18A/35 + 156A^2/385 + 6A^3/55)/C$
(15) $C_{13} = 761/831,600 + 937A/1,663,200 + (1/35 + 6A/35 + 11A^2/70 + 3A^3/70)/C$	(16) $C_{14} = 197/415,800 + 103A/332,640 - (1/35 + 6A/35 + 17A^2/70 + A^3/10)/C$
(17) $C_{15} = 233/831,600 + 97A/554,400 + (1/35 + 3A/35 + A^2/14 + 2A^3/105)/C$	(18) $C_{16} = C_1C_7C_{12} + C_2C_8C_3 + C_3C_8C_2 - (C_3^2C_7 + C_8^2C_1 + C_2^2C_{12})$
(19) $C_{17} = [C_4C_7C_{12} + C_2C_8C_{13} + C_3C_8C_9 - (C_{13}C_7C_3 + C_8^2C_4 + C_{12}C_2C_9)]/C_{16}$	(20) $C_{18} = [C_5C_7C_{12} + C_2C_8C_{14} + C_3C_8C_{10} - (C_{14}C_7C_3 + C_8^2C_5 + C_{12}C_2C_{10})]/C_{16}$
(21) $C_{19} = [C_6C_7C_{12} + C_2C_8C_{15} + C_3C_8C_{11} - (C_{15}C_7C_3 + C_8^2C_6 + C_{12}C_2C_{11})]/C_{16}$	(22) $C_{20} = [C_1C_9C_{12} + C_4C_8C_3 + C_3C_{13}C_2 - (C_3^2C_9 + C_{13}C_8C_1 + C_{12}C_4C_2)]/C_{16}$
(23) $C_{21} = [C_1C_{10}C_{12} + C_5C_8C_3 + C_3C_{14}C_2 - (C_3^2C_{10} + C_{14}C_8C_1 + C_{12}C_5C_2)]/C_{16}$	(24) $C_{22} = [C_1C_{11}C_{12} + C_6C_8C_3 + C_3C_{15}C_2 - (C_3^2C_{11} + C_{15}C_8C_1 + C_{12}C_6C_2)]/C_{16}$
(25) $C_{23} = [C_1C_7C_{13} + C_2C_9C_3 + C_4C_8C_2 - (C_3C_7C_4 + C_8C_9C_1 + C_2^2C_{13})]/C_{16}$	(26) $C_{24} = [C_1C_7C_{14} + C_2C_{10}C_3 + C_5C_8C_2 - (C_3C_7C_5 + C_8C_{10}C_1 + C_2^2C_{14})]/C_{16}$
(27) $C_{25} = [C_1C_7C_{15} + C_2C_{11}C_3 + C_6C_8C_2 - (C_3C_7C_6 + C_8C_{11}C_1 + C_2^2C_{15})]/C_{16}$	(28) $C_{26} = -(C/4)^{1/4}$
(29) $C_{27} = C_{20} - C_{17} - 5/12 - [C_{17}(C/4)^{1/4}]$	(30) $C_{28} = C_{22} - C_{19} - 1/12 - [C_{19}(C/4)^{1/4}]$
(31) $C_{29} = -(C/4)^{1/2}$	(32) $C_{30} = -(C/4)^{3/4}$

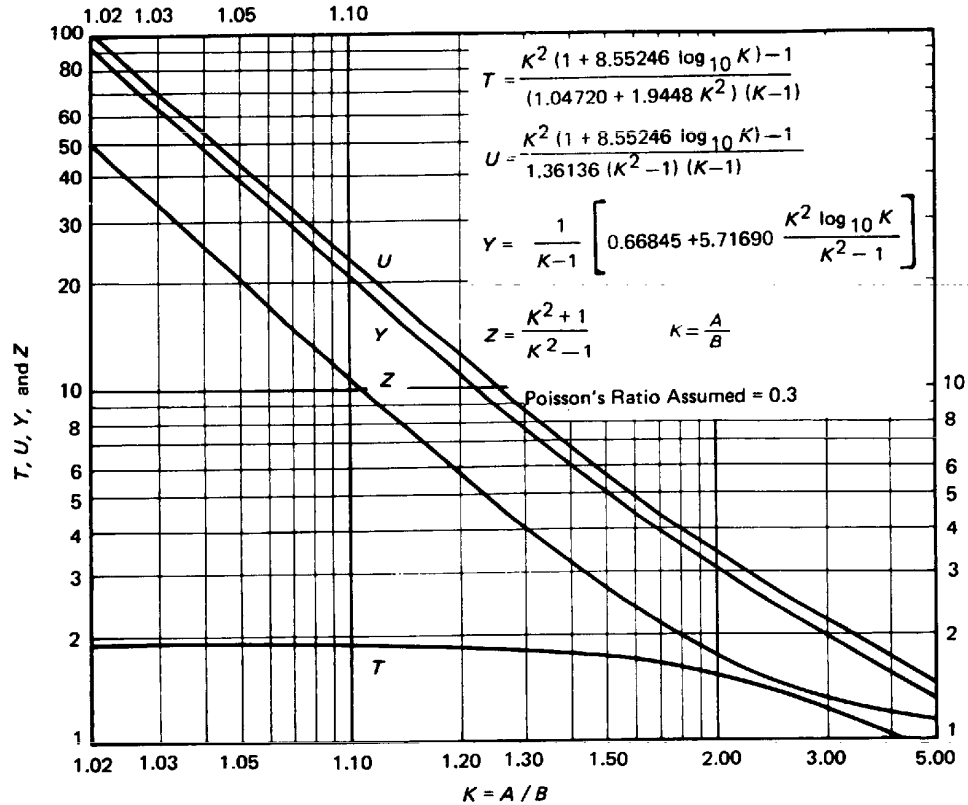
TABLE XI-3240-1 (CONT'D) FLANGE FACTORS IN FORMULA FORM

TABLE XI-3240-1 (CONT'D)
FLANGE FACTORS IN FORMULA FORM

Equations	
(33) $C_{31} = 3A/2 - C_{17}(C/4)^{3/4}$	(34) $C_{32} = 1/2 - C_{19}(C/4)^{1/4}$
(35) $C_{33} = 0.5C_{26}C_{32} + C_{28}C_{31}C_{29} - (0.5C_{30}C_{28} + C_{32}C_{27}C_{29})$	(36) $C_{34} = 1/12 + C_{18} - C_{21} - C_{18}(C/4)^{1/4}$
(37) $C_{35} = -C_{18}(C/4)^{3/4}$	(38) $C_{36} = (C_{28}C_{35}C_{29} - C_{32}C_{34}C_{29})/C_{33}$
(39) $C_{37} = [0.5C_{26}C_{35} + C_{34}C_{31}C_{29} - (0.5C_{30}C_{34} + C_{35}C_{27}C_{29})]/C_{33}$	(40) $E_1 = C_{17}C_{36} + C_{18} + C_{19}C_{37}$
(41) $E_2 = C_{20}C_{36} + C_{21} + C_{22}C_{37}$	(42) $E_3 = C_{23}C_{36} + C_{24} + C_{25}C_{37}$
(43) $E_4 = 1/4 + C_{37}/12 + C_{36}/4 - E_2/5 - 3E_2/2 - E_1$	(44) $E_5 = E_1(1/2 + A/6) + E_2(1/4 + 11A/84) + E_3(1/70 + A/105)$
(45) $E_6 = E_5 - C_{36}(1/120 + A/36 + 3A/C) - 1/40 - A/72 - C_{37}(1/60 + A/120 + 1/C)$	

TABLE XI-3240-1 (CONT'D) FLANGE FACTORS IN FORMULA FORM

$$(10) M_0 = H_D(h_D - h_G) + H_T(h_T - h_G)$$



98

FIG. XI-3240-1 VALUES OF T , U , Y , AND Z (TERMS INVOLVING K)
(The calculation of values of T , U , Y , and Z for values of K outside the boundaries of the graph is acceptable.)

[98]

FIG. XI-3240-1 VALUE OF T , U , Y , AND Z (TERMS INVOLVING K)

(The calculation of values of T , U , Y , and Z for values of K outside the boundaries of the graph is acceptable.)

for gasket seating,

$$(11) M_0 = W h_G$$

In Eqs. (10) and (11):

$$W = \frac{A_{m2} + A_b}{2} S_a$$

$$H_D = 0.785 B^2 P_e$$

$$H_T = H - H_D$$

$$H = 0.785 G^2 P_e$$

P_e = external Design Pressure, psi

See XI-3130 for definitions of other symbols.

XI-3262 Flanges for Both External and Internal Pressure

When flanges are subject at different times during service to external or internal pressure, the design shall satisfy the external pressure design requirements⁵ given in XI-3261 and the internal pressure design requirements given elsewhere in this Appendix.

⁵ The combined force of external pressure and bolt loading may plastically deform certain gaskets to result in loss of gasket contact pressure when the connection is depressurized. To maintain a tight joint when the unit is repressurized, consideration should be given to gasket and facing details, so that excessive deformation of the gasket will not occur. Joints subject to pressure reversals, such as in heat exchanger floating heads, are in this type of service.

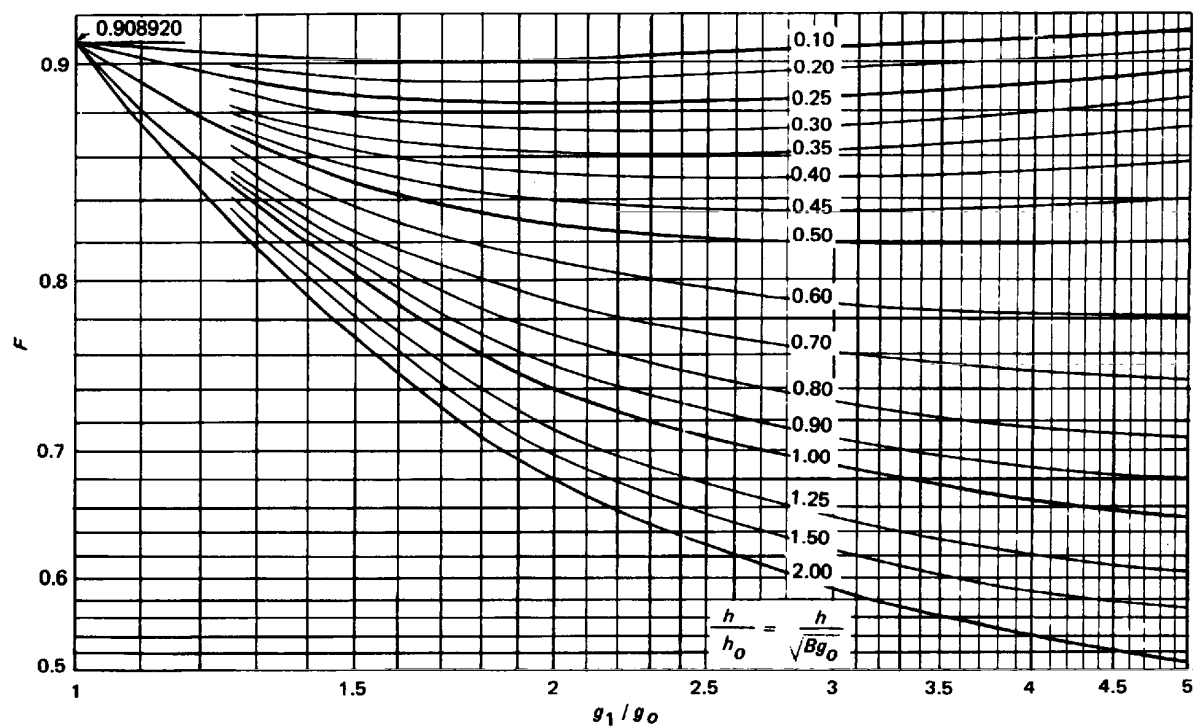


FIG. XI-3240-2 VALUES OF F (INTEGRAL FLANGE FACTORS)
(See Table XI-3240-1 for formulas.)

FIG. XI-3240-2 VALUES OF F (INTEGRAL FLANGE FACTORS)

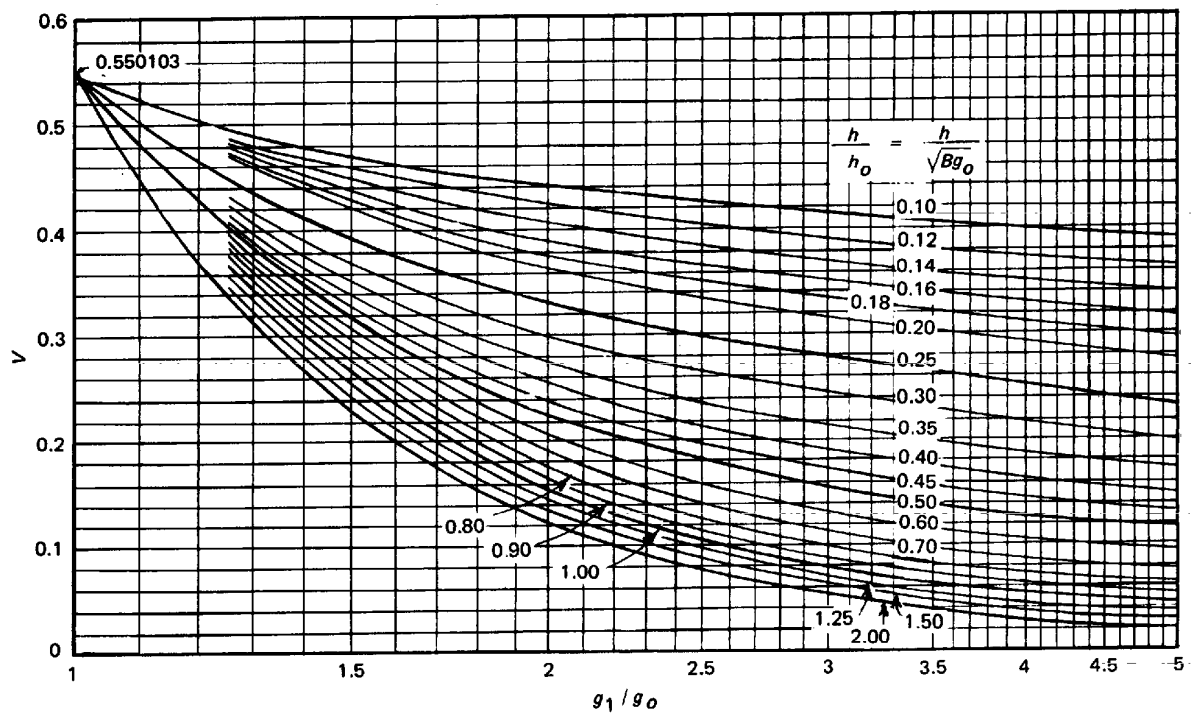
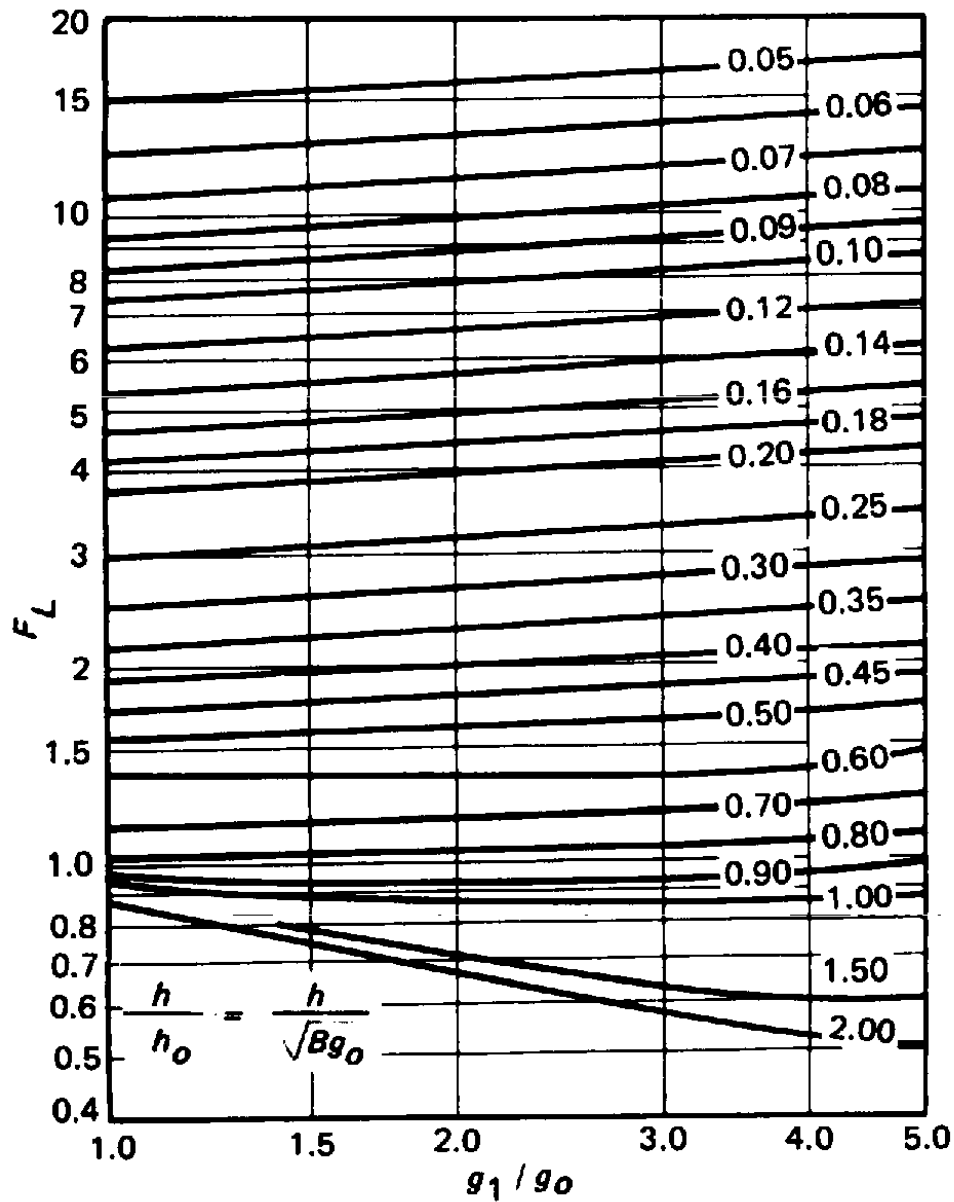
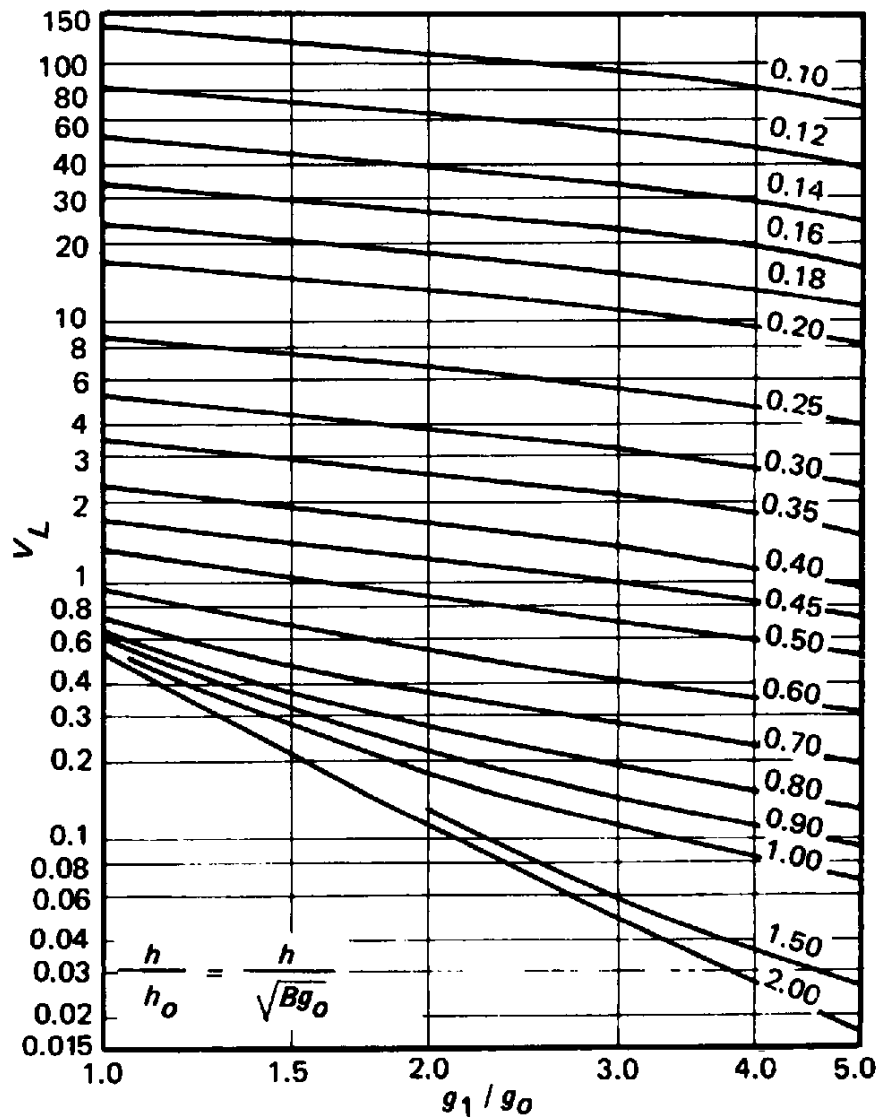


FIG. XI-3240-3 VALUES OF V (INTEGRAL FLANGE FACTORS)
(See Table XI-3240-1 for formulas.)

FIG. XI-3240-3 VALUES OF V (INTEGRAL FLANGE FACTORS)



**FIG. XI-3240-4 VALUES OF F_L
(LOOSE HUB FLANGE FACTORS)
(See Table XI-3240-1 for formulas.)**



98

FIG. XI-3240-5 VALUES OF V_L
(LOOSE HUB FLANGE FACTORS)
(See Table XI-3240-1 for formulas.)

[98]

FIG. XI-3240-5 VALUES OF V_L (LOOSE HUB FLANGE FACTORS)

(See Table XI-3240-1 for formulas.)

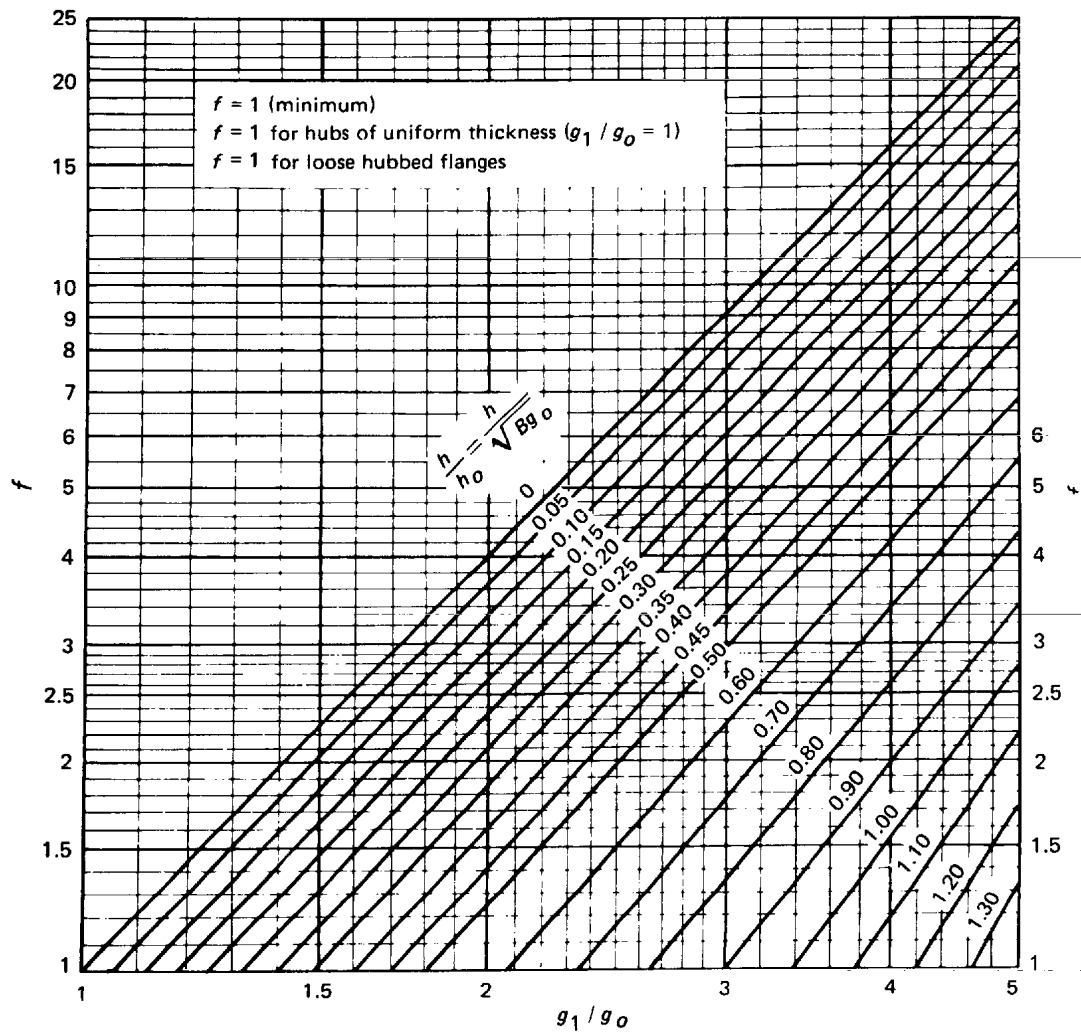


FIG. XI-3240-6 VALUES OF f (HUB STRESS CORRECTION FACTOR)

FIG. XI-3240-6 VALUES OF f (HUB STRESS CORRECTION FACTOR)

July 1, 1998

American Society Of Mechanical Engineers
SEC III D1 MA APP XII
APPENDIX XII DESIGN CONSIDERATIONS FOR BOLTED
FLANGE CONNECTIONS

Page 117

ARTICLE XII-1000 DESIGN CONSIDERATIONS FOR BOLTED FLANGE CONNECTIONS

XII-1100 CONSIDERATIONS

(a) The primary purpose of the rules for bolted flange connections in Appendix XI is to ensure safety, but there are certain other practical matters to be taken into consideration in order to obtain a serviceable design. One of the most important of these is the proportioning of the bolting, i.e., determining the number and size of the bolts.

(b) In the great majority of designs the practice that has been used in the past should be adequate: to follow the design rules in Appendix XI and tighten the bolts sufficiently to withstand the test pressure without leakage. The considerations presented in the discussion in (c) through (m) below will be important only when some unusual feature exists, such as a very large diameter, a high Design Pressure, a high temperature, severe temperature gradients, an unusual gasket arrangement, and so on.

(c) The maximum allowable stress values for bolting given in Section II, Part D, Subpart 1, Table 3 are design values to be used in determining the minimum amount of bolting required under the rules. However, a distinction must be kept carefully in mind between the design value and the bolt stress that might actually exist or that might be needed for conditions other than the Design Pressure. The initial tightening of the bolts is a prestressing operation, and the amount of bolt stress developed must be within proper limits to ensure, on the one hand, that it is adequate to provide against all conditions that tend to produce a leaking joint and, on the other hand, that it is not so excessive that yielding of the bolts or flanges can produce relaxation that also can result in leakage.

(d) The first important consideration is the need for the joint to be tight in the hydrostatic test. An initial bolt stress of some magnitude greater than the design value therefore must be provided. If it is not, further bolt strain develops during the test, which tends to part the joint and thereby to decompress the gasket enough to allow leakage. The test pressure is usually $1\frac{1}{2}$ times the Design Pressure, and on this basis it may be thought that 50% extra bolt stress above the design value will be sufficient. However, this is an oversimplification because, on the one hand, the safety factor against leakage under test conditions in general need not be as great as under Design Conditions. On the other hand, if a stress-strain analysis of the joint is made, it may indicate that an initial bolt stress still higher than $1\frac{1}{2}$ times the design value is needed. Such an analysis is one that considers the changes in bolt elongation, flange deflection, and gasket load that take place with the application of internal pressure, starting from the prestressed condition. In any event, it is evident that an initial bolt stress higher than the design value may and, in some cases, must be developed in the tightening operation, and it is the intent of Subsections NC, ND, and NE that such a practice is permissible, provided it includes necessary and appropriate provision to ensure against excessive flange distortion and gross crushing of the gasket.

(e) It is possible for the bolt stress to decrease after initial tightening, because of slow creep or relaxation of the gasket, particularly in the case of the softer gasket materials. This may be the cause of leakage in the hydrostatic test, in which case it may suffice merely to retighten the bolts. A decrease in bolt stress can also occur in service at elevated temperatures, as a result of creep in the bolt or flange or gasket material, with consequent relaxation. When this results in leakage under service conditions, it is common practice to retighten the bolts, and sometimes a single such operation or perhaps several repeated at long intervals is sufficient to correct the condition. To avoid chronic difficulties of this nature, however, it is advisable when designing a joint for high temperature service to give attention to the relaxation properties of the materials

Page 120

involved, especially for temperatures where creep is the controlling factor in design.

(f) In the other direction, excessive initial bolt stress can present a problem in the form of yielding in the bolting itself and may occur in the tightening operation to the extent of damage or even breakage. This is especially likely with bolts of small diameter and with bolt materials having a relatively low yield strength. The yield strength of mild carbon steel, annealed austenitic stainless steel, and certain of the nonferrous bolting materials can easily be exceeded with ordinary wrench effort in

the smaller bolt sizes. Even if no damage is evident, any additional load generated when internal pressure is applied can produce further yielding with possible leakage. Such yielding can also occur when there is very little margin between initial bolt stress and yield strength.

(g) An increase in bolt stress, above any that may be due to internal pressure, might occur in service during startup or other transient conditions, or perhaps even under normal service. This can happen when there is an appreciable differential in temperature between the flanges and the bolts or when the bolt material has a different coefficient of thermal expansion than the flange material. Any increase in bolt load due to this thermal effect, superposed on the load already existing, can cause yielding of the bolt material, whereas any pronounced decrease due to such effects can result in such a loss of bolt load as to be a direct cause of leakage. In either case, retightening of the bolts may be necessary, but it must not be forgotten that the effects of repeated retightening can be cumulative and may ultimately make the joint unserviceable.

(h) In addition to the difficulties created by yielding of the bolts as described above, the possibility of similar difficulties arising from yielding of the flange or gasket material, under like circumstances or from other causes, should also be considered.

(i) Excessive bolt stress, whatever the reason, may cause the flange to yield even though the bolts may not yield. Any resulting excessive deflection of the flange, accompanied by permanent set, can produce a leaking joint when other effects are superposed. It can also damage the flange by making it more difficult to effect a tight joint thereafter. For example, irregular permanent distortion of the flange due to uneven bolt load around the circumference of the joint can warp the flange face and its gasket contact surface out of a true plane.

(j) The gasket, too, can be overloaded, even without excessive bolt stress. The full initial bolt load is imposed entirely on the gasket, unless the gasket has a stop ring or the flange face detail is arranged to provide the equivalent. Without such means of controlling the compression of the gasket, consideration must be given to the selection of gasket type, size, and material that will prevent gross crushing of the gasket.

(k) From the foregoing, it is apparent that the bolt stress can vary over a considerable range above the design stress value. The design stress values for bolting have been set at a conservative value to provide a factor against yielding. At elevated temperatures, the design stress values are governed by the creep rate and stress rupture strength. Any higher bolt stress existing before creep occurs in operation will have already served its purpose of seating the gasket and holding the hydrostatic test pressure, all at atmospheric temperature, and is not needed at the Design Pressure and Temperature.

(l) Theoretically, the margin against flange yielding is not as great. The design values for flange materials may be as high as five-eighths or two-thirds of the yield strength. However, the highest stress in a flange is usually the bending stress in the hub or shell and is more or less localized. It is too conservative to assume that local yielding is followed immediately by overall yielding of the entire flange. Even if a plastic hinge should develop, the ring portion of the flange takes up the portion of the load that the hub and shell refuse to carry. Yielding is far more significant if it occurs first in the ring but the limitation in the rules on the combined hub and ring stresses provides a safeguard. In this connection, reference should be made to Note (2) of Section II, Part D, Subpart 1, Tables 1A and 1B which provides guidance in the case of high alloy materials to which a strain limiting factor may have to be applied.

(m) Another very important item in bolting design is the question of whether the necessary bolt stress is actually realized and what special means of tightening, if any, must be employed. Most joints are tightened manually by ordinary wrenching and it is advantageous to have designs that require no more than this. Some pitfalls must be avoided, however. The probable bolt stress developed manually, when using standard wrenches, is:

$$S = 45,000/\sqrt{d}$$

where S is the bolt stress and d is the nominal diameter of the bolt. It can be seen that smaller bolts will have excessive stress unless judgment is exercised in pulling up on them. On the other hand, it will be impossible to develop the desired stress in very large bolts by ordinary hand wrenching. Impact wrenches may prove

serviceable, but, if not, resort may be had to such methods as preheating the bolt or using hydraulically powered bolt tensioners. With some of these methods, control of the bolt stress is possible by means inherent in the procedure, especially if effective thread lubricants are employed, but in all cases the bolt stress can be regulated within reasonable tolerances by measuring the bolt elongation with suitable extensometer equipment. Ordinarily, simple wrenching without verification of the actual bolt stress meets all practical needs, and measured control of the stress is employed only when there is some special or important reason for doing so.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 MA APP XIII

APPENDIX XIII DESIGN BASED ON STRESS ANALYSIS FOR VESSELS DESIGNED IN ACCORDANCE WITH NC-3200

Page 123

ARTICLE XIII-1000 DESIGN BASED ON STRESS ANALYSIS

XIII-1100 GENERAL REQUIREMENTS

XIII-1110 SCOPE

This Appendix is applicable only to the design of Class 2 vessels meeting the requirements of NC-3200.

(a) When a fatigue evaluation is not required (NC-3217), a vessel or a vessel part may be designed using the stress analysis methods given in this Appendix. When a fatigue evaluation is required, this Appendix shall be used together with Appendix XIV, Design Based on Fatigue Analysis for Vessels Designed in Accordance With NC-3200.

(b) Use of the analytical methods contained in the Articles of this Appendix which follow this Article is an acceptable way of obtaining solutions to problems for which these procedures are applicable. Other techniques, analytical or experimental (Appendix II), may be used provided they are either more accurate or more conservative than those contained herein.

XIII-1120 DESIGN ACCEPTABILITY

XIII-1121 Requirements for Design Acceptability

The requirements for the acceptability of a design are given in (a) and (b) below.

(a) The design shall be such that the stresses shall not exceed the limits described in XIII-1140.

(b) For configurations where compressive stresses occur, in addition to the requirement in (a) above, the critical buckling stress shall be taken into account. For the case of external pressure, see NC-3245.

XIII-1122 Basis for Determining Stresses

The equivalent stress at any point in a vessel is the value of stress deduced from the stress condition at the point by means of a theory of failure for comparison with the mechanical properties of the material obtained in tests under uniaxial load. The theory of failure, used in the rules of this Appendix for combining stresses, is the maximum shear stress theory. The maximum shear stress at a point is equal to one-half the difference between the algebraically largest and the algebraically smallest of the three principal stresses at the point.

XIII-1123 Terms Relating to Stress Analysis

Terms used in this Appendix relating to stress analysis are defined in (a) through (r) below.

(a) *Stress Intensity*.¹ Stress intensity is the equivalent intensity of combined stress, or in short, the stress intensity is defined as twice the maximum shear stress. In other words, the stress intensity is the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tension stresses are considered positive and compression stresses are considered negative.

(b) *Gross Structural Discontinuity*. Gross structural discontinuity is a source of stress or strain intensification which affects a relatively large portion of a structure and has a significant effect on the overall stress or strain pattern or on the structure as a whole. Examples of gross structural discontinuities are: head-to-shell and flange-to-shell junctions, nozzles

and junctions between shells of different diameters or thicknesses.

(c) *Local Structural Discontinuity*. Local structural discontinuity is a source of stress or strain intensification which affects a relatively small volume of material and does not have a significant effect on the overall stress or strain pattern or on the structure as a whole. Examples are: small fillet radii, small attachments, and partial penetration welds.

1 This definition of stress intensity is not related to the definition of stress intensity applied in the field of Fracture Mechanics.

(d) *Normal Stress*. Normal stress is the component of stress normal to the plane of reference. This is also referred to as direct stress. Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to be made up in

Page 126

turn of two components, one of which is uniformly distributed and equal to the average value of stress across the thickness of the section under consideration and the other of which varies with the location across the thickness.

(e) *Shear Stress*. Shear stress is the component of stress tangent to the plane of reference.

(f) *Membrane Stress*. Membrane stress is the component of normal stress which is uniformly distributed and equal to the average value of stress across the thickness of the section under consideration.

(g) *Bending Stress*. Bending stress is the variable component of normal stress described in (d) above. The variation may or may not be linear across the thickness.

(h) *Primary Stress*. Primary stress is a normal stress developed by the imposed loading which is necessary to satisfy the laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses which considerably exceed the yield strength will result in failure or, at least, in gross distortion. A thermal stress is not classified as a primary stress. Primary membrane stress is divided into general and local categories. A general primary membrane stress is one which is so distributed in the structure that no redistribution of load occurs as a result of yielding. Examples of primary stress are as follows:

(1) general membrane stress in a circular cylindrical or a spherical shell due to internal pressure or to distributed live loads;

(2) bending stress in the central portion of a flat head due to pressure.

(i) *Secondary Stress*. Secondary stress is a normal stress or a shear stress developed by the constraint of adjacent parts or by self-constraint of a structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions which cause the stress to occur and failure from one application of the stress is not to be expected. Examples of secondary stress are as follows:

(1) general thermal stress [see (m) below];

(2) bending stress at a gross structural discontinuity.

(j) *Local Primary Membrane Stress*. Cases arise in which a membrane stress produced by pressure or other mechanical loading and associated with a discontinuity would, if not limited, produce excessive distortion in the transfer of load to other portions of the structure. Conservatism requires that such a stress be classified as a local primary-membrane stress even though it has some characteristics of a secondary stress. A stressed region may be considered local if the distance over which the membrane stress intensity exceeds $1.1S_m$ does not extend in the meridional direction more than $1.0\sqrt{Rt}$, where R is the minimum midsurface radius of curvature and t is the minimum thickness in the region considered. Regions of local primary stress intensity involving axisymmetric membrane stress distributions which exceed $1.1S_m$ shall not be closer in the meridional direction than $2.5\sqrt{Rt}$, where R is defined as $(R_1 + R_2)/2$ and t is defined as $(t_1 + t_2)/2$, where t_1 and t_2 are the minimum thicknesses at each of the regions considered, and R_1 and R_2 are the minimum midsurface radii of curvature at these regions where the membrane stress intensity exceeds $1.1S_m$. Discrete regions of local primary membrane stress intensity, such as those resulting from concentrated loads acting on brackets, where the membrane stress intensity exceeds $1.1S_m$ shall be spaced so that there is no overlapping of the areas in which the membrane stress intensity exceeds $1.1S_m$.

(k) *Peak Stress*. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture. A stress which is not highly localized falls

into this category if it is of a type which cannot cause noticeable distortion. Examples of peak stress are as follows:

- (1) the thermal stress in the austenitic steel cladding of a carbon steel vessel;
- (2) the thermal stress in the wall of a vessel or pipe caused by a rapid change in temperature of the contained fluid;
- (3) the stress at a local structural discontinuity.

(l) *Load Stress*. Load stress is the stress resulting from the application of a load, such as internal pressure or the effects of gravity, as distinguished from thermal stress.

(m) *Thermal Stress*. Thermal stress is a self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally should under a change in temperature. For the purpose of establishing allowable stresses, two types of thermal stress are recognized, depending on the volume or area in which distortion takes place, as described in (1) and (2) below.

(1) One type of thermal stress is general thermal stress which is associated with distortion of the structure in which it occurs. If a stress of this type, neglecting stress concentrations, exceeds twice the yield strength of the material, the elastic analysis may be invalid and

Page 127

successive thermal cycles may produce incremental distortion. Therefore, this type is classified as secondary stress in Table XIII-1130-1 and Fig. XIII-1141-1. Examples of general thermal stress are as follows:

- (a) stress produced by an axial temperature distribution in a cylindrical shell;
- (b) stress produced by the temperature difference between a nozzle and the shell to which it is attached;
- (c) the equivalent linear stress² produced by the radial temperature distribution in a cylindrical shell.

(2) The other type of thermal stress is local thermal stress which is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses shall be considered only from the fatigue standpoint and are therefore classified as local stresses in Table XIII-1130-1 and Fig. XIII-1141-1. In evaluating local thermal stresses the procedures of XIII-1151.1(b) shall be used. Examples of local thermal stresses are as follows:

- (a) the stress in a small hot spot in a vessel wall;
- (b) the difference between the actual stress and the equivalent linear stress resulting from a radial temperature distribution in a cylindrical shell;
- (c) the thermal stress in a cladding material which has a coefficient of expansion different from that of the base metal.

(n) *Total Stress*. Total stress is the sum of the primary, secondary, and peak stress contributions. Recognition of each of the individual contributions is essential to establishment of appropriate limitations.

(o) *Operational Cycle*. An operational cycle is defined as the initiation and establishment of new conditions followed by a return to the conditions that prevailed at the beginning of the cycle. Three types are considered:

- (1) startup-shutdown cycle, defined as any cycle which has atmospheric temperature or pressure as one of its extremes and normal operating conditions as its other extreme;
- (2) the initiation of and recovery from any loadings for which Level A or Level B Service Limits are designated and which are required to be considered in the design;
- (3) normal service cycle, defined as any cycle between startup and shutdown which is required for the vessel to perform its intended purpose.

² Equivalent linear stress is defined as the linear stress distribution which has the same net bending moment as the actual stress distribution.

(p) *Stress Cycle*. Stress cycle is a condition in which the alternating stress difference (XIV-1212) goes from an initial value through an algebraic maximum value and an algebraic minimum value and then returns to the initial value. A single service cycle may result in one or more stress cycles.

(q) *Fatigue Strength Reduction Factor*. Fatigue strength reduction factor is a stress intensification factor which accounts for the effect of a local structural discontinuity (stress concentration) on the fatigue strength. Values for some specific cases, based on experiment, are given elsewhere and in Subsection NC. In the absence of experimental data, the theoretical stress concentration factor may be used.

(r) *Shakedown*. Shakedown of a structure occurs if, after a few cycles of load application, ratcheting ceases. The subsequent structural response is elastic, or elastic-plastic, and progressive incremental inelastic deformation is absent. Elastic shakedown is the case in which the subsequent response is elastic.

(s) *Deformation*. Deformation of a component part is an alteration of its shape or size.

(t) *Inelasticity*. Inelasticity is a general characteristic of material behavior in which the material does not return to its original shape and size after removal of all applied loads. Plasticity and creep are special cases of inelasticity.

(u) *Creep*. Creep is the special case of inelasticity that relates to the stress induced time-dependent deformation under load. Small time-dependent deformations may occur after the removal of all applied loads.

(v) *Plasticity*. Plasticity is the special case of inelasticity in which the material undergoes time-independent nonrecoverable deformation.

(w) *Plastic Analysis*. Plastic analysis is that method which computes the structural behavior under given loads considering the plasticity characteristics of the materials including strain hardening and the stress redistribution occurring in the structure.

(x) *Plastic Analysis - Collapse Load*. A plastic analysis may be used to determine the collapse load for a given combination of loads on a given structure. The following criterion for determination of the collapse load shall be used. A load-deflection or load-strain curve is plotted with load as the ordinate and deflection or strain as the abscissa. The angle that the linear part of the load-deflection or load-strain curve makes with the ordinate is called θ . A second straight line, hereafter called the collapse limit line, is drawn through the origin so that it makes an angle $\phi = \tan^{-1} (2 \tan \theta)$ with the ordinate. The collapse load is the load at the intersection of the load-deflection or load-strain curve and the collapse limit line. If this method is used, particular care should be given to ensure that the strains or deflections that are used are indicative of the load carrying capacity of the structure.

Page 128

(y) *Plastic Instability Load*. The plastic instability load for members under predominantly tensile or compressive loading is defined as that load at which unbounded plastic deformation can occur without an increase in load. At the plastic tensile instability load the true stress in the material increases faster than strain hardening can accommodate.

(z) *Limit Analysis*. Limit analysis is a special case of plastic analysis in which the material is assumed to be ideally plastic (nonstrain-hardening). In limit analysis the equilibrium and flow characteristics at the limit state are used to calculate the collapse load. The two bounding methods which are used in limit analysis are the lower bound approach, which is associated with a statically admissible stress field, and the upper bound approach, which is associated with a kinematically admissible velocity field. For beams and frames the term *mechanism* is commonly used in lieu of *kinematically admissible velocity field*.

(aa) *Collapse Load - Lower Bound*. If, for a given load, any system of stresses can be found which everywhere satisfies equilibrium, and nowhere exceeds the material yield strength, the load is at or below the collapse load. This is the lower bound theorem of limit analysis which permits calculations of a lower bound to the collapse load.

(bb) *Limit Analysis - Collapse Load*. The methods of limit analysis are used to compute the maximum load that a structure assumed to be made of ideally plastic material can carry. At this load, which is termed the collapse load, the deformations of the structure increase without bound.

(cc) *Plastic Hinge*. A plastic hinge is an idealized concept used in Limit Analysis. In a beam or a frame, a plastic hinge is formed at the point where the moment, shear, and axial force lie on the yield interaction surface. In plates and shells a plastic hinge is formed where the generalized stresses lie on the yield surface.

(dd) *Strain Limiting Load*. When a limit is placed upon a strain, the load associated with the strain limit is called the

strain limiting load.

(ee) *Test Collapse Load*. Test collapse load is the collapse load determined by tests according to the criteria given in II-1430 of Section III.

(ff) *Ratcheting*. Ratcheting is a progressive incremental inelastic deformation or strain which can occur in a component that is subjected to variations of mechanical stress, thermal stress, or both.

XIII-1130 DERIVATION OF STRESS INTENSITIES

One requirement for the acceptability of a design [XIII-1121(a)] is that the calculated stress intensities shall not exceed specified allowable limits. These limits differ depending on the stress category (primary, secondary, etc.) from which the stress intensity is derived. This paragraph describes the procedure for the calculation of the stress intensities which are subject to specified limits. The steps in the procedure are given in (a) through (f) below.

(a) At the point on the vessel which is being investigated, choose an orthogonal set of coordinates, such as tangential, longitudinal, and radial, and designate them by the subscripts t , l , and r . The stress components in these directions are then designated σ_t , σ_r , and σ_l for direct stresses and τ_{tl} , τ_{lr} , and τ_{rl} for shear stresses.

(b) Calculate the stress components for each type of loading to which the part will be subjected and assign each set of stress values to one or a group of the following categories:³

(1) general primary membrane stress P_m [XIII-1123(f) and (h)];

(2) local primary membrane stress P_L [XIII-1123(j)];

(3) primary bending stress P_b [XIII-1123(g) and (h)];

(4) secondary stress⁴ Q [XIII-1123(i)];

(5) peak stress F [XIII-1123(k)].

(c) Group the stress components in accordance with XIII-1130(b). Figure XIII-1141-1 is to provide assistance in assigning the stress values to the appropriate category. At any rectangular box calculate the algebraic sum of the values of σ_t which result from the different types of loadings and which have entered the box, and similarly for the other five stress components. The result is a set of six stress components in each box.

(d) Translate the stress components in the t , l , and r directions into principal stresses σ_1 , σ_2 , and σ_3 . (In many pressure vessel calculations, the t , l , and r directions may be so chosen that the shearing stress components are zero and so σ_1 , σ_2 , and σ_3 are identical to σ_t , σ_r , and σ_l .)

(e) Calculate the stress differences S_{12} , S_{23} , and S_{31} from the relations:

$$S_{12} = \sigma_1 - \sigma_2$$

$$S_{23} = \sigma_2 - \sigma_3$$

$$S_{31} = \sigma_3 - \sigma_1$$

³ See Table XIII-1130-1 and Note (4) of Fig. XIII-1141-1.

⁴ Subdivision of secondary stresses into membrane and bending components is not required because of the same stress limits apply to both components.

TABLE XIII-1130-1
CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES

Vessel Component	Location	Origin of Stress	Type of Stress	Classification
Cylindrical or spherical shell	Shell plate remote from discontinuities	Internal pressure	General membrane Gradient through plate thickness	P_m Q
		Axial thermal gradient	Membrane Bending	Q Q
	Junction with head or flange	Internal pressure	Membrane Bending	P_L Q [Note (4)]
Any shell or head	Any section across entire vessel	External load or moment, or internal pressure	General membrane averaged across full section	P_m
		External load or moment	Bending across full section	P_m
	Near nozzle or other opening	External load or moment, or internal pressure	Local membrane Bending Peak (fillet or corner)	P_L Q F
	Any location	Temperature difference between shell and head	Membrane Bending	Q Q
Dished head or conical head	Crown	Internal pressure	Membrane Bending	P_m P_b
	Knuckle or junction to shell	Internal pressure	Membrane Bending	P_L [Note (1)] Q
Flat head	Center region	Internal pressure	Membrane Bending	P_m P_b
	Junction to shell	Internal pressure	Membrane Bending	P_L P_b or Q [Note (4)]
Perforated head or shell	Typical ligament in a uniform pattern	Pressure	Membrane (averaged through cross section)	P_m
			Bending (averaged through width of ligament, but gradient through plate) Peak	P_b F
	Isolated or atypical ligament	Pressure	Membrane Bending Peak	Q F F

(Table XIII-1130-1 continues on next page)

TABLE XIII-1130-1 CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES

**TABLE XIII-1130-1 (CONT'D)
CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES**

Vessel Component	Location	Origin of Stress	Type of Stress	Classification
Nozzle (XIII-1170)	Within the limits of reinforcement defined by NC-3334	Pressure and external loads and moments, including those attributable to restrained free end displacements of the attached piping	General membrane Bending (other than gross structural discontinuity stresses) averaged through nozzle thickness	P_m P_m
		Pressure and external axial, shear, and torsional loads other than those attributable to restrained free end displacements of the attached piping	General membrane stresses	P_m
	Outside the limits of reinforcement defined by NC-3334	Pressure and external loads and moments other than those attributable to restrained free end displacements of the attached piping	Membrane Bending	P_L P_b
		Pressure and all external loads and moments	Membrane Bending Peak	P_L Q F
	Nozzle wall	Gross structural discontinuities	Local membrane Bending Peak	P_L Q F
		Differential expansion	Membrane Bending Peak	Q Q F
Cladding	Any	Differential expansion	Membrane Bending	F F
Any	Any	Radial temperature distribution [Note (3)]	Equivalent linear stress [Note (2)]	Q
			Nonlinear portion of stress distribution	F
Any	Any	Any	Stress concentration (notch effect)	F

NOTES:

- (1) Consideration shall also be given to the possibility of wrinkling and excessive deformation in vessels with a large diameter-thickness ratio.
- (2) Consider possibility of thermal stress ratchet.
- (3) Equivalent linear stress is defined as the linear stress distribution which has the same net bending moment as the actual stress distribution.
- (4) If the bending moment at the edge is required to maintain the bending stress in the middle to acceptable limits, the edge bending is classified as P_b . Otherwise, it is classified as Q .

TABLE XIII-1130-1 (CONT'D) CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES

The stress intensity S is the largest absolute value of S_{12} , S_{23} , and S_{31} .

(f) The stress intensity calculated as in (e) above from the stress components in any rectangle in Fig. XIII-1141-1 shall not exceed the allowable values of XIII-1140 which are shown in the circle adjacent to the rectangle in Fig. XIII-1141-1.

NOTE: Membrane stress intensity is derived from the stress components averaged across the thickness of the section. The averaging shall be performed at the component level, in step (b) or (c) above.

XIII-1140 BASIC STRESS INTENSITY LIMITS

XIII-1141 Five Basic Limits

The five basic stress intensity limits which are to be satisfied are given in XIII-1142 through XIII-1146 (Fig. XIII-1141-1).

XIII-1142 General Primary Membrane Stress Intensity

This is the stress intensity, derived from the average value across the thickness of a section, of the general primary stresses [XIII-1123(b)] produced by design internal pressure and other specified Design Mechanical Loads, but excluding all secondary and peak stresses. The allowable value of this stress intensity is kS_m as given in Section II, Part D, Subpart 1, Tables 2A and 2B. Values of k are given in Table NC-3217-1.

XIII-1143 Local Membrane Stress Intensity

This is the stress intensity, derived from the average value across the thickness of a section, of the local primary stresses [XIII-1123(j)] produced by Design Pressure and specified Design Mechanical Loads, but excluding all thermal and peak stresses. The allowable value of this stress intensity is $1.5kS_m$.

XIII-1144 Primary Membrane Plus Primary Bending Stress Intensity

This is the stress intensity, derived from the highest value across the thickness of a section, of the general or local primary membrane stresses plus primary bending stresses produced by Design Pressure and other specified Design Mechanical Loads, but excluding all secondary and peak stresses. For solid rectangular sections, the allowable value of this stress intensity is $1.5kS_m$. For other than solid rectangular sections, a value of α times the limit established in NC-3217 (b) may be used, where the factor α is defined as the ratio of the load set producing a fully plastic section to the load set producing initial yielding in the extreme fibers of the section. In the evaluation of the initial yield and fully plastic section capacities, the ratios of each individual load in the respective load set to each other load in that load set shall be the same as the respective ratios of the individual loads in the specified design load set. The value of α shall not exceed the value calculated for bending only ($P_m = 0$). In no case shall the value of α exceed 1.5. The propensity for buckling of the part of the section that is in compression shall be investigated. The α factor is not permitted for Level D Service Limits when inelastic component analysis is used as permitted in Appendix F.

XIII-1145 Primary Plus Secondary Stress Intensity

This is the stress intensity, derived from the highest value at any point across the thickness of a section, of the general or local primary membrane stresses plus primary bending stresses plus secondary stresses produced by specified service pressure and other specified mechanical loads and by general thermal effects. The effects of gross structural discontinuities but not of local structural discontinuities (stress concentrations) shall be included. The allowable value of this stress intensity is $3S_m$ [Note (1) of Fig. XIII-1141-1].

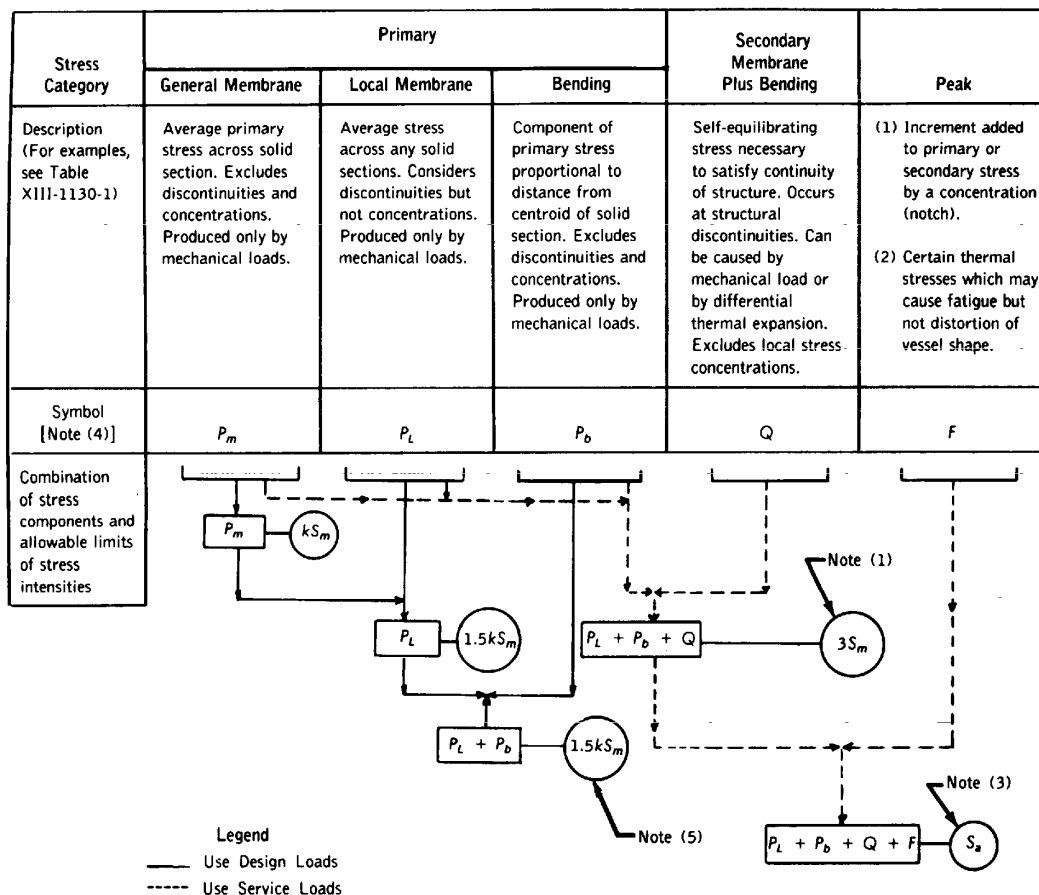
XIII-1146 Peak Stress Intensity

This is the stress intensity, derived from the highest value at any point across the thickness of a section, of the combination of all primary, secondary, and peak stresses produced by specified service pressures and other mechanical loads and by general and local thermal effects and including the effects of gross and local structural discontinuities. The allowable value of this stress intensity is dependent on the range of the stress difference from which it is derived and on the number of times it is to be applied. The stress intensity is to be compared with the allowable value obtained by the

methods of analysis for cyclic operation described in XIV-1200 through the use of the fatigue curves [Figs. XIV-1221.3(c)-1, XIV-1221.3(c)-2, and XIV-1221.3(c)-3].

Page 132

Page 133



NOTES

- (1) This limitation applies to the range of stress intensity. When the secondary stress is due to a temperature excursion at the point at which the stresses are being analyzed, the value of S_m shall be taken as the average of the S_m values tabulated in Section II, Part D, Subpart 1, Tables 2A and 2B for the highest and the lowest temperature of the metal during the transient. When part or all of the secondary stress is due to mechanical load, the value of S_m shall be taken as the S_m value for the highest temperature of the metal during the transient.
- (2) The stresses in category Q are those parts of the total stress which are produced by thermal gradients, structural discontinuities, etc., and do not include primary stresses which may also exist at the same point. It should be noted, however, that a detailed stress analysis frequently gives the combination of primary and secondary stresses directly and, when appropriate, this calculated value represents the total of P_m (or P_L) + P_b + Q and not Q alone. Similarly, if the stress in category F is produced by a stress concentration, the quantity F is the additional stress, produced by the notch, over and above the nominal stress. For example, if a plate has a nominal stress intensity S and has a notch with a stress concentration factor K , then $P_m = S$, $P_b = 0$, $Q = 0$, $F = P_m(K - 1)$, and the peak stress intensity equals $P_m + P_m(K - 1) = KP_m$.
- (3) S_2 is obtained from the fatigue curves [Figs. XIV-1221.3(c)-1, XIV-1221.3(c)-2, and XIV-1221.3(c)-3]. The allowable stress intensity for the full range of fluctuation is $2S_2$.
- (4) The symbols P_m , P_L , P_b , Q , and F do not represent single quantities but rather sets of six quantities representing the six stress components σ_x , σ_y , σ_z , τ_{xy} , τ_{yz} , and τ_{zx} .
- (5) Values shown are applicable when $P_L \leq 0.67S_y$. When $P_L > 0.67S_y$, use $[2.5 - 1.5(P_L/S_y)](kS_m)$. This relationship applies only to Service Level C.

FIG. XIII-1141-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY

XIII-1150 PLASTIC ANALYSIS, LIMIT ANALYSIS, AND SHAKEDOWN ANALYSIS

XIII-1151 Plastic Analysis

(a) Certain of the allowable stresses permitted in these design criteria are such that the maximum stress calculated on an elastic basis may exceed the yield strength of the material. The limit on primary plus secondary stress intensity of $3S_m$ (XIII-1145) has been placed at a level which ensures shakedown to elastic action after a few repetitions of the stress cycle except in regions containing significant local structural discontinuities or local thermal stresses. These last two factors are considered only in the performance of a fatigue evaluation.

(b) The limits on local membrane stress intensity (XIII-1143) and primary membrane plus primary bending stress intensity of $1.5kS_m$ (XIII-1144) have been placed at a level which conservatively ensures the prevention of collapse as determined by the principles of limit analysis. The following subparagraphs provide guidance in the application of plastic analysis and some relaxation of the basic stress limits which are allowed if plastic analysis is used.

XIII-1151.1 Value of Poisson's Ratio

(a) In evaluating stresses for comparison with any stress limits other than fatigue allowables, stresses shall be calculated on an elastic basis using the elastic value of Poisson's ratio.

(b) In evaluating stresses for comparison with fatigue allowables, the elastic equations shall be used, except that the numerical value substituted for Poisson's ratio shall be determined from the expression:

$$\nu = 0.5 - 0.2(S_y/S_a), \text{ but not less than } 0.3$$

where

S_y

= the yield strength, psi, of the material at the mean value of the temperature of the cycle

S_a

= the value, psi, obtained from the applicable design fatigue curve for the specified number of cycles of the condition being considered

XIII-1151.2 Plastic Analysis Procedures.

The limits on local membrane stress intensity (XIII-1143), primary plus secondary stress intensity (XIII-1145), thermal stress ratchet in shell (XIV-1410), and thermal stress in nonintegral connections (XIV-1420) need not be satisfied at a specific location if at that location the procedures of (a), (b), and (c) below are used.

(a) In evaluating stresses for comparison with the stress limits of XIII-1142, XIII-1144 (general primary membrane plus primary bending stress intensity only), XIII-1180, NC-3214.3, XIII-1160, and XIII-1121(b), the stresses are calculated on an elastic basis.

(b) In lieu of satisfying the specific requirements of XIII-1143, XIII-1145, NC-3214.3, and XIV-1420 at a specific location, the structural action is calculated on a plastic basis and the design shall be considered to be acceptable if shakedown occurs, as opposed to continuing deformation, and if the deformations which occur prior to shakedown do not exceed specified limits.

(c) In evaluating stresses for comparison with fatigue allowables, the numerically maximum principal total strain range which occurs after shakedown shall be multiplied by one-half of the modulus of elasticity of the material at the mean value of the temperature of the cycle.

XIII-1152 Limit Analysis

The limits on local membrane stress intensity (XIII-1143) and primary membrane plus primary bending stress intensity need not be satisfied at a specific location if it can be shown by means of limit analysis or by tests that the specified

mechanical and thermal loadings do not exceed two-thirds the lower bound collapse load.

XIII-1153 Shakedown Analysis

The $3S_m$ stress intensity limit on the range of primary plus secondary stress intensity (XIII-1145) may be exceeded provided that the range of primary plus secondary membrane plus bending stress intensity, excluding thermal bending stresses, shall be $\leq 3S_m$ and that the requirements of (a) through (e) below are met.

(a) The value of S_a used for entering the design fatigue curve is multiplied by the factor K_e , where

$$K_e = \begin{cases} 1.0, & \text{for } S_n < 3S_m \\ 1.0 + [(1 - n)/n(m - 1)][(S_n/3S_m) - 1], & \text{for } 3S_m < S_n < 3mS_m \\ 1/n, & \text{for } S_n \geq 3mS_m \end{cases}$$

$$S_n = \text{range of primary plus secondary stress intensity}$$

The values of the material parameters m and n are given for the various classes of permitted materials in Table XIII-1153(a)-1.

(b) The rest of the fatigue evaluation stays the same as required in Appendix XIV, except that the procedure of XIII-1151.1 need not be used.

(c) The component meets the thermal ratcheting requirement of Appendix XIV-1400.

Page 134

**TABLE XIII-1153(a)-1
VALUES OF m , n , AND $T_{\max}$ FOR VARIOUS
CLASSES OF PERMITTED MATERIALS**

Materials	m	n	$T_{\max}$, °F
Low alloy steel	2.0	0.2	700
Martensitic stainless steel	2.0	0.2	700
Carbon steel	3.0	0.2	700
Austenitic stainless steel	1.7	0.3	800
Nickel–chromium–iron	1.7	0.3	800
Nickel–copper	1.7	0.3	800

TABLE XIII-1153(a)-1 VALUES OF m , n , AND $T^{\max}$ FOR VARIOUS CLASSES OF PERMITTED MATERIALS

(d) The temperature does not exceed those listed in Table XIII-1153(a)-1 for the various classes of permitted materials.

(e) The material shall have a specified minimum yield strength to specified minimum tensile strength ratio of less than

0.80.

XIII-1160 TRIAXIAL STRESSES

The algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) shall not exceed four times the tabulated value of S_m .

XIII-1170 NOZZLE PIPING TRANSITION

The P_m classification of stresses in nozzles resulting from external load or moment is applicable for that length of nozzle which lies within the limits of reinforcement whether or not nozzle reinforcement is required. Beyond the limits of reinforcement, a P_L classification may be applied to the stresses resulting from external load or moment attributable to thermal expansion of the attached piping. However, the pressure and mechanical load induced membrane stresses retain a P_m classification.

XIII-1180 BOLTING

XIII-1181 Bolt and Gasket Requirements

(a) The number and cross-sectional area of bolts required to resist internal pressure shall be determined in accordance with the procedures of Appendix XI. The allowable bolt design stresses, as used in the equations of Appendix XI, shall be the values given in Section II, Part D, Subpart 1, Table 4 for bolting materials. When sealing is effected by a seal weld instead of a gasket, the gasket factor m and the minimum design seating stress y may be taken as zero.

(b) When gaskets are used for preservice testing only, the design is satisfactory if the above requirements are satisfied for $m = y = 0$ and the requirements of XIII-1182 are satisfied when the appropriate m and y are used for the test gasket.

XIII-1182 Allowable Maximum Service Stresses in Bolts

It is recognized that actual service stresses in bolts, such as those produced by the combination of preload, pressure, and differential thermal expansion, may be higher than the values given in Section II, Part D, Subpart 1, Table 4. The maximum of such service stress, averaged across the bolt cross section and neglecting stress concentrations, shall not exceed two times the stress values of Section II, Part D, Subpart 1, Table 4. Except as restricted by XIV-1322(b), the maximum value of such service stress at the periphery of the bolt cross section resulting from direct tension plus bending and neglecting stress concentrations shall not exceed three times the stress values of Section II, Part D, Subpart 1, Table 4. Stress intensity, rather than maximum stress, shall be limited to this value when the bolts are tightened by methods other than heaters, stretchers, or other means which minimize residual torsion.

Page 135

ARTICLE XIII-2000 PRESSURE STRESSES IN OPENINGS FOR FATIGUE EVALUATION

XIII-2100 METHODS OF EVALUATION

XIII-2110 ACCEPTABLE METHODS

For the purpose of detecting peak stresses around the opening, three acceptable methods are listed in (a), (b), and (c) below.

(a) *Analytical Method.* This method uses suitable analytical techniques, such as finite element computer analyses, which provide detailed stress distributions around openings. In addition to peak stresses due to pressure, the effects of other loadings shall be included. The total peak stress at any given point shall be determined by combining stresses due to pressure, thermal, and external loadings in accordance with the rules of para. XIII-1000.

(b) *Experimental Stress Analysis.* This is based on data from experiments (para. XIII-2130).

(c) *Stress Index Method.* This uses various formulas based on data obtained from an extensive series of tests covering a range of variations of applicable dimensional ratios and configurations (para. XIII-2120). This method covers only single, isolated openings. Stress indices may also be determined by theoretical or experimental stress analysis. Such analysis may be included in the Design Report.

XIII-2120 STRESS INDEX METHOD

XIII-2121 Stress Index

The term *stress index*, as used herein, is defined as the numerical ratio of the stress components σ_p , σ_r , and σ_t under consideration to the computed membrane hoop stress in the unpenetrated vessel material. However, the material which increases the thickness of a vessel wall locally at the nozzle shall not be included in the calculations of these stress components. When the thickness of the wall is increased over that required, the values of r_1 and r_2 in Fig. XIII-2124(e)-1 shall be referred to the thickened section.

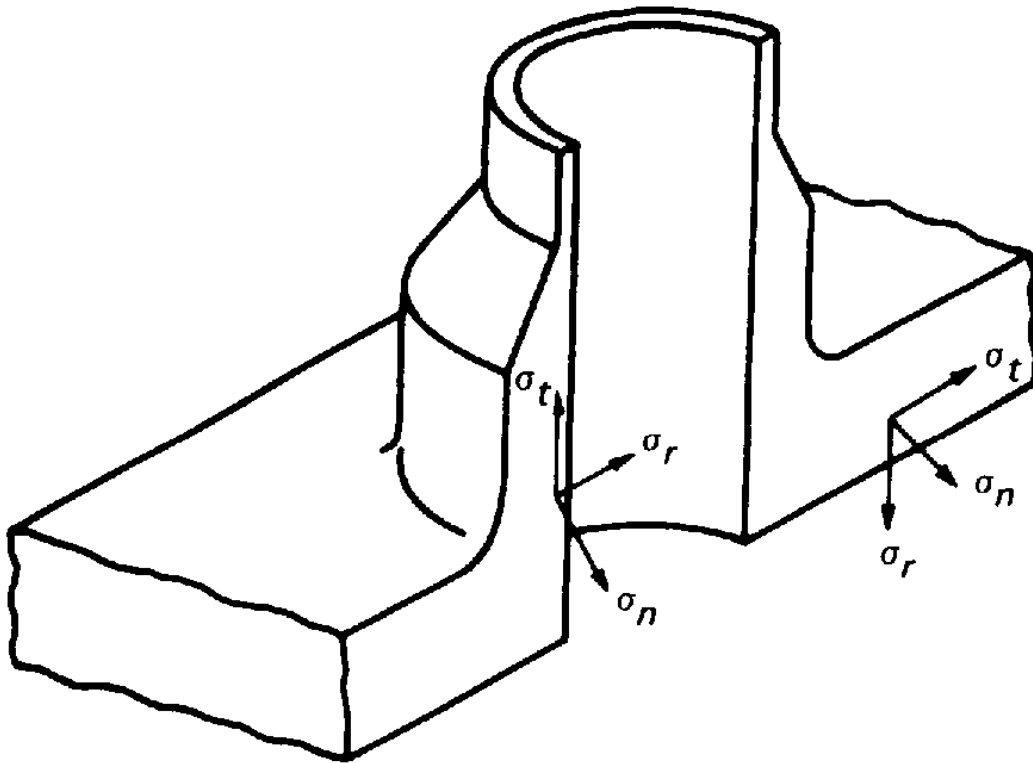


FIG. XIII-2122-1 DIRECTION OF STRESS COMPONENTS

FIG. XIII-2122-1 DIRECTION OF STRESS COMPONENTS

XIII-2122 Nomenclature

The nomenclature for the stress components are shown in Fig. XIII-2122-1 and are defined as follows:

σ_t	= the stress component in the plane of the section under consideration and parallel to the boundary of the section, psi
σ_n	= the stress component normal to the plane of the section, such as the circumferential stress around the hole in the shell, psi
σ_r	= the stress component normal to the boundary of the section, psi
S	= the stress intensity at the point under consideration, psi
R	= inside radius, in corroded condition, of cylindrical vessel, spherical vessel, or spherical head, in.

t	= nominal wall thickness less corrosion allowance, of vessel or head, in.
-----	---

**TABLE XIII-2123-1
NOZZLES IN SPHERICAL SHELLS AND
FORMED HEADS**

Stress	Inside Corner	Outside Corner
σ_n	2.0	2.0
σ_t	-0.2	2.0
σ_r	$-2t/R$	0
S	2.2	2.0

TABLE XIII-2123-1 NOZZLES IN SPHERICAL SHELLS AND FORMED HEADS

**TABLE XIII-2123-2
NOZZLES IN CYLINDRICAL SHELLS**

Stress	Longitudinal Plane		Transverse Plane	
	Inside	Outside	Inside	Outside
σ_n	3.1	1.2	1.0	2.1
σ_t	-0.2	1.0	-0.2	2.6
σ_r	$-t/R$	0	$-t/R$	0
S	3.3	1.2	1.2	2.6

TABLE XIII-2123-2 NOZZLES IN CYLINDRICAL SHELLS

XIII-2123 Stress Indices for Nozzles

When the conditions of XIII-2122 are satisfied, the stress indices given in Tables XIII-2123-1 and XIII-2123-2 may be used for nozzles designed in accordance with the applicable rules of NC-3230 and NC-3259. These stress indices deal only with the maximum stresses, at certain general locations, due to internal pressure. In the evaluation of stresses in or adjacent to vessel openings and connections, it is often necessary to consider the effect of stresses due to external loadings or thermal stresses. In such cases, the total stress at a given point may be determined by superposition. In the case of combined stresses due to internal pressure and nozzle loading, the maximum stresses for a given location shall be considered as acting at the same point and added algebraically unless positive evidence is available to the contrary.

XIII-2124 Limitations of Indices of XIII-2123

The indices of XIII-2123 apply provided the conditions set forth in (a) through (g) below exist.

(a) The opening is for a circular nozzle whose axis is normal to the vessel wall. If the axis of the nozzle makes an angle ϕ with the normal to the vessel wall, an estimate of the σ_n index on the inside may be obtained from one of the following equations, provided $d/D \leq 0.15$.

For hillside connections in spheres or cylinders,

$$K_2 = K_1(1 + 2\sin^2 \phi)$$

For lateral connections in cylinders,

$$K_2 = K_1 [1 + (\tan \phi)^{4/3}]$$

where

K_1 = the σ_n inside stress index of XIII-2123 for a Radial connection

K_2 = the estimated σ_n inside stress index for the nonradial connection

(b) The arc distance measured between the center lines of adjacent nozzles along the inside surface of the shell is not less than three times the sum of their inside radii for openings in a head or along the longitudinal axis of a shell, and is not less than two times the sum of their radii for opening along the circumference of a cylindrical shell. See NC-3231.1(a)(3) when two nozzles are not on a longitudinal or circumferential line.

(c) The following dimensional ratios are met:

Ratio	Cylinder	Sphere
D/t	10 to 100	10 to 100
d/D	0.5 max	0.5 max
$d/\sqrt{Dt}$	-	0.8 max
$d/\sqrt{Dt} \sqrt{r_2/t}$	1.5 max	-

where D is the inside shell diameter, t is the shell thickness, and d is the inside nozzle diameter. In the case of cylindrical shells, the total nozzle reinforcement area on the transverse axis of the connections, including any outside of the reinforcement limits, shall not exceed 200% of that required for the longitudinal axis compared to 50% permitted by Fig. NC-3332.2-1 unless a tapered transition section is incorporated into the reinforcement and the shell, meeting the requirements of NC-3261.

(d) In the case of spherical shells and formed heads, at least 40% of the total nozzle reinforcement area shall be located beyond the outside surface of the minimum required vessel wall thickness.

(e) The inside corner radius r_1 [Fig. XIII-2124(e)-1] is between 10% and 100% of the shell thickness t .

(f) The outer corner radius r_2 [Fig. XIII-2124(e)-1] is large enough to provide a smooth transition between the nozzles and the shell. In addition, for opening diameters in cylindrical shells and 2:1 ellipsoidal heads

Page 137

greater than $1\frac{1}{2}$ shell thicknesses and in spherical shells greater than 3 shell thicknesses, the value of r_2 shall be not less than one-half the thickness of the shell or nozzle wall, whichever is greater.

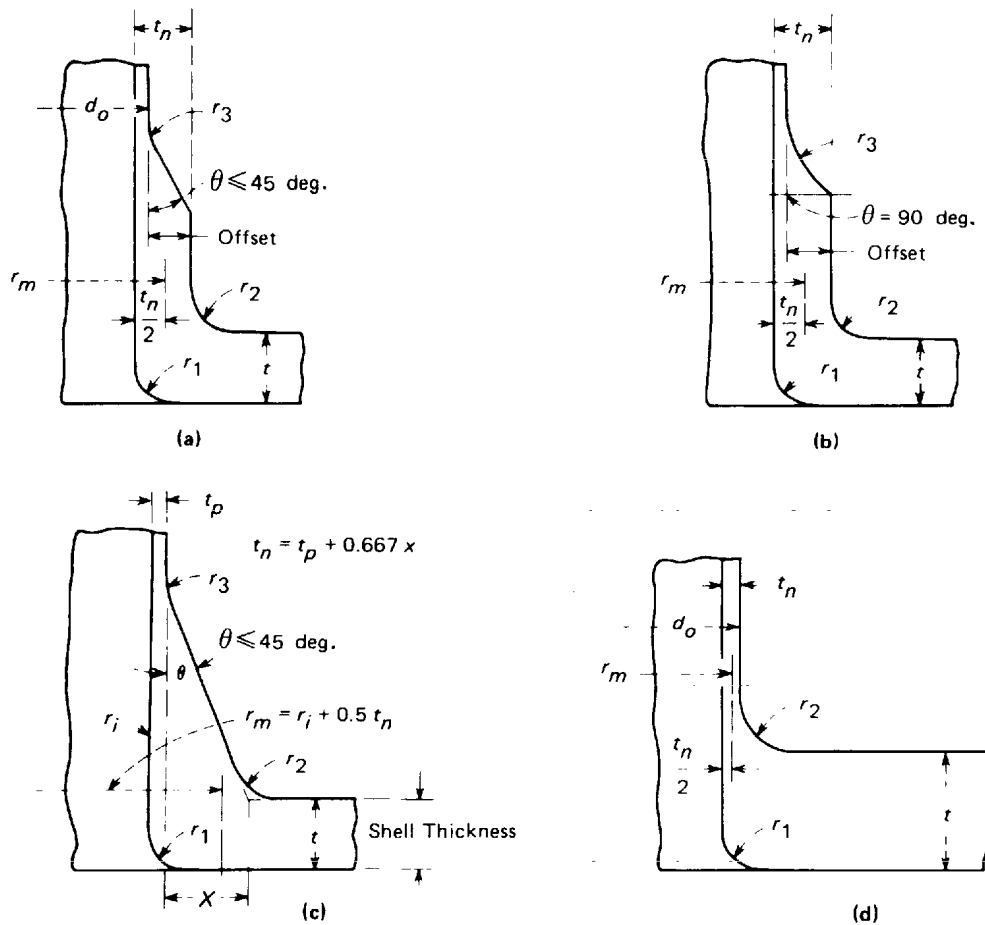


FIG. XIII-2124(e)-1 NOZZLE NOMENCLATURE AND DIMENSIONS

FIG. XIII-2124(e)-1 NOZZLE NOMENCLATURE AND DIMENSIONS

(g) The radius r_3 [Fig. XIII-2124(e)-1] is not less than the greater of (1) or (2) below:

(1) $0.002\theta d_o$ where d_o is the outside diameter of the nozzle and is as shown in Fig. XIII-2124(e)-1 and the angle θ is expressed in degrees;

(2) $2(\sin \theta)^3$ times offset for the configuration shown in Fig. XIII-2124(e)-1 sketches (a) and (b).

XIII-2130 EXPERIMENTAL STRESS ANALYSIS METHOD

XIII-2131 Determination of Stress Intensities

The stress intensities for opening configurations which do not meet the requirements of NC-3230 or of XIII-2124 shall be determined in accordance with methods of Appendix II.

XIII-2132 Evaluation of Data for Similar But Slightly Different Configurations

In accordance with II-1112, reevaluation is not required for configurations for which there are available detailed experimental results that are consistent with the requirements of Appendix II. In order that available experimental data may be interpreted as providing information pertinent to the analysis of slightly different configurations, thereby possibly minimizing the need for additional investigations, the guidelines of (a) through (d) below are presented.

(a) For an unreinforced opening or for an opening where the reinforcement is provided primarily by a uniform increase in vessel wall thickness, the stresses around the opening will increase with increasing d/D

Page 138

ratio of the opening (diameter of nozzle or opening to diameter of shell). Therefore, experimental data for a small d/D ratio cannot be safely applied to a larger d/D ratio but can be applied to a smaller d/D ratio provided the experiments were made at a d/D ratio <0.5 .

(b) For an unreinforced opening or for an opening where the reinforcement is provided primarily by a uniform increase in vessel wall thickness, the stresses around the opening will increase with increasing D/t ratio for thinner shells. Therefore, experimental data for a relatively small D/t ratio cannot be safely applied to a larger D/t ratio but can be applied to a smaller D/t ratio.

(c) Generally speaking, the stress data available in the literature are applicable only to single openings. Such data should be considered valid only for a connection sufficiently removed from another nozzle, opening, flange, or other major discontinuity so that superposition of stresses will not produce an unacceptable value of stress intensity.

(d) Stresses at the outside juncture of a nozzle and shell are greatly influenced by the fillet or transition at the juncture. Generally speaking, stress data available in the literature are for certain specific fillet radii. Other factors being equal, these stress data may be considered valid for fillet radii equal to or greater than used in the test but should not be considered valid for smaller fillet radii or undefined fillets and transitions, such as for a triangular weld fillet, as commonly used.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 MA APP XIV

APPENDIX XIV DESIGN BASED ON FATIGUE ANALYSIS FOR VESSELS DESIGNED IN ACCORDANCE WITH NC-3200

Page 139

ARTICLE XIV-1000 DESIGN BASED ON FATIGUE ANALYSIS

XIV-1100 INTRODUCTION

XIV-1110 SCOPE

This Appendix is applicable only to the fatigue analysis of Class 2 vessels meeting the requirements of NC-3200.

XIV-1200 ANALYSIS FOR CYCLIC SERVICE OF VESSELS

XIV-1210 GENERAL REQUIREMENTS

XIV-1211 Suitability of Vessel for Cyclic Service

The suitability of a vessel component for specified Service Conditions involving cyclic application of loads and thermal conditions shall be determined by the methods described in this Appendix, except that the suitability of high strength bolts shall be determined by the methods of XIV-1300 and the possibility of thermal stress ratchet shall be investigated in accordance with XIV-1400. If the specified service of the vessel meets all of the conditions of NC-3219, no analysis for cyclic service is required and it may be assumed that the limits on peak stress intensities as governed by fatigue have been satisfied by compliance with the applicable requirements for materials, design, fabrication, examination, and testing of Subsection NC

Subsection NC. If the service does not meet all the conditions of NC-3219, a fatigue analysis shall be made in accordance with XIV-1220 or a fatigue test shall be made in accordance with II-1150.

XIV-1212 Allowable Amplitude of Alternating Stresses

The conditions and procedures of NC-3219 and XIV-1220 are based on a comparison of peak stresses with strain cycling fatigue data. The strain cycling fatigue data are represented by the design fatigue strength curves of Figs. I-9.1, I-9.2, and I-9.3.¹ These curves show the allowable amplitude S_a of the alternating stress component (one-half of the alternating stress range) plotted against the number of cycles. The stress amplitude is calculated on the assumption of elastic behavior and hence has the dimensions of stress, but it does not represent a real stress when the elastic range is exceeded. The fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided, so as to make the calculated stress intensity and amplitude and the allowable stress amplitude directly comparable. The curves have been adjusted, where necessary, to include the maximum effects of mean stress, which is the condition where the stress fluctuates about a mean value which is different from zero. As a consequence of this procedure, it is essential that the requirements of XIII-1145 and XIII-1160 be satisfied at all times, with transient stresses included and that the calculated value of the alternating stress intensity be proportional to the actual strain amplitude. To evaluate the effect of alternating stresses of varying amplitudes, a linear damage relation is assumed in XIV-1220.

1 The tests on which the design curves are based did not include tests at temperatures in the creep range or in the presence of unusually corrosive environments, either of which might accelerate fatigue failure. Therefore, these curves are not applicable at service temperatures for which creep is a significant factor. In addition, the designer shall evaluate separately any effects on fatigue life which might result from an unusually corrosive environment.

XIV-1213 Loadings to Be Considered

The loadings to be considered shall include those loads that are due to testing of the vessel when such testing is in addition to that required by NC-6700.

Page 142

XIV-1220 CYCLIC LOADING

XIV-1221 Design for Cyclic Loading

XIV-1221.1 Determination of Vessel's Ability to Withstand Cyclic Loading.

If the specific service of the vessel does not meet the conditions of NC-3219, the ability of the vessel to withstand the specified cyclic service without fatigue failure shall be determined as provided herein. The determination shall be made on the basis of the stresses at a point of the vessel and the allowable stress cycles shall be adequate for the specified service at every point. Only the stresses due to the specified service cycle need be considered; stresses produced by any load or thermal condition which does not vary during the cycle need not be considered, since they are mean stresses and the maximum possible effect of mean stress is included in the fatigue design curves.

XIV-1221.2 Significance of Compliance With Requirements for Cyclic Loading.

Compliance with these requirements means only that the vessel is suitable from the standpoint of possible fatigue failure; complete suitability for the specified service is also dependent on meeting the general stress limits of XIII-1140 and any applicable special stress limits of XIV-1410.

XIV-1221.3 Cyclic Loading Design Procedure

(a) *When Principal Stress Direction Does Not Change.* For any case in which the directions of the principal stresses at the point being considered do not change during the cycle, steps (1), (2), and (3) below shall be followed to determine the alternating stress intensity:

(1) *Principal Stresses.* Consider the values of the three principal stresses at the point versus time for the complete stress cycle, taking into account both the gross and local structural discontinuities and the thermal effects which vary during the cycle. These are designated as σ_1 , σ_2 , and σ_3 for later identification.

(2) *Stress Differences.* Determine the stress differences $S_{12} = \sigma_1 - \sigma_2$, $S_{23} = \sigma_2 - \sigma_3$, and $S_{31} = \sigma_3 - \sigma_1$ versus time for the complete cycle. In what follows, the symbol S_{ij} is used to represent any one of these three stress differences.

(3) *Alternating Stress Intensity.* Determine the extremes of the range through which each stress difference S_{ij} fluctuates, and find the absolute magnitude of this range for each S_{ij} . Call this magnitude S_{rij} and let $S_{altij} = 0.5S_{rij}$. The alternating stress intensity S_{alt} is the largest of the S_{altij} values.

(b) *When Principal Stress Direction Changes.* For any case in which the directions of the principal stresses at the point being considered change during the stress cycle, it is necessary to use steps (1) through (5) below.

(1) Consider the values of the six stress components σ_p , σ_p , σ_p , τ_{lp} , τ_{lp} , and τ_{rp} versus time for the complete stress cycle, taking into account both the gross and local structural discontinuities and the thermal effects which vary during the cycle.

(2) Choose a point in time when the conditions are one of the extremes for the cycle, either maximum or minimum algebraically, and identify the stress components at this time by the subscript i . In most cases it will be possible to choose at least one time during the cycle when the conditions are known to be extreme. In some cases it may be necessary to try different points in time to find the one which results in the largest value of alternating stress intensity.

(3) Subtract each of the six stress components σ_{ip} , σ_{ip} , etc., from the corresponding stress components σ_p , σ_p , etc., at each point in time during the cycle and call the resulting components σ'_p , σ'_p , etc.

(4) At each point in time during the cycle, calculate the principal stresses σ'_1 , σ'_2 , and σ'_3 derived from the six stress components σ'_p , σ'_p , etc. Note that the directions of the principal stresses may change during the cycle but each principal stress retains its identity as it rotates.

(5) Determine the stress differences $'_{12} = \sigma'_1 - \sigma'_2$, $S'_{23} = \sigma'_2 - \sigma'_3$, and $S'_{31} = \sigma'_3 - \sigma'_1$ versus time for the complete cycle and find the largest absolute magnitude of any stress difference at any time. The alternating stress intensity S_{alt} is one-half of this magnitude.

(c) *Design Fatigue Curves.* Figures I-9.1, I-9.2.1, I-9.2.2, I-9.3, I-9.4, and I-9.5 contain the applicable fatigue design curves for some of the materials permitted by Subsection NC. When more than one curve is resented for a given material, the applicability of each curve to materials of various strength levels is identified. Linear interpolation may be used for intermediate strength levels of these materials. As used herein, the strength level is the specified minimum room temperature value.

(d) *Use of Design Fatigue Curve.* Multiply S_{alt} as determined in (a) or (b), by the ratio of the modulus of elasticity given on the design fatigue curve to the value used in the analysis. Enter the applicable design fatigue curve at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the operational cycle being considered is the only one which produces significant fluctuating stresses, this is the allowable number of cycles.

(e) *Cumulative Damage.* If there are two or more types of stress cycles which produce significant stresses,

Page 143

their cumulative effect shall be evaluated as given in (1) through (6) below.

(1) Designate the specified number of times each type of stress cycle of types 1, 2, 3, ..., n will be repeated during the life of the vessel as n_1 , n_2 , n_3 , ..., n_n respectively. In determining n_1 , n_2 , n_3 , ..., n_n consideration shall be given to the superposition of cycles of various origins which produce a total stress difference range greater than the stress difference ranges of the individual cycles. For example, if one type of stress cycle produces 1000 cycles of a stress difference variation from 0 to +60.0 ksi and another type of stress cycle produces 10,000 cycles of a stress difference variation from 0 to -50.0 ksi, the two types of cycle to be considered are defined by the following parameters.

For type 1 cycle,

$$n_1 = 1000$$

$$S_{alt 1} = (60,000 + 50,000)/2 = 55,000 \text{ psi}$$

For type 2 cycle,

$$n_2 = 9000$$

$$S_{alt\ 2} = (50,000 + 0)/2 = 25,000 \text{ psi}$$

(2) For each type of stress cycle determine the alternating stress intensity S_{alt} by the procedures of (a) or (b) above. Call these quantities $S_{alt\ 1}, S_{alt\ 2}, S_{alt\ 3}, \dots, S_{alt\ n}$

(3) For each value $S_{alt\ 1}, S_{alt\ 2}, S_{alt\ 3}, \dots, S_{alt\ n}$ use the applicable design fatigue curve to determine the maximum number of repetitions which would be allowable if this type of cycle were the only one acting. Call these values $N_1, N_2, N_3, \dots, N_n$

(4) For each type of stress cycle, calculate the usage factors $U_1, U_2, U_3, \dots, U_n$ from $U_1 = n_1/N_1, U_2 = n_2/N_2, U_3 = n_3/N_3, \dots, U_n = n_n/N_n$

(5) Calculate the cumulative usage factor U from $U = U_1 + U_2 + U_3 + \dots + U_n$

(6) The cumulative usage factor U shall not exceed 1.0.

XIV-1222 Local Structural Discontinuities

These effects shall be evaluated for all conditions using stress concentration factors determined from theoretical, experimental, or photoelastic studies, or numerical stress analysis techniques. Experimentally determined fatigue strength reduction factors may be used when determined in accordance with the procedures of II-1600, except for high strength alloy steel bolting for which the requirements of NB-3232.2(c) shall apply when using the design fatigue curve of Fig. I-9.4. Except for the case of crack-like defects, no fatigue strength factor greater than five need be used.

XIV-1223 Fillet Welds

Fillet welds shall not be used in vessels for joints of Categories A, B, C, or D (Fig. NC-3251-1) except as permitted for joints of Category C for slip on flanges (NC-3252.3 and NC-3262.2) and for the joints of Category D as permitted in NC-3259. Fillet welds may be used for attachment to pressure vessels using one-half the stress limits of XIII-1142 through XIII-1145 for primary and secondary stresses. Evaluation for cyclic loading shall be made in accordance with Appendix XIV using a fatigue strength reduction factor of four and shall include consideration of temperature differences between the vessel and the attachment and expansion or contraction of the vessel produced by internal or external pressure.

XIV-1300 ANALYSIS FOR CYCLIC SERVICE OF BOLTS

XIV-1310 GENERAL REQUIREMENTS

XIV-1311 Suitability of Bolts for Cyclic Service

Unless the vessel on which they are installed meets all the conditions of NC-3219 and thus requires no fatigue analysis, the suitability of bolts for cyclic service shall be determined in accordance with the procedures of XIV-1320.

XIV-1320 EVALUATION OF BOLTS DEPENDENT ON THEIR MATERIAL PROPERTIES

XIV-1321 Bolts With Tensile Strengths Less Than 100 ksi (689 MPa)

Bolts made of materials which have minimum specified tensile strengths of less than 100.0 ksi (689 MPa) shall be evaluated for cyclic operation by the methods of XIV-1220, using the applicable design fatigue curve, Fig. I-9.1 or Fig. I-9.2 and an appropriate stress concentration factor (XIV-1324).

Page 144

XIV-1322 High Strength Bolts

High strength alloy steel bolts and studs may be evaluated for cyclic operation by the methods of XIV-1220, using the design fatigue curve of Fig. I-9.4, provided the requirements of (a) through (e) below are met.

(a) The material is one of the following: SA-193 Grade B-7 or B-16; SA-320 Grade L-43; SA-540 Grades B-23 and

B-24, heat treated in accordance with SA-540, Section 5.

(b) The maximum value of the service stress at the periphery of the bolt cross section resulting from direct tension plus bending and neglecting stress concentrations shall not exceed $2.7S_m$, if the higher of the two fatigue design curves given in Fig. I-9.4 is used. The $2.0S_m$ limit for direct tension is unchanged.

(c) Threads shall be of a Vee type, having a minimum thread root radius no smaller than 0.003 in. (0.076 mm).

(d) Fillet radii at the end of the shank shall be such that the ratio of fillet radius to shank diameter is not less than 0.060.

(e) The fatigue strength reduction factor used in the fatigue evaluation shall not be less than 4.0.

XIV-1323 Acceptability for Cyclic Service

The bolts shall be acceptable for the specific cyclic application of loads and thermal stresses provided the cumulative usage factor U , as determined in XIV-1221.3(e), does not exceed 1.0.

XIV-1324 Fatigue Strength Reduction Factor for Threads

Unless it can be shown by analysis or test that a lower value is appropriate, the fatigue strength reduction factor used in the fatigue evaluation of threaded members shall not be less than 4.0.

XIV-1400 ANALYSIS FOR THERMAL STRESS RATCHET

XIV-1410 THERMAL STRESS RATCHET IN SHELL

Under certain combinations of steady state and cyclic loadings there is a possibility of large distortions developing as the result of ratchet action, that is, the deformation increases by a nearly equal amount for each cycle. Examples of this phenomenon are treated in XIV-1410 and in XIV-1420.

(a) The limiting value of the maximum cyclic thermal stress permitted in a shell loaded by steady state internal pressure in order to prevent cyclic growth in diameter is as follows. Let

y' = maximum allowable thermal stress, computed on an elastic basis, divided by the yield strength² S_y

x = maximum general membrane stress due to pressure divided by the yield strength² S_y

Case 1: Linear variation of temperature through the shell wall

$$y' = 1/x \text{ for } 0 < x < 0.5$$

$$y' = 4(1 - x) \text{ for } 0.5 < x < 1.0$$

Case 2: Parabolic constantly increasing or constantly decreasing variation of temperature through the shell wall

$$y' = 5.2(1 - x) \text{ for } 0.615 < x < 1.0$$

and approximately, for $x < 0.615$, $y' = 4.65$, 3.55, and 2.70 for $x = 0.3$, 0.4, and 0.5, respectively.

(b) Use of the yield strength S_y in the above relations instead of the proportional limit allows a small amount of growth during each cycle until strain hardening raises the proportional limit to S_y . If the yield strength of the material is higher than the endurance limit³ for the material, the latter value shall be used, if there are to be a large number of cycles, because strain softening may occur.

² It is permissible to use $1.5S_m$ whenever it is greater than S_y .

³ The endurance limit shall be taken as two times the S_a value at 10^6 cycles in the applicable fatigue curve of Fig. I-9.1 or Fig. I-9.2.

XIV-1420 PROGRESSIVE DISTORTION OF NONINTEGRAL CONNECTIONS

Screwed on caps, screwed in plugs, shear ring closures, and breech lock closures are examples of nonintegral connections

Screwed on caps, screwed in plugs, shear ring closures, and breech lock closures are examples of nonintegral connections which are subject to failure by bell mouthing or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can

Page 145

eventually lose engagement. Therefore, primary plus secondary stress intensities (XIII-1145) which result in slippage between the parts of a nonintegral connection in which disengagement could occur as a result of progressive distortion shall be limited to the allowable stress limits given in XIII-1142 and XIII-1143.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 MA APP XVIII

APPENDIX XVIII CAPACITY CONVERSIONS FOR PRESSURE RELIEF VALVES

Page 147

ARTICLE XVIII-1000 CAPACITY CONVERSIONS FOR PRESSURE RELIEF VALVES

XVIII-1100 PROCEDURE FOR CONVERSION

XVIII-1110 EQUATIONS FOR CONVERSION (COMPRESSIBLE FLUIDS)

The capacity of a relief valve in terms of a gas or vapor other than the medium for which the valve was officially rated shall be determined by application of the following equations:¹

For dry saturated steam:

pressures up to 1500 psig

$$(1) W_s = 51.5KA P$$

1 Knowing the rated capacity of a pressure relief valve which is stamped on the valve, it is possible to determine the overall value of KA in either of the following equations in cases where the value of these individual terms is not known:

Rated Steam Capacity

For pressure up to 1500 psig

$$KA = W_s / 51.5P$$

For pressure over 1500 psig to 3200 psig

$$KA = \frac{W_s}{51.5P \left(\frac{0.1906P - 1000}{0.2292P - 1061} \right)}$$

Rated Air Capacity

$$KA = (W_s/CP) \sqrt{MT}$$

This value for KA is then substituted in the above equation to determine the capacity of the safety valve in term of the new gas or vapor.

Pressures over 1500 psig and up to 3200 psig, the value of W_s , calculated by the above equation, shall be multiplied by the following factors.

$$\frac{0.1906P - 1000}{0.2232P - 1061}$$

For superheated steam:

For superheated steam the value of W_s shall be multiplied by the appropriate superheat correction factor, K_{sh} , of Table XVIII-1110-1.

For wet saturated steam:

For wet saturated steam with a quality (dryness fraction) of 0.90 or greater, the value of W shall be corrected by dividing

by the quality of the steam used for testing.

For air:

$$(2) W_a = CKAP \sqrt{M/T}$$

where

C	= 356
M	= 28.97 mol. wt.
T	= 520 when W_a is the rated capacity

² Rated capacity (lb/hr air @ 60°F @ 14.7 psia)/0.0766 = rated capacity (scfm air).

For any gas or vapor (other than steam):

$$(3) W = CKAP \sqrt{M/T}$$

where

W_s	= rated capacity, lb/hr of steam
W_a	= rated capacity, ² converted to lb/hr of air at 60°F inlet temperature
W	= flow of any gas or vapor, lb/hr
C	= constant for gas or vapor which is a function of the ratio of specific heats, $k = c_p/c_v$ (Fig. XVIII-1110-1)

K	= coefficient of discharge
A	= actual discharge area of the pressure relief valve, sq in.
P	= (set pressure + overpressure) plus atmospheric pressure, psia
M	= molecular weight
T	= absolute temperature at inlet (°F plus 460)
Z	= ratio of deviation of the actual gas from a perfect gas, a ratio evaluated at inlet conditions

TABLE XVIII-1110-1
SUPERHEAT CORRECTION FACTOR K_{sh}

Flowing Pressure (psia)	Superheat Correction Factor K_{sh} Total Temperature, °F, of Superheated Steam																
	400	450	500	550	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200
50	0.987	0.957	0.930	0.905	0.882	0.861	0.841	0.823	0.805	0.789	0.774	0.759	0.745	0.732	0.719	0.708	0.696
100	0.998	0.963	0.935	0.909	0.885	0.864	0.843	0.825	0.807	0.790	0.775	0.760	0.746	0.733	0.720	0.708	0.697
150	0.984	0.970	0.940	0.913	0.888	0.866	0.846	0.826	0.808	0.792	0.776	0.761	0.747	0.733	0.721	0.709	0.697
200	0.979	0.977	0.945	0.917	0.892	0.869	0.848	0.828	0.810	0.793	0.777	0.762	0.748	0.734	0.721	0.709	0.698
250	...	0.972	0.951	0.921	0.895	0.871	0.850	0.830	0.812	0.794	0.778	0.763	0.749	0.735	0.722	0.710	0.698
300	...	0.968	0.957	0.926	0.898	0.874	0.852	0.832	0.813	0.796	0.780	0.764	0.750	0.736	0.723	0.710	0.699
350	...	0.968	0.963	0.930	0.902	0.877	0.854	0.834	0.815	0.797	0.781	0.765	0.750	0.736	0.723	0.711	0.699
400	...	...	0.963	0.935	0.906	0.880	0.857	0.836	0.816	0.798	0.782	0.766	0.751	0.737	0.724	0.712	0.700
450	...	...	0.961	0.940	0.909	0.883	0.859	0.838	0.818	0.800	0.783	0.767	0.752	0.738	0.725	0.712	0.700
500	...	...	0.961	0.946	0.914	0.886	0.862	0.840	0.820	0.801	0.784	0.768	0.753	0.739	0.725	0.713	0.701
550	...	...	0.962	0.952	0.918	0.889	0.864	0.842	0.822	0.803	0.785	0.769	0.754	0.740	0.726	0.713	0.701
600	...	...	0.964	0.958	0.922	0.892	0.867	0.844	0.823	0.804	0.787	0.770	0.755	0.740	0.727	0.714	0.702
650	...	...	0.968	0.958	0.927	0.896	0.869	0.846	0.825	0.806	0.788	0.771	0.756	0.741	0.728	0.715	0.702
700	...	...	...	0.958	0.931	0.899	0.872	0.848	0.827	0.807	0.789	0.772	0.757	0.742	0.728	0.715	0.703
750	...	...	...	0.958	0.936	0.903	0.875	0.850	0.828	0.809	0.790	0.774	0.758	0.743	0.729	0.716	0.703
800	...	...	...	0.960	0.942	0.906	0.878	0.852	0.830	0.810	0.792	0.774	0.759	0.744	0.730	0.716	0.704
850	...	...	...	0.962	0.947	0.910	0.880	0.855	0.832	0.812	0.793	0.776	0.760	0.744	0.730	0.717	0.704
900	...	...	...	0.965	0.953	0.914	0.883	0.857	0.834	0.813	0.794	0.777	0.760	0.745	0.731	0.718	0.705
950	...	...	...	0.969	0.958	0.918	0.886	0.860	0.836	0.815	0.796	0.778	0.761	0.746	0.732	0.718	0.705
1000	...	...	...	0.974	0.959	0.923	0.890	0.862	0.838	0.816	0.797	0.779	0.762	0.747	0.732	0.719	0.706
1050	...	...	...	...	0.960	0.927	0.893	0.864	0.840	0.818	0.798	0.780	0.763	0.748	0.733	0.719	0.707
1100	...	...	...	...	0.962	0.931	0.896	0.867	0.842	0.820	0.800	0.781	0.764	0.749	0.734	0.720	0.707
1150	...	...	...	...	0.964	0.936	0.899	0.870	0.844	0.821	0.801	0.782	0.765	0.749	0.735	0.721	0.708
1200	...	...	...	...	0.966	0.941	0.903	0.872	0.846	0.823	0.802	0.784	0.766	0.750	0.735	0.721	0.708
1250	...	...	...	...	0.969	0.946	0.906	0.875	0.848	0.825	0.804	0.785	0.767	0.751	0.736	0.722	0.709
1300	...	...	...	...	0.973	0.952	0.910	0.878	0.850	0.826	0.805	0.786	0.768	0.752	0.737	0.723	0.709
1350	...	...	...	...	0.977	0.958	0.914	0.880	0.852	0.828	0.807	0.787	0.769	0.753	0.737	0.723	0.710
1400	...	...	...	...	0.982	0.963	0.918	0.883	0.854	0.830	0.808	0.788	0.770	0.754	0.738	0.724	0.710
1450	...	...	...	...	0.987	0.968	0.922	0.886	0.857	0.832	0.809	0.790	0.771	0.754	0.739	0.724	0.711
1500	...	...	...	...	0.993	0.970	0.926	0.889	0.859	0.833	0.811	0.791	0.772	0.755	0.740	0.725	0.711
1550	...	...	...	...	...	0.972	0.930	0.892	0.861	0.835	0.812	0.792	0.773	0.756	0.740	0.726	0.712
1600	...	...	...	...	...	0.973	0.934	0.894	0.863	0.836	0.813	0.792	0.774	0.756	0.740	0.726	0.712
1650	...	...	...	...	...	0.973	0.936	0.895	0.863	0.836	0.812	0.791	0.772	0.755	0.739	0.724	0.710
1700	...	...	...	...	...	0.973	0.938	0.895	0.863	0.835	0.811	0.790	0.771	0.754	0.738	0.723	0.709
1750	...	...	...	...	...	0.974	0.940	0.896	0.862	0.835	0.810	0.789	0.770	0.752	0.736	0.721	0.707
1800	...	...	...	...	...	0.975	0.942	0.897	0.862	0.834	0.810	0.788	0.768	0.751	0.735	0.720	0.705
1850	...	...	...	...	...	0.976	0.944	0.897	0.862	0.833	0.809	0.787	0.767	0.749	0.733	0.718	0.704
1900	...	...	...	...	...	0.977	0.946	0.898	0.862	0.832	0.807	0.785	0.766	0.748	0.731	0.716	0.702
1950	...	...	...	...	...	0.979	0.949	0.898	0.861	0.832	0.806	0.784	0.764	0.746	0.729	0.714	0.700
2000	...	...	...	...	...	0.982	0.952	0.899	0.861	0.831	0.805	0.782	0.762	0.744	0.728	0.712	0.698
2050	...	...	...	...	...	0.985	0.954	0.899	0.860	0.830	0.804	0.781	0.761	0.742	0.726	0.710	0.696
2100	...	...	...	...	...	0.988	0.956	0.900	0.860	0.828	0.802	0.779	0.759	0.740	0.724	0.708	0.694
2150	...	...	...	...	...	...	0.956	0.900	0.859	0.827	0.801	0.778	0.757	0.738	0.722	0.706	0.692
2200	...	...	...	...	...	...	0.955	0.901	0.859	0.826	0.799	0.776	0.755	0.736	0.720	0.704	0.690
2250	...	...	...	...	...	...	0.954	0.901	0.858	0.825	0.797	0.774	0.753	0.734	0.717	0.702	0.687
2300	...	...	...	...	...	...	0.953	0.901	0.857	0.823	0.795	0.772	0.751	0.732	0.715	0.699	0.685
2350	...	...	...	...	...	...	0.952	0.902	0.856	0.822	0.794	0.769	0.748	0.729	0.712	0.697	0.682
2400	...	...	...	...	...	...	0.952	0.902	0.855	0.820	0.791	0.767	0.746	0.727	0.710	0.694	0.679
2450	...	...	...	...	...	...	0.951	0.902	0.854	0.818	0.789	0.765	0.743	0.724	0.707	0.691	0.677
2500	...	...	...	...	...	...	0.951	0.902	0.852	0.816	0.787	0.762	0.740	0.721	0.704	0.688	0.674
2550	...	...	...	...	...	...	0.951	0.902	0.851	0.814	0.784	0.759	0.738	0.718	0.701	0.685	0.671
2600	...	...	...	...	...	...	0.951	0.903	0.849	0.812	0.782	0.756	0.735	0.715	0.698	0.682	0.664
2650	...	...	...	...	...	...	0.952	0.903	0.848	0.809	0.779	0.754	0.731	0.712	0.695	0.679	0.664
2700	...	...	...	...	...	...	0.952	0.903	0.846	0.807	0.776	0.750	0.728	0.708	0.691	0.675	0.661
2750	...	...	...	...	...	...	0.953	0.903	0.844	0.804	0.773	0.747	0.724	0.705	0.687	0.671	0.657
2800	...	...	...	...	...	...	0.956	0.903	0.842	0.801	0.769	0.743	0.721	0.701	0.684	0.668	0.653
2850	...	...	...	...	...	...	0.959	0.902	0.839	0.798	0.766	0.739	0.717	0.697	0.679	0.663	0.649
2900	...	...	...	...	...	...	0.963	0.902	0.836	0.794	0.762	0.735	0.713	0.693	0.675	0.659	0.645
2950	...	...	...	...	...	...	...	0.902	0.834	0.790	0.758	0.731	0.708	0.688	0.671	0.655	0.640
3000	...	...	...	...	...	...	...	0.901	0.831	0.786	0.753	0.726	0.704	0.684	0.666	0.650	0.635
3050	...	...	...	...	...	...	...	0.899	0.827	0.782	0.749	0.722	0.699	0.679	0.661	0.645	0.630
3100	...	...	...	...	...	...	...	0.896	0.823	0.777	0.744	0.716	0.693	0.673	0.656	0.640	0.625
3150	...	...	...	...	...	...	...	0.894	0.819	0.772	0.738	0.711	0.688	0.668	0.650	0.634	0.620
3200	...	...	...	...	...	...	...	0.889	0.815	0.767	0.733	0.705	0.682	0.662	0.644	0.628	0.614

TABLE XVIII-1110-1 SUPERHEAT CORRECTION FACTOR K_{sh}

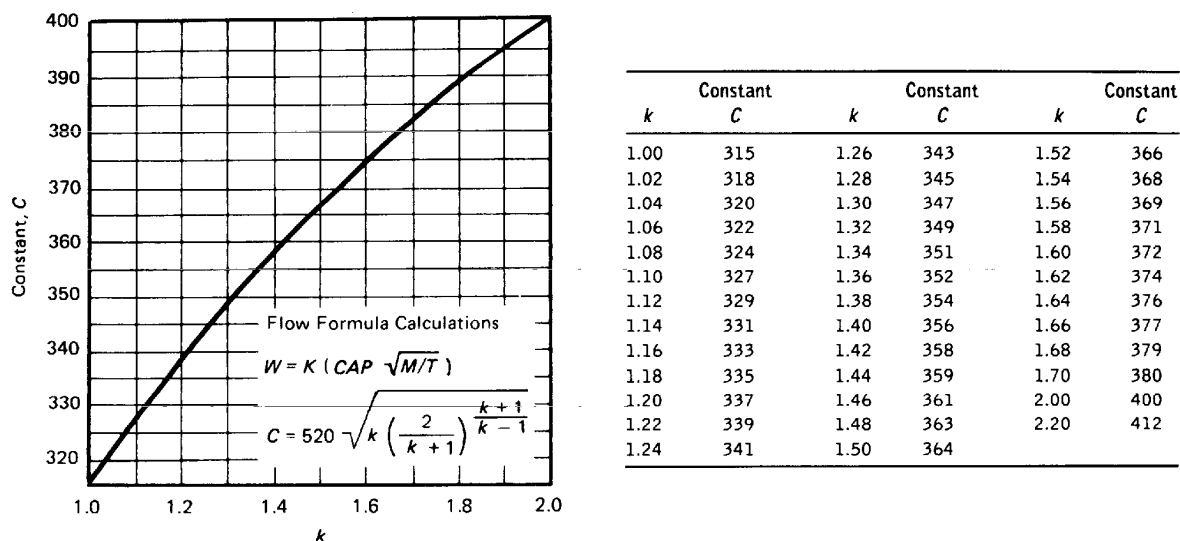


FIG. XVIII-1110-1 CONSTANT C FOR GAS OR VAPOR RELATED TO RATIO OF SPECIFIC HEATS ($k = c_p/c_v$)

FIG. XVIII-1110-1 CONSTANT C FOR GAS OR VAPOR RELATED TO RATIO OF SPECIFIC HEATS ($k = c_p/c_v$)

These equations shall also be used when the required flow of any gas or vapor is known and it is necessary to compute the rated capacity of steam or air.

(a) Molecular weight of some of the common gases and vapors are given in Table XVIII-1110(a)-1.

(b) In the case of hydrocarbons, the compressibility factor Z shall be included in the equation for gases and vapors as follows:

$$(4) W = CKAP \sqrt{M/ZT}$$

**TABLE XVIII-1110(a)-1
MOLECULAR WEIGHTS OF GASES AND VAPORS**

Gas or Vapor	Molecular Weight	Gas or Vapor	Molecular Weight
Air	28.97	Freon 22	86.48
Acetylene	26.04	Freon 114	170.90
Ammonia	17.03	Hydrogen	2.02
Butane	58.12	Hydrogen sulfide	34.08
Carbon dioxide	44.01	Methane	16.04
Chlorine	70.91	Methyl chloride	50.48
Ethane	30.07	Nitrogen	28.02
Ethylene	28.05	Oxygen	32.00
Freon 11	137.371	Propane	44.09
Freon 12	120.9	Sulfur dioxide	64.06

TABLE XVIII-1110(a)-1 MOLECULAR WEIGHTS OF GASES AND VAPOR

XVIII-1120 EXAMPLES

Example 1

Given: A pressure relief valve bears a rated capacity of 3020 lb/hr of saturated steam for a pressure setting of 200 psi.

Problem: What is the relieving capacity of that valve in terms of air at 100°F for the same pressure setting?

Page 152

Solution:

For steam:

$$W_s = 51.5KAP$$

$$3020 = 51.5KAP$$

$$KAP = 3020/51.5 = 58.6$$

For air:

$$\begin{aligned}
 W_a &= CKAP \sqrt{\frac{M}{T}} \\
 &= 356 KAP \sqrt{\frac{28.97}{460 + 100}} \\
 &= (356)(58.6) \sqrt{\frac{28.97}{560}} \\
 &= 4745 \text{ lb/hr}
 \end{aligned}$$

Example 2

Given: It is required to relieve 5000 lb/hr of propane from a pressure vessel through a pressure relief valve set to relieve at a pressure of P_s psi, and with an inlet temperature of 125°F.

Problem: What total capacity in lb/hr of steam in pressure relief valves must be furnished?

Solution:

For propane:

$$W = CKAP \sqrt{\frac{M}{T}}$$

Value of C is not definitely known. Use the conservative value, $C = 315$:

$$5000 = 315 KAP \sqrt{\frac{44.09}{460 + 125}}$$

$$KAP = 57.7$$

For steam:

W_s

$$= 51.5 KAP$$

$$= (51.5)(57.7)$$

$$= 2970 \text{ lb/hr set to relieve at } P_s, \text{ psi}$$

Example 3

Given: It is required to relieve 1000 lb/hr of ammonia from a pressure vessel at 150°F.

Problem: What is the required total capacity in lb/hr of steam at the same pressure setting?

Solution:

For ammonia:

$$W = CKAP\sqrt{M/T}$$

Manufacturer and Owner agree to use $k = 1.33$. From Fig. XVIII-1110-1, $C = 350$:

$$1000 = 350 KAP \sqrt{\frac{17.03}{460 + 150}}$$

$$KAP = 17.10$$

For steam:

$$\begin{aligned} W_s &= 51.5 KAP \\ &= (51.5)(17.10) \\ &= 880 \text{ lb/hr} \end{aligned}$$

Example 4

Given: A safety valve having a certified rating of 8000 lb/hr of steam for a pressure setting of 2000 psi.

Problem: Find the relieving capacity under the following conditions:

- (a) Steam quality (dryness fraction) of 0.93
- (b) Superheat of 100°F (total temperature of 737°F)

Solution:

The wet saturated capacity:

$$W = \frac{W_s}{0.93} = \frac{8000}{0.93}$$

$$= 8600 \text{ lb/hr}$$

The superheat capacity:

$$W = K_{sh} W_s = (0.9152)(8000)$$

$$= 7320 \text{ lb/hr}$$

NOTE: K_{sh} interpolated from Table XVIII-1110-1 for flowing conditions.

XVIII-1130 THEORETICAL FLOW

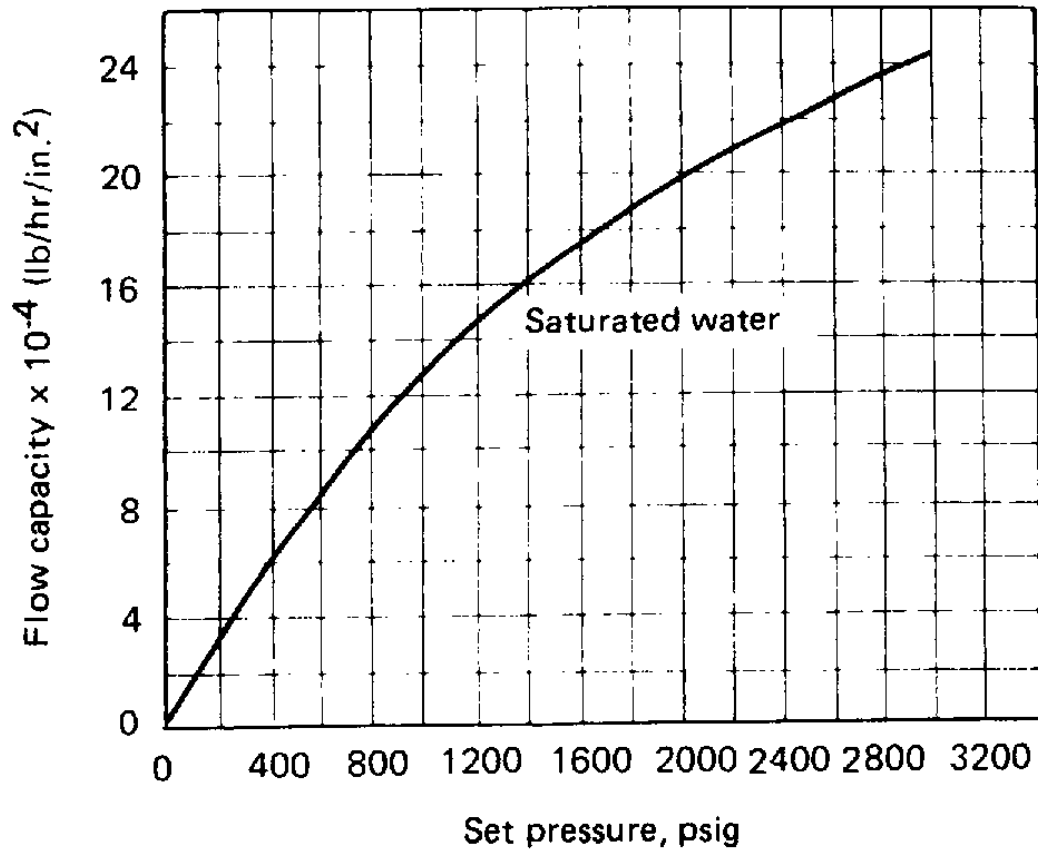
The theoretical flow for use in the establishment of the coefficient of discharge shall be calculated using Eqs. (1) through (4) of XVIII-1110 with K being deleted.

XVIII-1140 SATURATED WATER CAPACITY

(a) Because the saturated water capacity is configuration sensitive, the following applies only to those safety valves that have a nozzle type construction (throat to inlet diameter ratio of 0.25 to 0.80 with a continuously contoured change and have exhibited a coefficient K_D in excess of 0.90). No saturated water rating shall apply to other types of construction.

NOTE: The manufacturer, user, and Inspector are all cautioned that for the following rating to apply, the valve shall be continuously subjected to saturated water. If, after initial relief, the flow medium changes to quality steam, the valve shall be rated as per saturated steam. Valves installed on vessels or lines containing steam-water mixture shall be rated on saturated steam.

(b) To determine the saturated water capacity of a valve currently rated and meeting the requirements of (a) above, refer to Fig. XVIII-1140-1. Enter the graph at the set pressure of the valve, move upward to the saturated water line, and read horizontally the relieving capacity. This capacity is the theoretical, isentropic value arrived at by assuming equilibrium flow and calculated values for the critical pressure ratio.



**FIG. XVIII-1140-1 FLOW CAPACITY CURVE FOR
RATING NOZZLE TYPE SAFETY VALVES ON
SATURATED WATER (BASED ON 10%
OVERPRESSURE)**

FIG. XVIII-1140-1 FLOW CAPACITY CURVE FOR RATING NOZZLE TYPE SAFETY VALVES ON SATURATED WATER (BASED ON 10% OVERPRESSURE)

³ This conversion is not valid for liquid flashing valve operating conditions.

⁴ Knowing the rated capacity of pressure relief valve stamped with a liquid capacity, it is possible to determine the overall value of KA in the following equation where the value of the individual terms is not known:

$$KA = \frac{W_w \times 500}{2407 \sqrt{(P - 14.7)(62.3)}}$$

XVIII-1150 EQUATIONS FOR CONVERSION (INCOMPRESSIBLE FLUIDS)³

The capacity of a pressure relief valve in terms of a liquid other than the medium for which the valve was officially rated shall be determined by application of the following equation:⁴

$$W_l = 38 KA \sqrt{\frac{(P - P_d)}{G}}$$

where

W_l	= rated capacity, gpm of any liquid
W_w	= rated capacity, gpm water @ 70°F

Page 154

K	= coefficient of discharge
A	= actual discharge area of valve, sq in.
P	= (set pressure $\times$ 1.10) plus atmospheric pressure, psia
P_d	= pressure at discharge from valve, psia

G

= specific gravity of liquid⁵ ($G = 1$ for water)

XVIII-1160 EXAMPLE

Given: Pressure relief valve bearing a certified rating of 1500 gpm water @ 70°F with a set pressure of 120 psig.

⁵ Rated capacity (gpm water @ 70°F) = rated capacity (lb/hr water @ 70°F) × 1/500.

Problem: Find the flow capacity of this pressure relief valve in gpm of kerosene ($G = 0.82$) at the same pressure rating.

Solution:

For water at 70°F:

$$KA = \frac{W_w \times 500}{2407 \sqrt{(p - 14.7)(62.3)}}$$

$$KA = \frac{1500 \times 500}{2407 \sqrt{(146.7 - 14.7)(62.3)}} = 3.436$$

For kerosene:

$$W_l = 38 (3.436) \sqrt{\frac{(146.7 - 14.7)}{0.82}}$$

$$W_l = 1656.60 \text{ gpm}$$

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 MA APP XIX

APPENDIX XIX INTEGRAL FLAT HEAD WITH A LARGE OPENING

Page 155

ARTICLE XIX-1000 INTEGRAL FLAT HEAD WITH A LARGE OPENING

XIX-1100 GENERAL REQUIREMENTS

XIX-1110 SCOPE

(a) Rules of this Appendix apply to flat heads which have a single, circular, centrally located opening that exceeds one-half of the head diameter and have a shell/head juncture which is integrally formed or integrally attached with a full penetration weld similar to those shown in Fig. XIX-1110-1. Heads of this type shall be designed according to the rules which follow and related parts of Appendix XI.

(b) A general arrangement of an integral flat head with and without a nozzle attached at the central opening is shown in Fig. XIX-1110-2.

XIX-1120 NOMENCLATURE

(a) Except as given below, the symbols used in the equations of XIX-1200 are defined in XI-3130:

P	= internal design pressure, psi
A	= outside diameter of flat head and shell, in.
B_s	= inside diameter of shell (measured below tapered hub if one exists), in.
B_n	= diameter of central opening (for nozzle, this is inside diameter and for opening without a nozzle, diameter of the opening), in.
t	= flat head nominal thickness, in.
M_H	= moment acting at shell/head junction, in.-lb

B_p, g_p, g_r, h_p, F, V , and f are defined in XI-3130. These terms may refer to either the shell/flat head juncture or to the flat head/central opening juncture and depend upon details of those junctures.

XIX-1200 DESIGN PROCEDURE

(a) Disregard the shell attached to the outside diameter of the flat head and then analyze the flat head with a central opening (with or without nozzle) in accordance with these rules.

(1) Calculate the operating moment, M_p , according to XI-3230 (there is no M_0 for gasket seating to be considered). The formulas in Appendix XI for loads (XI-3130) and moment arms (Table XI-3230-1) shall be used directly with the following designations and terms substituted for terms in Appendix XI. Let

C	= G = inside diameter of shell B_s , in.
B	= B_n , in., where B_n is as shown in Fig. XIX-1110-2 depending on the presence of an integral nozzle or opening without a nozzle

(2) With $K = A/B_n$, use XI-3240 to calculate stresses. Designate the calculated stresses S_H^* , S_R^* , and S_T^* .

(b) Calculate $(E\theta)^*$ as follows:

(1) for integrally attached nozzle:

$$(E\theta)^* = \frac{0.91(g_1/g_0)^2 B_1 V}{fh_0} S_H^*$$

(2) for an opening without a nozzle:

$$(E\theta)^* = (B_n/t)S_T^*$$

where g_0, g_1, B_1, V, f, h_0 and B_n all pertain to the flat head/opening as described in XIX-1200(a).

(c) Calculate $(E\theta)^*/M_0$

(d) Calculate M_H :

$$M_H = \frac{(E\theta)^*}{\frac{1.74 h_0 V}{g_0^3 B_1} + \frac{(E\theta)^*}{M_0} (1 + Ft/h_0)}$$

where h_0, V, g_0, B_1 , and F refer to the shell attached to the outside diameter of the flat head.

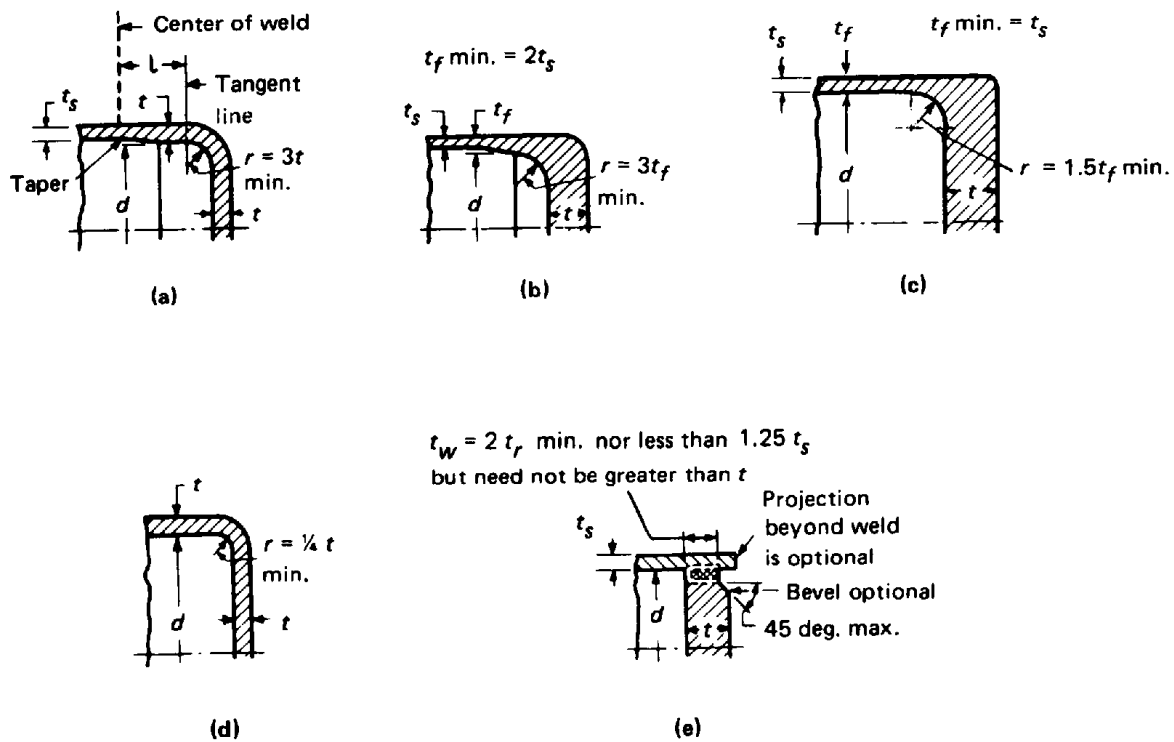


FIG. XIX-1110-1 APPLICABLE CONFIGURATIONS OF FLAT HEADS

FIG. XIX-1110-1 APPLICABLE CONFIGURATIONS OF FLAT HEADS

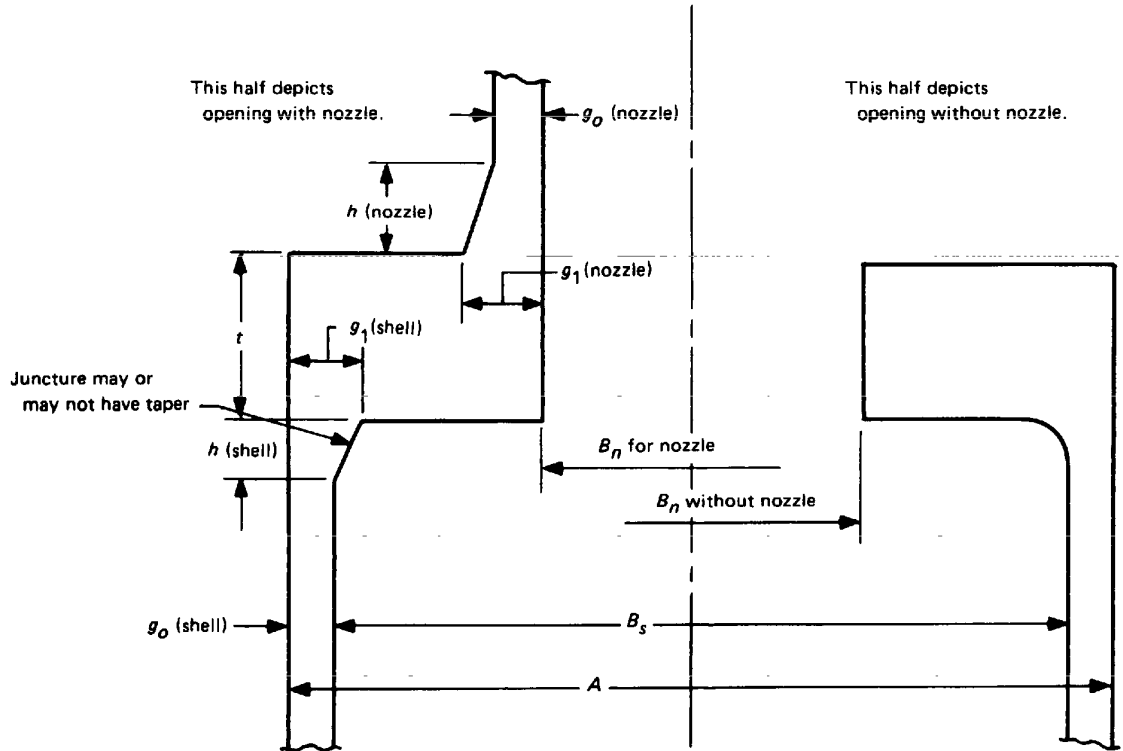


FIG. XIX-1110-2 INTEGRAL FLAT HEAD WITH LARGE CENTRAL OPENING

FIG. XIX-1110-2 INTEGRAL FLAT HEAD WITH LARGE CENTRAL OPENING

(e) Calculate X_1 :

$$X_1 = \frac{M_0 - M_H (1 + Ft/h_0)}{M_0}$$

where F and h_0 refer to the shell.

(f) Calculate stresses at head/shell juncture as follows.

(1) For longitudinal hub stress in shell:

$$S_{HS} = (X_1)(E\theta) * \frac{1.10 h_0 f}{(g_1 / g_0)^2 B_s V}$$

where h_0, f, g_0, g_1, B_s , and V refer to the shell.

(2) For radial stress at outside diameter:

$$S_{RS} = \frac{1.91 M_H (1 + Ft/h_0)}{B_s t^2} + \frac{0.64 F M_H}{B_s h_0 t}$$

where B_s, F , and h_0 refer to the shell.

(3) For tangential stress at outside diameter:

$$S_{TS} = \frac{(X_1)(E\theta)^*t}{B_s} - \frac{0.57(1 + Ft/h_0)M_H}{B_s t^2} + \frac{0.64 FZ M_H}{B_s h_0 t}$$

where B_s , F , and h_0 refer to the shell, and

$$Z = \frac{K^2 + 1}{K^2 - 1}$$

(g) Calculate stresses at opening/head juncture as follows.

(1) For longitudinal hub stress in central opening:

$$S_{HO} = X_1 S_H^*$$

(2) For radial stress at central opening:

$$S_{RO} = X_1 S_R^*$$

(3) For tangential stress at diameter of central opening:

$$S_{TO} = X_1 S_T^* + \frac{0.64 F Z_1 M_H}{B_s h_0 t}$$

where F , B_s , and h_0 refer to the shell, and

$$Z_1 = \frac{2K^2}{K^2 - 1}$$

(h) The calculated stresses above shall meet the allowable stresses in XI-3250.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 MA APP XX

APPENDIX XX SUBMITTAL OF TECHNICAL INQUIRIES TO THE BOILER AND PRESSURE VESSEL COMMITTEE

Page 161

ARTICLE XX-1000 SUBMITTAL OF TECHNICAL INQUIRIES TO THE BOILER AND PRESSURE VESSEL COMMITTEE

XX-1000 INTRODUCTION

The ASME Boiler and Pressure Vessel Committee and its Subcommittees, Subgroups, and Working Groups meet regularly to consider revisions of the Code rules, new Code rules as dictated by technological development, Code Cases, and Code

interpretations. This Appendix provides guidance to Code users for submitting technical inquiries to the Committee. Technical inquiries include requests for revisions or additions to the Code rules, requests for Code Cases, and requests for Code interpretations.

Code Cases may be issued by the Committee when the need is urgent. Code Cases clarify the intent of existing Code requirements or provide alternative requirements. Code Cases are written as a question and a reply and are usually intended to be incorporated into the Code at a later date. Code interpretations provide the meaning of or the intent of existing rules in the Code and are also presented as a question and a reply. Both Code Cases and Code interpretations are published by the Committee.

The Code rules, Code Cases, and Code interpretations established by the Committee are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design or as limiting in any way the freedom of manufacturers or constructors to choose any method of design or any form of construction that conforms to the Code rules.

As an alternative to the requirements of this Appendix, members of the Committee and its Subcommittees, Subgroups, and Working Groups may introduce requests for Code revisions or additions, Code Cases, and Code interpretations at their respective Committee meetings or may submit such requests to the secretary of a Subcommittee, Subgroup, or Working Group.

Inquiries that do not comply with the provisions of this Appendix or that do not provide sufficient information for the Committee's full understanding may result in the request being returned to the inquirer with no action.

XX-2000 INQUIRY FORMAT

Submittals to the Committee shall include:

(a) *Scope*. Specify one of the following:

- (1) Revision of present Code rule(s).
- (2) New or additional Code rule(s).
- (3) Code Case.
- (4) Code interpretation.

(b) *Background*. Provide the information needed for the Committee's Understanding of the inquiry, being sure to include reference to the applicable Code Section, Division, Edition, Addenda, paragraphs, figures, and tables. Preferably, provide a copy of the specific referenced portions of the Code.

(c) *Presentations*. The inquirer may desire or be asked to attend a meeting of the Committee to make a formal presentation or to answer questions from the Committee members with regard to the inquiry. Attendance at a Committee meeting shall be at the expense of the inquirer. The inquirer's attendance or lack of attendance at a meeting shall not be a basis for acceptance or rejection of the inquiry by the Committee.

XX-3000 CODE REVISIONS OR ADDITIONS

Requests for Code revisions or additions shall provide the following:

(a) *Proposed Revision(s) or Addition(s)*. For revisions, identify the rules of the Code that require revision and submit a copy of the appropriate rules as they appear in the Code marked up with the proposed

Page 164

revision. For additions, provide the recommended wording referenced to the existing Code rules.

(b) *Statement of Need*. Provide a brief explanation of the need for the revisions(s) or addition(s).

(c) *Background Information*. Provide background information to support the revision(s) or addition(s) including any data or changes in technology that form the basis for the request that will allow the Committee to adequately evaluate the proposed revision(s) or addition(s). Sketches, tables, figures, and graphs should be submitted as appropriate. When applicable, identify any pertinent paragraph in the Code that would be affected by the revision(s) or addition(s) and paragraphs in the Code that

reference the paragraphs that are to be revised or added.

XX-4000 CODE CASES

Requests for Code Cases shall provide a *Statement of Need* and *Background Information* similar to that defined in XX-3000 (b) and XX-3000(c), respectively, for Code revisions or additions. The proposed Code Case should identify the Code Section and Division and be written as a *Question* and a *Reply* in the same format as existing Code Cases.

XX-5000 CODE INTERPRETATIONS

Requests for Code interpretations shall provide the following:

(a) *Inquiry*. Provide a condensed and precise question, omitting superfluous background information, and, when possible, composed in such a way that a "yes" or a "no" *Reply*, possibly with brief provisos, is acceptable. The question should be technically and editorially correct.

(b) *Reply*. Provide a proposed *Reply* that will clearly and concisely answer the *Inquiry* question. Preferably, the *Reply* should be "yes" or "no" with brief provisos.

(c) *Background Information*. Provide any background information that will assist the Committee in understanding the proposed *Inquiry* and *Reply*.

XX-6000 SUBMITTALS

Submittals to and responses from the Committee shall meet the following:

(a) *Submittal*. Inquiries from Code users shall preferably be submitted in typewritten form; however, legible handwritten inquiries will also be considered. They shall include the name, address, telephone number, and a fax number, if available, of the inquirer and be mailed to the following address:

Secretary
ASME Boiler and Pressure Vessel Committee
Three Park Avenue
New York, N.Y. 10016-5990

(b) *Response*. The Secretary of the ASME Boiler and Pressure Vessel Committee or of the appropriate Subcommittee shall acknowledge receipt of each properly prepared inquiry and shall provide a written response to the inquirer upon completion of the requested action by the Code Committee.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 MA APP XXI

APPENDIX XXI ADHESIVE ATTACHMENT OF NAMEPLATES

Page 165

ARTICLE XXI-1000 ADHESIVE ATTACHMENT OF NAMEPLATES

XXI-1100 INTRODUCTION

XXI-1110 SCOPE

This Appendix provides minimum requirements for the use of adhesive systems for the attachment of nameplates, limited to:

(a) the use of pressure sensitive acrylic adhesives that have been preapplied by the nameplate manufacturer to a normal thickness of at least 0.005 in. (0.13 mm) and that are protected with a moisture stable liner;

- (b) use on items with Design Temperatures within the range of -40°F to 300°F (-40°C to 149°C), inclusive;
- (c) application to clean, bare metal surfaces, with removal of antiweld spatter compound which may contain silicone;
- (d) nameplate nominal thickness not less than 0.020 in.;
- (e) use of prequalified application procedures as outlined in this Article;
- (f) use of the reapplied adhesive within an interval of 2 yr after adhesive application.

XXI-1120 NAMEPLATE APPLICATION PROCEDURE QUALIFICATION

(a) The Certificate Holder's Quality Assurance Manual shall require that written procedures, acceptable to the Authorized Inspection Agency, for the application of adhesive backed nameplates shall be prepared and qualified.

(b) The application procedure qualification shall include the following essential variable, using the adhesive and nameplate manufacturers' recommendations where applicable:

- (1) description of the pressure sensitive acrylic adhesive system employed, including generic composition;
- (2) the qualified temperature range [the cold box test temperature shall be -40°F (-40°C) for all applications];
- (3) materials of nameplate and item when the mean coefficient of expansion at design temperature of one material is less than 85% of that for the other material;
- (4) finish of the nameplate and item surfaces to which the nameplate is to be attached;
- (5) the nominal thickness and modulus of elasticity at application temperature of the nameplate when nameplate preforming is employed. A change of more than 25% in the quantity $[(\text{nameplate nominal thickness})^2 \times \text{nameplate modulus of elasticity at application temperature}]$ will require requalification;
- (6) the qualified range of preformed nameplate and companion item contour combinations when preforming is employed;
- (7) cleaning requirements for the item prior to attachment of the nameplate;
- (8) application temperature range and application pressure technique;
- (9) application steps and safeguards.

(c) Each procedure used for nameplate attachment by pressure sensitive acrylic adhesive systems shall be qualified for outdoor exposure in accordance with Standard UL-969-82, Marking and Labeling Systems, with the following additional requirements.

- (1) Width of nameplate test strip shall not be less than 1 in.
- (2) Nameplates shall have an average adhesion of not less than 8 lb/in. of width after all exposure conditions, including low temperature.
- (d) Any change in (b) above shall require requalification.
- (e) Each package of nameplates shall be identified with the adhesive application date.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 MA APP XXII

**APPENDIX XXII DESIGN OF REINFORCEMENT FOR
CONE-TO-CYLINDER JUNCTION UNDER EXTERNAL
PRESSURE**

ARTICLE XXII-1000 RULES FOR REINFORCEMENT OF CONE-TO-CYLINDER JUNCTION UNDER EXTERNAL PRESSURE

XXII-1100 INTRODUCTION

XXII-1110 SCOPE

(a) The formulas of this Appendix provide for the design of reinforcement, if needed, at the cone-to-cylinder junctions for reducer sections and conical heads where all the elements have a common axis and the half-apex angle $\alpha \leq 60$ deg. Subparagraph XXII-1300(d) provides for special analysis in the design of cone-to-cylinder intersections with or without reinforcing rings where α is greater than 60 deg.

(b) In the design of reinforcement for a cone-to-cylinder juncture, the requirements of ND-3336 shall be met.

XXII-1200 NOMENCLATURE

The nomenclature given below is used in the formulas of the following subparagraphs:

A	= factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in the stiffening ring, corresponding to the factor B , below, and the design temperature for the shell under consideration
A_e	= effective area of reinforcement due to excess metal thickness, sq in.
A_{rL}	= required area of reinforcement at large end, sq in.
A_{rS}	= required area of reinforcement at small end, sq in.
A_s	= cross-sectional area of the stiffening ring, sq in.
A_T	= equivalent area of cylinder, cone, and stiffening ring, sq in.

where

$$A_{T_L} = \frac{L_L t_s}{2} + \frac{L_c t_c}{2} + A_s, \text{ for large end}$$

$$A_{T_s} = \frac{L_s t_s}{2} + \frac{L_c t_c}{2} + A_s, \text{ for small end}$$

B	= factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used for the stiffening (see ND-3112.2)
D_L	= outside diameter of large end of conical section under consideration, in.
D_o	= outside diameter of cylindrical shell, in. (In conical shell calculations, the value of D_s and D_L should be used in calculations in place of D_o depending on whether the small end D_s , or large end D_L , is being examined.)
D_s	= outside diameter at small end of conical section under consideration, in.
E	= lowest efficiency of the longitudinal joint in the shell or head or of the joint in the reducer; $E = 1$ for butt welds in compression
E_c	= modulus of elasticity of cone material, psi
E_R	= modulus of elasticity of reinforcing material, psi
E_s	= modulus of elasticity of shell material, psi
E_x	= E_c , E_R or E_s
f_1	= axial load at large end (excluding pressure P), lb/in.
f_2	= axial load at small end (excluding pressure P), lb/in.
I_s	= required moment of inertia of the stiffening ring cross section about its neutral axis parallel to the axis of the shell, in. ⁴

I'_s

= required moment of inertia of the combined ring-shell-cone cross section about its neutral

Page 172

axis parallel to the axis of the shell, in.⁴ The width of shell which is taken as contributing to the moment of inertia of the combined section shall not be greater than $1.10 \sqrt{D_o T}$ and shall be taken as lying one-half on each side of the centroid of the ring. Portions of the shell plate shall not be considered as contributing area to more than one stiffening ring. If the stiffeners should be so located that the maximum permissible effective shell sections overlap on either or both sides of a stiffener, the effective shell section for that stiffener shall be shortened by one-half of each overlap.

$$k = \frac{S_s E_s}{S_R E_R} \text{ but not less than } 1.0$$

 L

= axial length of cone, in.

 L_c

= length of cone between stiffening rings measured along surface of cone, in. For cones without intermediate stiffeners,

$$L_c = \sqrt{L^2 + (\bar{R}_L - \bar{R}_s)^2}$$

 L_L

= design length of a vessel section, in., taken as the largest of the following: (a) the center-to-center distance between the cone-to-large-shell junction and an adjacent stiffening ring on the large shell; (b) the distance between the cone-to-large-shell junction and one-third the depth of head on the other end of the large shell if no other stiffening rings are used.

 L_s

= design length of a vessel section, in., taken as the largest of the following: (a) the center-to-center distance between the cone-to-small-shell junction and an adjacent stiffening ring on the small shell; (b) the distance between the cone-to-small-shell junction and one-third the depth of the head on the other end of the small shell if no other stiffening rings are used.

 P

= external design pressure, psi

$$Q_L = \frac{PR_L}{2} + f_1; \text{ axial compressive force at large end due to pressure and } f_1$$

$$Q_s = \frac{PR_s}{2} + f_2; \text{ axial compressive force at small end due to pressure and } f_2$$

R_L	= inside radius of large cylinder, in.
R_s	= inside radius of small cylinder, in.
S	= the lesser of twice the allowable stress at design metal temperature from Section II, Part D, Subpart 1, Tables 1A and 1B or 0.9 times the tabulated yield strength at design metal temperature from Section II, Part D, Subpart 2, Tables Y-1 and Y-2, psi
S_R	= allowable stress of reinforcing material, psi
S_s	= allowable stress of shell, psi
T	= minimum required thickness of cylinder at cone-to-cylinder junction, exclusive of corrosion allowance, in. (see ND-3133.3)
T_c	= nominal thickness of cone at cone-to-cylinder junction, exclusive of corrosion allowance, in. (see ND-3121)
T_L	= the smaller of $(T_s - T)$ or $(T_c - T_r)$, in.
T_r	= minimum required thickness of cone at cone-to-cylinder junction, exclusive of corrosion allowance, in.
T_s	= nominal thickness of cylinder at cone-to-cylinder junction, exclusive of corrosion allowance, in. (see ND-3121)
α	= one-half the included (apex) angle of the cone at the center line of the head
Δ	= value to indicate need for reinforcement at cone-to-cylinder intersection having a half-apex angle $\alpha \leq 60$ deg. When $\Delta \geq \alpha$, no reinforcement is required at the junction (see Table XXII-1200-1).

TABLE XXII-1200-1
VALUES OF Δ FOR JUNCTIONS AT THE LARGE
CYLINDER FOR $\alpha \geq 60$ deg.

$P/S E$	0	0.002	0.005	0.010	0.02
Δ , deg.	0	5	7	10	15
$P/S E$	0.04	0.08	0.10	0.125	0.15
Δ , deg.	21	29	33	37	40
$P/S E$	0.20	0.25	0.30	0.35	
Δ , deg.	47	52	57	60	Note (1)

NOTE:

(1) $\Delta = 60$ deg. for greater values of $P/S E$.

TABLE XXII-1200-1 VALUES OF Δ FOR JUNCTIONS AT THE LARGE CYLINDER FOR $\alpha \geq 60$ deg.

XXII-1300 DESIGN PRESSURE

(a) Reinforcement shall be provided at the junction of the cone with the large cylinder for conical heads and reducers without knuckles when the value of Δ obtained from Table XXII-1200-1 using the appropriate ratio $P/S E$, is less than α . Interpolation may be made in the Table.

The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following formula:

$$A_{rL} = \frac{k Q_L R_L \tan \alpha}{S' E} \left[1 - \frac{1}{4} \left(\frac{P R_L - Q_L}{Q_L} \right) \frac{\Delta}{\alpha} \right] \quad (1)$$

(1)

When the thickness, less corrosion allowance, of both the reducer and cylinder exceeds that required by the applicable design formulas, the minimum excess thickness may be considered to contribute to the required reinforcement ring in accordance with the following formula:

$$(2) A_e = 4T_L \sqrt{R_L \bar{T}_s}$$

Any additional area of reinforcement which is required shall be situated within a distance of $\sqrt{R_L \bar{T}_s}$ from the junction of the reducer and the cylinder. The centroid of the added area shall be within a distance of $0.5 \sqrt{R_L \bar{T}_s}$ from the junction.

The reinforcement ring at the cone-to-cylinder junction shall also be considered as a stiffening ring. The required moment of inertia of a circumferential stiffening ring cross section shall not be less than that determined by the following formula:

$$I_s = \frac{AD_L^2 A_{TL}}{14.0}$$

The required moment of inertia of the combined ring-shell-core cross section shall not be less than that determined by the following formula:

$$I_s' = \frac{AD_L^2 A_{TL}}{10.9}$$

The moment of inertia for a stiffening ring at the large end shall be determined by the following procedure:

Step 1. Assuming that the shell has been designed and D_L , L_L , and T are known, select a member to be used for the stiffening ring and determine cross sectional area A . Then calculate factor B using the following formula:

$$B = \sqrt[3]{\frac{F_L D_L}{A_{TL}}}$$

where

$$F_L = PM + f_1 \tan \alpha$$

A_{TL} was defined previously.

Step 2. Enter the right-hand side of the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening ring, use the material chart resulting in the larger value of A in Step 4, below.

Step 3. Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5.

Step 4. Move vertically to the bottom of the chart and read the value of A .

Step 5. For value of B falling below the left end of the material/temperature line for the design temperature, the value of A can be calculated using the formula $A = 2B/E_x$.

Step 6. Compute the value of the required moment of inertia from the formulas for I_s or I'_s above.

Step 7. Calculate the available moment of inertia of the stiffening ring using the section corresponding to that used in Step 6.

Step 8. If the required moment of inertia is greater than the moment of inertia for the section selected in Step 1, a new section with a larger moment of inertia must be selected and a new moment of inertia determined. If the required moment of inertia is smaller than the moment of inertia of the section selected in Step 1, that section is satisfactory.

The requirements of ND-4430 are to be met in attaching stiffening rings to the shell.

(b) Reinforcement shall be provided at the junction of the conical shell of a reducer without a flare and the small cylinder. The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following formula:

$$A_{rS} = \frac{kQ_s R_s \tan \alpha}{S' E} \quad (3)$$

(3)

When the thickness, less corrosion allowance, of either the reducer or cylinder exceeds that required by the applicable design formula, the thickness may be considered to contribute to the required reinforcement ring in accordance with the following formula:

Page 174

$$A_e = \sqrt{\frac{R_s T_c}{\cos \alpha}} (T_c - T_r) + \sqrt{RT_s} (T_s - T) \quad (4)$$

(4)

Any additional area of reinforcement which is required shall be situated within a distance of $\sqrt{R_s T_s}$ from the junction, and the centroid of the added area shall be within a distance of $0.5\sqrt{R_s T_s}$ from the junction.

The reinforcement ring at the cone-to-cylinder junction shall also be considered as a stiffening ring. The required moment of

inertia of a circumferential stiffening ring cross section shall not be less than that determined by the following formula:

$$I_s = \frac{AD_s^2 A_{Ts}}{14.0}$$

The required moment of inertia of the combined ring-shell-cone cross section shall not be less than that determined by the following formula:

$$I'_s = \frac{AD_s^2 A_{Ts}}{10.9}$$

The moment of inertia for a stiffening ring at the small end shall be determined by the following procedure.

Step 1. Assuming that the shell has been designed and D_s , L_s , and T are known, select a member to be used for the stiffening ring and determine cross-sectional area A_{Ts} . Then calculate factor B using the following formula:

$$B = \frac{3}{4} \left(\frac{F_s D_s}{A_{T_s}} \right)$$

where

$$F_s = PN + f_2 \tan \alpha$$

$$N = \frac{R_s \tan \alpha}{2} + \frac{L_s}{2} + \frac{R_L^2 - R_s^2}{3R_L \tan \alpha}$$

A_{Ts} was defined previously.

Step 2. Enter the right-hand side of the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening ring, use the material chart resulting in the larger value of A in Step 4, below.

Step 3. Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5.

Step 4. Move vertically to the bottom of the chart and read the value of A .

Step 5. For values of B falling below the left end of the material/temperature line for the design temperature, the value of A can be calculated using the formula $A = 2B/E_x$.

Step 6. Compute the value of the required moment of inertia from the formulas for I_s or I'_s above.

Step 7. Calculate the available moment of inertia of the stiffening ring using the section corresponding to that used in Step 6.

Step 8. If the required moment of inertia is greater than the moment of inertia for the section selected in Step 1, a new section with a larger moment of inertia must be selected and a new moment of inertia determined. If the required moment of inertia is smaller than the moment of inertia for the section selected in Step 1, that section is satisfactory.

The requirements of ND-4430 are to be met in attaching stiffening rings to the shell.

(c) Reducers, such as those made up of two or more conical frustums having different slopes, may be designed in accordance with (d) below.

(d) As an alternative to the rules provided in (a) and (b) above and when half the apex angle is greater than 60 deg., the design may be based on special analysis such as numerical methods or the beam-on-elastic-foundation analysis of Timoshenko, Hetenyi, or Watts and Lang. The stresses at the junction shall meet all of the allowable stress limits of this Division. The effect of shell and cone buckling on the required area and moment of inertia at the joint shall also be considered in the analysis. The theoretical buckling pressure of the junction shall be at least 3.3 times the allowable external design pressure of the junction.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 MA APP XXIII

APPENDIX XXIII QUALIFICATIONS AND DUTIES OF
SPECIALIZED PROFESSIONAL ENGINEERS

XXIII-1100 SCOPE

This Appendix presents minimum requirements for the qualification of personnel engaged in the certification activities. The personnel addressed are those who perform the following specialty fields:

(a) for Division 1:

- (1) certification of the Design Specification on behalf of the Owner;
- (2) certification of the Design Report on behalf of the N Certificate Holder;
- (3) certification of the Overpressure Protection Report on behalf of the Owner;
- (4) certification of the Load Capacity Data Sheet on behalf of the N Certificate Holder.

(b) for Division 2:

- (1) certification of the Design Specification on behalf of the Owner;
- (2) certification of the Construction Specification, Design Drawings, and Design Report on behalf of the Designer.

Also provided are the duties of these personnel in the performance of the activities described above.

XXIII-1200 QUALIFICATIONS

XXIII-1210 GENERAL

One or more Registered Professional Engineers (PE) shall be selected by the Owner, Designer, or N Certificate Holder, as applicable, to perform Code activities in the appropriate specialized fields(s), provided the qualifications of the PE in meeting the requirements of this Appendix have been evaluated and verified by the Owner, Designer, or N Certificate Holder, as applicable, responsible for the activity being certified or reviewed. Guidelines for demonstrating PE qualifications are contained in Guide C. A record of the qualifications of the PE shall be maintained by the responsible organization or the PE.

XXIII-1220 REGISTRATION AND EXPERIENCE

He shall be a Registered Professional Engineer in at least one state of the United States or Province of Canada and have the following qualifications.

He shall have 4 years of varied application experience at least 2 of which have been in each specialty field for which he performs certifying or review activities as delineated in XXIII-1230 through XXIII-1250. In addition, he shall keep current his knowledge of Code requirements and continue his professional development in his specialty field through personal study and experience, or by attendance at appropriate courses, seminars, Society meetings, and technical committee meetings. The Owner, Designer, or N Certificate Holder, as applicable, shall review the qualifications of the PE at least once every 3 years to assure that his qualifications have been maintained. A continuing record of all such activity shall be included in the qualification records of the PE.

XXIII-1230 CERTIFIER OF THE DESIGN SPECIFICATION

To qualify as certifier of the Design Specification on behalf of the Owner, the PE shall be experienced in the applicable field of design and related nuclear power plant requirements, and in the application of the requirements of the Code relating to the construction of nuclear power plant items. This experience shall indicate that the PE has sufficient knowledge of anticipated plant and system operating and test conditions and their relationship to Code design criteria pertinent to the applicable Code item. In addition, he shall

be knowledgeable of the specific Code requirements pertaining to his specialty field. Guidelines reflecting the degree of knowledge appropriate for preparation of the Design Specification are contained in Guide B, Table B1.

knowledge appropriate for preparation of the Design Specification are contained in Guide B, Table B1.

XXIII-1240 CERTIFIER OF THE LOAD CAPACITY DATA SHEET, CONSTRUCTION SPECIFICATION, DESIGN DRAWINGS, AND DESIGN REPORT

To qualify as certifier of the Load Capacity Data Sheet, the Construction Specification, Design Drawings, or Design Report, the PE shall be experienced in the applicable field of design and analysis and in the application of the requirements of the Code. In addition, he shall be knowledgeable of the specific Code requirements pertaining to his specialty field. Guidelines reflecting the degree of knowledge appropriate for preparation of the Design Report (Division 1), the Load Capacity Data Sheet, and the Construction Specification, Design Drawings, and Design Report (Division 2) are contained in Guide B, Tables B2, B4, and B5, respectively.

XXIII-1250 CERTIFIER OF THE OVERPRESSURE PROTECTION REPORT

To qualify as certifier of the Overpressure Protection Report on behalf of the Owner, the PE shall be experienced in nuclear power plant systems design, and in plant operation and safety control. In addition, he shall be knowledgeable of the specific Code requirements pertaining to his specialty field. Guidelines reflecting the degree of knowledge appropriate for preparation of the Report on Overpressure Protection are contained in Guide B, Table B3.

XXIII-1300 DUTIES

XXIII-1310 GENERAL

The certification activities covered in this Appendix may be performed only if the PE has assured himself that he is qualified to do so by virtue of a self-review establishing that his qualifications meet those required by this Appendix. He shall be familiar with the Quality Assurance requirements of the organization responsible for providing the document as these requirements relate to his work. For certification activities, the document being certified must have been reviewed in detail by the certifying PE, or prepared by him or prepared under his responsible direction. He shall prepare a statement¹ to be affixed to the document attesting to compliance with the applicable requirements of the Code.

XXIII-1320 CERTIFICATION OF THE DESIGN SPECIFICATION

It is the responsibility of the PE certifying the Owner's Design Specification to assure that the Design Specification is correct, complete, and in compliance with the requirements of the applicable Edition and Addenda of the Code. As a minimum, the certifier of the Design Specification shall assure that:

- (a) the function of the item is properly specified;
- (b) the design requirements, including identification of the item Design and Service Loadings and their combinations and associated Limits, are properly specified;
- (c) the proper environmental conditions, including corrosion, erosion, and radiation, are specified;
- (d) the Code classification is properly specified;
- (e) the definition of the specific boundaries and load conditions on these boundaries for each item is specified, and that the boundaries and associated load conditions between adjacent components and structure are compatible with the overall system design;
- (f) the specified materials for items covered by the Code are permitted by the Code for the applicable item;
- (g) all requirements with regard to impact testing are specified;
- (h) any restrictions on or additional requirements for heat treating are specified;
- (i) any restrictions on cladding materials are specified;
- (j) any reduction to design stress intensity values, allowable stress, or fatigue curves necessitated by the given environmental conditions are specified;
- (k) the necessary information concerning the load is given carrying capacity of structures supporting Code items;

(l) when operability of a component is a requirement, the Design Specification shall make reference to other appropriate documents that specify the operating requirements;

(m) the overpressure protection requirements are specified;

1 Illustrative samples of statements are shown in Guide A.

Page 179

(n) the Code Edition, Addenda, and Code Cases to be used for construction are specified.

XXIII-1330 CERTIFICATION OF THE DIVISION 1 DESIGN REPORT

It is the responsibility of the PE certifying the Division 1 Design Report to assure that the design of the item complies with the requirements of the applicable Edition and Addenda of the Code for the Design, Service, and Test Loadings that have been specified in the Design Specification. As a minimum, the certifier of the Design Report shall assure that:

(a) the Design Report reflects the design as shown by the drawings used for construction and that all modifications to the drawings and construction deviations have been reconciled with the Design Report;

(b) the design as shown by the drawings is in accordance with the requirements of the Code;

(c) the Design Report is in accordance with the requirements of the Code;

(d) materials specified for Code items are permitted by the Code, and that any reduction of material impact properties from heat treatments, welding, and forming have been taken into account;

(e) the Design Report is based on the Design, Service, and Test Loadings stated in the Design Specification;

(f) the specified requirements for protection against nonductile fracture are specified;

(g) all special nondestructive examinations required to validate unique features have been specified in appropriate documents/drawings;

(h) the specified test pressure and temperature are in compliance with Code requirements;

(i) adequate analytical techniques have been employed to assess the structural adequacy of the item of concern for the Design, Service, and Test Loadings specified.

XXIII-1340 CERTIFICATION OF THE OVERPRESSURE PROTECTION REPORT

It is the responsibility of the PE certifying the Overpressure Protection Report to assure that the report has been reconciled with the system requirements and with the requirements of the applicable Subsection of the Code.

XXIII-1350 CERTIFICATION OF THE LOAD CAPACITY DATA SHEET

It is the responsibility of the PE certifying the Load Capacity Data Sheet on behalf of the N Certificate Holder to determine that the load capacity of the component or piping support is rated in accordance with Subsection NF of the Code. He shall assure that the design of the component or piping support complies with the requirements of the applicable Edition and Addenda of the Code for the Design, Service, and Test Loadings specified in the Design Specification. In addition, his duties shall include the requirements of XXIII-1330(a) through (i) for the data substantiating the Load Capacity Data Sheet.

XXIII-1360 CERTIFICATION OF THE CONSTRUCTION SPECIFICATION DESIGN DRAWINGS, OR DESIGN REPORT FOR DIVISION 2

It is the responsibility of the PE certifying the Construction Specification, Design Drawings, or Design Report on behalf of the Designer for Division 2 to assure that each of the above principal Code documents is correct, complete, and in accordance with the Design Specification and Section III, Division 2. As a minimum, the certifier of each of the principal Code documents shall assure:

(a) that the Design Drawings contain:

(1) concrete and steel liner thicknesses;

(2) size and location of reinforcing steel, prestressing tendons, and penetrations;

(3) the latest revisions to reflect any change in design.

(b) that the Design Report includes the requirements of XXIII-1330(a) through (i), as applicable.

(c) that the Construction Specification has provided the following in accordance with the Code:

(1) material specifications;

(2) material shipping, handling, and storage requirements;

(3) requirements for personnel or equipment qualification;

(4) material or part examination and testing requirements;

(5) acceptance and leakage testing requirements;

(6) requirements for shop drawings;

(7) requirements for batching, mixing, placing, and curing of concrete;

(8) requirements for the fabrication and installation of the prestressing system, reinforcing steel, and embedments;

Page 180

(9) identification of parts requiring a Code stamp;

(10) design life for parts and materials where necessary to establish compliance with the Design Specification;

(11) construction surveillance to be performed by the Designer as required by the Design Specification;

(12) the latest revisions to reflect any change in design.

Page 181

GUIDE A - NONMANDATORY SAMPLE STATEMENTS

Page 182

FORM A-1 DESIGN SPECIFICATION

CERTIFICATION

I, the undersigned, being a Registered Professional Engineer competent in the applicable field of design and related nuclear power plant requirements relative to this Design Specification, certify that to the best of my knowledge and belief it is correct and complete with respect to the Design and Service Conditions given and provides a complete basis for construction in accordance with NCA-3250 and other applicable requirements of the ASME Boiler and Pressure Vessel Code, Section III, Division _____, _____ Edition with Addenda up to and including _____.

The Specification and Revision being certified is: _____

Certified by _____ P.E.

Registration No. _____ State* _____

Date _____

* or Province of Canada

FORM A-1 DESIGN SPECIFICATION

Page 183

FORM A-2 DESIGN REPORT

CERTIFICATION¹

I, the undersigned, being a Registered Professional Engineer competent in the applicable field of design and using the certified Design Specification and the drawings identified below as a basis for design, do hereby certify that to the best of my knowledge and belief the Design Report is complete and accurate and complies with the design requirements of the ASME Boiler and Pressure Vessel Code, Section III, Division _____, _____ Edition with Addenda up to and including _____.

Design Specification and Revision:

Drawings and Revision:

Design Report and Revision:

Certified by _____ P.E.

Registration No. _____ State* _____

Date _____

¹ Similar statement may also be used for certification of Load Capacity Data Sheet when supplied in lieu of Design Report (NCA-3551).

* or Province of Canada

FORM A-3 OVERPRESSURE PROTECTION REPORT

CERTIFICATION

I, the undersigned, being a Registered Professional Engineer competent in the applicable field of design and overpressure protection requirements, do hereby certify that to the best of my knowledge and belief the Overpressure Protection Report complies with the requirements of the ASME Boiler and Pressure Vessel Code Section III, Division _____, _____ Edition with Addenda up to and including _____.

Overpressure Protection Report and Revision:

Design Specification and Revision:

Certified by _____ P.E.

Registration No. _____ State* _____

Date _____

* or Province of Canada

FORM A-3 OVERPRESSURE PROTECTION REPORT

GUIDE B - NONMANDATORY GUIDELINES FOR ESTABLISHING ASME CODE KNOWLEDGE

This Guide provides guidelines for establishing the degree of Code knowledge required by the certifying PE in his specialty field. In the paragraphs that follow, the degree of knowledge required by the PE of the requirements of the Code pertaining to his specialty field is indicated by the terminology "general knowledge" and "working knowledge."

As used in this Guide, "general knowledge" signifies having sufficient acquaintance with the Code to be conversant with other persons involved in its applications, and to make prudent judgements in the application of Code requirements.

As used in this Guide, "working knowledge" signifies understanding by prior customary involvement in a specialty field of the Code requirements and of the principles on which the Code rules are based, to the extent that the PE may apply or direct others in the application of the requirements.

In this sense, "working knowledge" implies a more thorough understanding of the Code requirements and the ability to apply them than does "general knowledge" of the Code.

The degree of knowledge in the various areas of the Code cited in Tables B1 through B5 is based upon the more common Code items and activities. There may be special items or activities for which the degree of knowledge in a specific Code area must be more detailed than shown in the applicable table, or may require knowledge of specific Code areas that are not cited.

In the following tables, the degree of knowledge required by the PE of the various requirements of the Code pertinent to his specialty field is indicated by the letter G for "general knowledge" and the letter W for "working knowledge."

Page 186

**TABLE B1 DESIGN SPECIFICATION —
DIVISIONS 1 AND 2
(W = Working Knowledge; G = General Knowledge)**

NCA-1000	W	NX-3700	G •
2000	W	3800	G •
3100	W	3900	G •
3200	W	4100	G
3300	W •	4210	G
3400	W •	4220	G
3500	W •	4240	G
3600	W	4620	G
3700	G	5100	G
3800	G	5200	G
3900	G •	6000	W •
4000	G		
5000	G	NF-NG-1000	W •
8000	G	2100	G •
		2300	G •
NX-1000	W	3000	G •
2100	G	4100	G •
2300	G	4200	G •
2500	G	5000	G •
2600	G		
3100	G	CB/CC-1000	W
3200	G	2000	G
3300	G •	3000	G
3400	G •	4000	G
3500	G •	5000	G
3600	G •	6000	G

NX = NB/NC/ND/NE/NH, as applicable

• = as applicable

TABLE B2 DESIGN REPORT – DIVISION 1
(W = Working Knowledge; G = General Knowledge)

NCA-1000	G	NX-3400	W •
2000	G	3500	W •
3100	W	3600	W •
3200	G	3700	W •
3300	W •	3800	W •
3400	W •	3900	W •
3500	W •	4100	G
3600	G	4210	G
3700	G	4220	G
3800	G	4240	G
3900	G	4620	G
4000	G	5100	G
8000	G	5200	G
		6000	W
NX-1000	W		
2100	W	NF-NG-1000	W •
2300	W	2100	W •
2500	W •	2300	W •
2600	G	3000	W •
3100	W	4100	G •
3200	W •	4200	G •
3300	W •	5000	G •

NX = NB/NC/ND/NE/NH, as applicable

• = as applicable

**TABLE B3 OVERPRESSURE PROTECTION
REPORT – DIVISIONS 1 AND 2
(W = Working Knowledge; G = General Knowledge)**

NCA-1000	G	NX-3521	G
2000	W	3621	G
3100	G	6200	G
3200	G	6300	G
3500	G	7000	W
3600	G		
4000	G	CC-1000	G
		3100	G
NX-1000	G	3200	W
3110	W	6100	G
3220	G	6211	G
3230	G	7000	W
3414	G		

NX = NB/NC/ND/NE/NH, as applicable

TABLE B3 OVERPRESSURE PROTECTION REPORT - DIVISIONS 1 AND 2

Page 187

**TABLE B4 LOAD CAPACITY DATA
SHEET – DIVISION 1**
(W = Working Knowledge; G = General Knowledge)

NCA All	G	NF-3500	W •
NCA-1250	W	3600	W •
2140	W		
3550	W	Appendix	
		I	G
NF All	G	II	G •
NF-3100	W	II-1220	W •
3200	W	II-1430	W •
3300	W •	F	G
3400	W	F-1321	W
		F-1370	W

• = as applicable

TABLE B4 LOAD CAPACITY DATA SHEET - DIVISION 1

Page 189

**TABLE B5 CONSTRUCTION SPECIFICATION, DESIGN DRAWINGS,
AND DESIGN REPORT – DIVISION 2**
(W = Working Knowledge; G = General Knowledge)

	Construction Specification	Design Drawings	Design Report		Construction Specification	Design Drawings	Design Report
NCA-1000	W	W	W	CC-1000	W	W	W
2000	W	W	W	2000	W	G	W
3100	W	W	W	3100	W	W	W
3200	W	W	W	3200	G	G	W
3300	W	W	W	3300	G	W	W
3400	W	W	W	3400	G	W	W
3500	G	G	G	3500	W	W	W
3600	G	G	G	3600	W	W	W
3700	G	G	G	3700	W	W	W
3800	W	G	G	3800	W	W	W
3900	W	G	G	4100	W	W	W
4000	W	G	W	4200	W	W	G
5000	G	G	G	4300	W	W	G
8000	G	G	G	4400	W	W	G
				4500	W	W	G
				5000	W	W	W
				6000	W	G	G
				7000	W	G	G
				8000	W	G	G

TABLE B5 CONSTRUCTION SPECIFICATION, DESIGN DRAWINGS, AND DESIGN REPORT - DIVISION 2

Guide C - NONMANDATORY GUIDELINES FOR DEMONSTRATING PE QUALIFICATIONS

This Guide provides suggested methods for demonstrating that the requirements for the qualification of personnel engaged in certification activities have been met. The Owner, Designer, or N Certificate Holder, as applicable, responsible for the activity being certified should establish procedures or instructions for evaluating, verifying, and documenting the qualifications of the PE engaged in certifying activities as required by this Appendix

The PE's qualifications for the requirements of XXIII-1220 may be demonstrated as follows.

(a) PE registration in one or more states of the United States or provinces of Canada should be documented on records that, as a minimum, include:

- (1) PE's identification
- (2) state or province of registration
- (3) registration number
- (4) expiration date

(b) The 4 years of varied application experience, including 2 years in his specialty field(s), should be documented in a resume describing the PE's Code experience and places and dates of employment.

(c) In order for the PE to keep current his knowledge of the Code requirements and to continue his professional development in his specialty field(s), as required by this Appendix, he should, in the 36-month period preceding the date of qualification, have performed Code activities requiring certification in his specialty field(s), or have been engaged in the application of Code requirements to an equivalent extent, but not necessarily including Certification. Alternatively, he should have done two or

more of the following:

- (1) taught or attended an appropriate course or training program;
 - (2) taught or attended an appropriate seminar;
 - (3) attended an ASME or ASME/ACI Code meeting;
 - (4) attended a technical society meeting related to his specialty field.
- (d) The PE's participation in these activities should be documented in appropriate records that, as a minimum, include:
- (1) PE's identification
 - (2) description of Code activities performed
 - (3) course or training program description, duration, and date completed
 - (4) seminar description, duration, and date attended
 - (5) ASME or ASME/ACI Code meeting(s) and date(s) attended
 - (6) technical society meeting(s) and date(s) attended
 - (7) the PE's function (i.e., attendee, member, speaker, chairman, etc.) indicating the nature of his participation.

Guide B provides guidance regarding knowledge of the Code that the PE should have in each specialty field. The PE's qualifications regarding knowledge of the Code may be demonstrated by any one of the following methods:

(e) The Owner, Designer, or N Certificate Holder, as applicable, upon review of the experience record of the PE, declares in writing that (1) the PE's knowledge of the Code in his specialty field meets the requirements, and (2) the PE's experience record reflects successful performance of the applicable Code activities in connection with the construction of ASME Code items.

(f) Another PE previously qualified to this Appendix, designated by the Owner, Designer, or N Certificate Holder, as applicable, and familiar with the requirements of the Code, after reviewing the qualifications of the PE to be qualified, attests in writing that the PE's knowledge of the Code in his specialty field(s) meets the requirements of this Appendix.

(g) Attendance of the PE at appropriate courses or seminars that provide instruction in the Code for his specialty field(s) to import knowledge of the Code required by this Appendix. Training should be scheduled as required by this Appendix, at a frequency consistent with significant changes to the Code in his specialty field(s). Training may be accomplished by attending in-house courses or courses presented by others. Training should be documented on appropriate records that, as a minimum, include:

- (1) attendee's identification
- (2) instructor's name and affiliation
- (3) outline or description of course or seminar
- (4) date and duration of course or seminar

(h) Examination of the PE in his specialty field(s), either written or oral, to verify his knowledge of the Code as required by this Appendix. The examination may be developed and/or administered either in-house

Page 190

or by others. Examinations should be documented on appropriate records that, as a minimum, include:

- (1) attendee's identification
- (2) examiner's name and affiliation
- (3) outline or description of examination
- (4) date and results of the examination

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP A

APPENDIX A STRESS ANALYSIS METHODS

Page 191

NONMANDATORY

APPENDICES

Page 193

ARTICLE A-1000 STRESS ANALYSIS METHODS

A-1100 INTRODUCTION

A-1110 SCOPE

(a) The Articles of this Appendix illustrate some acceptable methods of analysis to determine the stresses and stress intensities required to ensure the adequacy of a design as defined in NB-3200.

(b) The methods presented here are not intended to exclude others such as computer programs working directly with shell equations or finite element breakdowns of the component under investigation.

Page 200

ARTICLE A-2000 ANALYSIS OF CYLINDRICAL SHELLS

A-2100 INTRODUCTION

A-2110 SCOPE

(a) In this Article equations are given for stress and deformations in cylindrical shells subjected to internal pressure only. Refer to NB-3133.3 for cylindrical shells subjected to external pressure.

(b) Equations are given for bending analysis for uniformly distributed edge loads.

A-2120 SIGN CONVENTION AND NOMENCLATURE

The sign convention arbitrarily chosen for the analysis of cylindrical shells in this Article is as indicated in Fig. A-2120-1. Positive directions assumed for pertinent quantities are indicated.

The symbols and sign convention adopted in this Article for the analysis of cylindrical shells are defined as follows:

D	$= Et^3/12(1 - \nu^2)$, in.-lb
E	= modulus of elasticity, psi
L	= length cylinder, in., used as subscript to denote evaluation of a quantity at end of cylinder removed from reference end
M	= longitudinal bending moment per unit length of circumference, in.-lb/in.
o	= used as subscript to denote evaluation of a quantity at reference end of cylinder, $x = 0$

p	= internal pressure, psi
Q	= radial shearing forces per unit length of circumference, lb/in.
R	= inside radius, in.
S	= stress intensity, psi
t	= thickness of cylinder, in.
w	= radial displacement of cylinder wall, in.
x	= axial distance measured from the reference end of cylinder, in.
Y	= ratio of outside radius to inside radius
Z	= ratio of outside radius to an intermediate radius
β	= $[3(1 - \nu^2)/(R + t/2)^2 t]^{\frac{1}{4}}$, in. ⁻¹
θ	= rotation of cylinder wall, rad
	= dw/dx
ν	= Poisson's ratio
σ_t	= tangential (circumferential) stress component, psi
σ_l	= longitudinal (meridional) stress component, psi
σ_r	= radial stress component, psi
$F_{11}(\beta x)$	= $(\cosh \beta x \sin \beta x - \sinh \beta x \cos \beta x)/2$
$F_{12}(\beta x)$	= $\sinh \beta x \sin \beta x$
$F_{13}(\beta x)$	= $(\cosh \beta x \sin \beta x + \sinh \beta x \cos \beta x)/2$
$F_{14}(\beta x)$	= $\cosh \beta x \cos \beta x$
$f_1(\beta x)$	= $e^{-\beta x} \cos \beta x$
$f_2(\beta x)$	= $e^{-\beta x} (\cos \beta x - \sin \beta x)$

Page 201

$f_3(\beta x)$	= $e^{-\beta x} (\cos \beta x + \sin \beta x)$
$f_4(\beta x)$	= $e^{-\beta x} \sin \beta x$
B_{11}	= $B_{11}(\beta L)$ = $(\sinh 2\beta L - \sin 2\beta L)/2(\sinh^2 \beta L - \sin^2 \beta L)$
B_{12}	= $B_{12}(\beta L)$ = $(\cosh 2\beta L - \cos 2\beta L)/2(\sinh^2 \beta L - \sin^2 \beta L)$
B_{22}	= $B_{22}(\beta L)$ = $(\sinh 2\beta L + \sin 2\beta L)/2(\sinh^2 \beta L - \sin^2 \beta L)$
G_{11}	= $G_{11}(\beta L)$

G_{12}

G_{22}

$$= -(\cosh \beta L \sin \beta L - \sinh \beta L \cos \beta L)/(\sinh^2 \beta L - \sin^2 \beta L)$$

$$= G_{12}(\beta L)$$

$$= -2 \sinh \beta L \sin \beta L/(\sinh^2 \beta L - \sin^2 \beta L)$$

$$= G_{22}(\beta L)$$

$$= -2(\cosh \beta L \sin \beta L + \sinh \beta L \cos \beta L)/(\sinh^2 \beta L - \sin^2 \beta L)$$

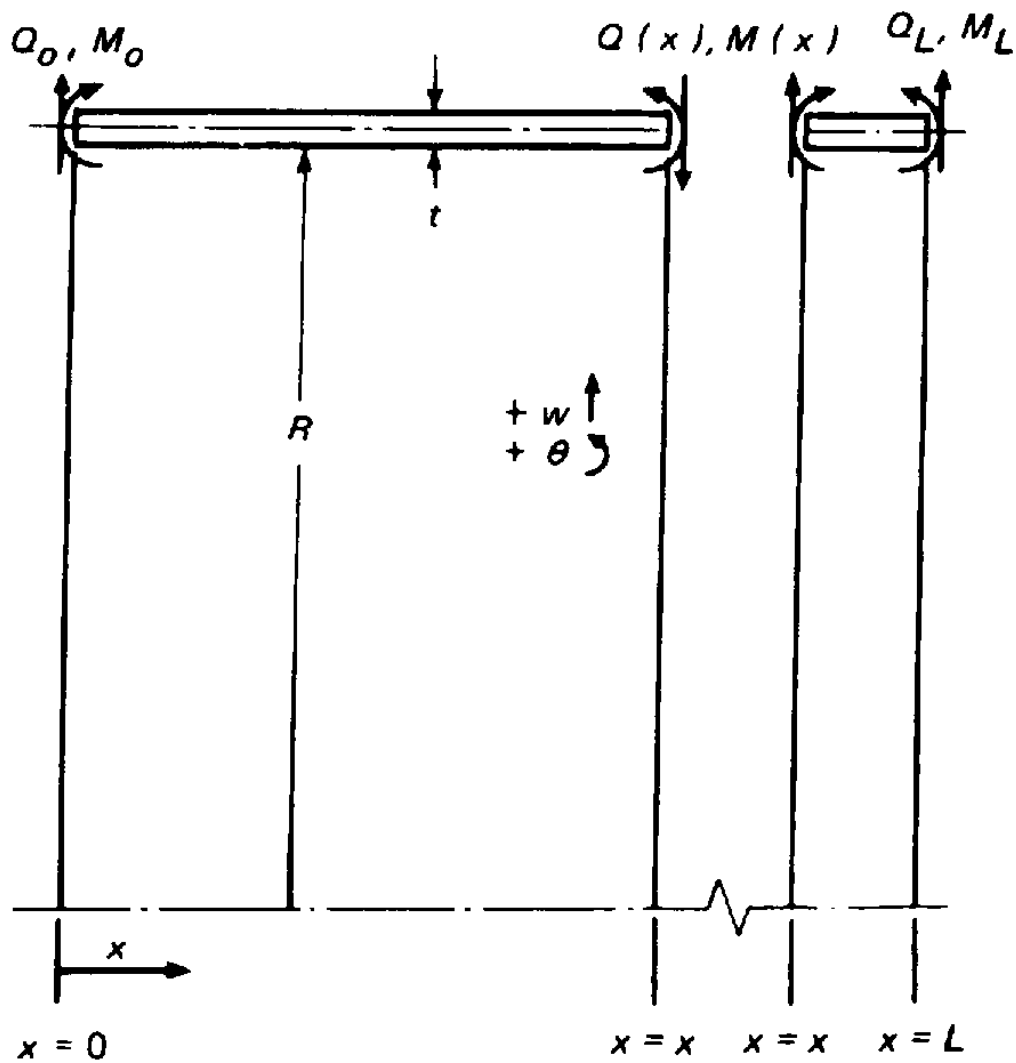


FIG. A-2120-1

A-2200 STRESS INTENSITIES, DISPLACEMENTS, BENDING MOMENTS, AND LIMITING VALUES

A-2210 PRINCIPAL STRESSES AND STRESS INTENSITIES DUE TO INTERNAL PRESSURE

A-2211 Loading Effects Considered

In this Subarticle equations are given for principal stresses and stress intensities resulting from uniformly distributed internal pressure in cylindrical shells. The effects of discontinuities in geometry and loading are not included and should be evaluated independently. The stresses resulting from all effects shall be combined by superposition.

A-2212 Principal Stresses

The principal stresses developed at any point in the wall of a cylindrical shell due to internal pressure are given by the following equations:

$$(1) \sigma_1 = \sigma_t = p(1 + Z^2)/(Y^2 - 1)$$

$$(2) \sigma_2 = \sigma_l = p/(Y^2 - 1)$$

$$(3) \sigma_3 = \sigma_r = p(1 - Z^2)/(Y^2 - 1)$$

A-2220 STRESS INTENSITIES

A-2221 General Primary Membrane Stress Intensity

The general primary membrane stress intensity developed in a cylindrical shell as a result of internal pressure is given by the equation:

$$(4) S = (pR/t) + (p/2)$$

A-2222 Maximum Value of Primary Plus Secondary Stress Intensity

The maximum value of the primary plus secondary stress intensity in a cylindrical shell as a result of internal pressure occurs at the inside surface and is given by the equation:

$$(5) S = 2pY^2/(Y^2 - 1)$$

[98]

A-2223 Values of Radial Stress Used

Note that in evaluating the general primary membrane stress intensity, the average value of the radial stress has been taken as $p/2$. This has been done to obtain a result consistent with burst pressure analyses. On the other hand, the radial stress value used in A-2212 is p , the value at the inner surface, since the purpose of that quantity is to control local behavior.

[98]

A-2230 BENDING ANALYSIS FOR UNIFORMLY DISTRIBUTED EDGE LOADS

A-2231 Behavior of Shells Subjected to Bending Moments

The equations in this Subarticle describe the behavior of cylindrical shells when subjected to the action of bending moments M , in.-lb/in. of circumference, and radial shearing forces Q , lb/in. of circumference, uniformly distributed at the edges and acting at the mean radius of the shell. The behavior of shells due to all other loadings must be evaluated independently and combined by superposition.

A-2240 DISPLACEMENTS, BENDING MOMENTS, AND SHEARING FORCES IN TERMS OF CONDITIONS AT REFERENCE EDGE ($x = 0$)

A-2241 Equations for Conditions of Any Axial Location

The radial displacement $w(x)$, the angular displacement or rotation $\theta(x)$, the bending moments $M(x)$, and the radial shearing forces $Q(x)$ at any axial location of the cylinder are given by the following equations in terms of w_o , θ_o , M_o , and Q_o .

$$w(x) = (Q_o/2\beta^3 D)F_{11}(\beta x) + (M_o/2\beta^2 D)F_{12}(\beta x) + (\theta_o/\beta)F_{13}(\beta x) + w_o F_{14}(\beta x) \quad (6)$$

$$\begin{aligned} \theta(x)/\beta &= (Q_o/2\beta^3 D)F_{12}(\beta x) \\ &+ 2(M_o/2\beta^2 D)F_{13}(\beta x) \\ &+ (\theta_o/\beta)F_{14}(\beta x) - 2w_o F_{11}(\beta x) \end{aligned} \quad (7)$$

$$\begin{aligned} M(x)/2\beta^2 D &= (Q_o/2\beta^3 D)F_{13}(\beta x) \\ &+ (M_o/2\beta^2 D)F_{14}(\beta x) \\ &- (\theta_o/\beta)F_{11}(\beta x) - w_o F_{12}(\beta x) \end{aligned} \quad (8)$$

$$\begin{aligned} Q(x)/2\beta^3 D &= (Q_o/2\beta^3 D)F_{14}(\beta x) \\ &- 2(M_o/2\beta^2 D)F_{11}(\beta x) \\ &- (\theta_o/\beta)F_{12}(\beta x) - 2w_o F_{13}(\beta x) \end{aligned} \quad (9)$$

(6 - 9)

[98]

A-2242 Equations When Cylinder Length $\geq 3/\beta$

In the case of cylinders of sufficient length, the equations in A-2241 reduce to those given below. These equations may be used for cylinders characterized by lengths not less than $3/\beta$. The combined effects of loadings at the two edges may be evaluated by applying the equations to the loadings at each edge, separately, and superposing the results.

$$\begin{aligned} w(x) = & (Q_o/2\beta^3 D)f_1(\beta x) \\ & + (M_o/2\beta^2 D)f_2(\beta x) \end{aligned} \quad (10)$$

(10)

$$\begin{aligned} \theta(x)/\beta = & - (Q_o/2\beta^3 D)f_3(\beta x) \\ & - 2(M_o/2\beta^2 D)f_1(\beta x) \end{aligned} \quad (11)$$

$$\begin{aligned} M(x)/2\beta^2 D = & (Q_o/2\beta^3 D)f_4(\beta x) \\ & + (M_o/2\beta^2 D)f_3(\beta x) \end{aligned} \quad (12)$$

$$\begin{aligned} Q(x)/2\beta^3 D = & (Q_o/2\beta^3 D)f_2(\beta x) \\ & - 2(M_o/2\beta^2 D)f_4(\beta x) \end{aligned} \quad (13)$$

(11 - 13)

[98]

A-2243 Edge Displacements and Rotations in Terms of Edge Loads

The radial displacement w_o and w_L and rotations θ_o and $-\theta_L$, developed at the edges of a cylindrical shell sustaining the action of edge loads Q_o , M_o , Q_L , and M_L , are given by the following equations:

$$\begin{aligned} w_o = & (B_{11}/2\beta^3 D)Q_o + (B_{12}/2\beta^2 D)M_o \\ & + (G_{11}/2\beta^3 D)Q_L + (G_{12}/2\beta^2 D)M_L \end{aligned} \quad (14)$$

$$\begin{aligned} -\theta_o = & (B_{12}/2\beta^2 D)Q_o + (B_{22}/\beta D)M_o \\ & + (G_{12}/2\beta^2 D)Q_L + (G_{22}/2\beta D)M_L \end{aligned} \quad (15)$$

$$\begin{aligned} w_L = & (G_{11}/2\beta^3 D)Q_o + (G_{12}/2\beta^2 D)M_o \\ & + (B_{11}/2\beta^3 D)Q_L + (B_{12}/2\beta^2 D)M_L \end{aligned} \quad (16)$$

$$\begin{aligned} \theta_L = & (G_{12}/2\beta^2 D)Q_o + (G_{22}/2\beta D)M_o \\ & + (B_{12}/2\beta^2 D)Q_L + (B_{22}/\beta D)M_L \end{aligned} \quad (17)$$

(14 - 17)

A-2250 LIMITING VALUE OF FUNCTIONS

A-2251 General Limiting Values of Influence Functions

The influence functions B and G , appearing in the equations in A-2243, rapidly approach limiting values as the length L of the cylinder increases. The limiting values are

Page 203

$$B_{11} = B_{12} = B_{22} = 1$$

$$G_{11} = G_{12} = G_{22} = 0$$

(a) Thus, for cylindrical shells of sufficient length, the loading conditions prescribed at one edge do not influence the displacements at the other edge.

(b) In the case of cylindrical shells characterized by lengths not less than $3/\beta$, the influence functions B and G , are sufficiently close to the limiting values so that the limiting values may be used in the equations in A-2243 without significant error.

A-2252 Limiting Values of Influence Functions for Short Cylinders

In the case of sufficiently short cylinders, the influence functions B and G , appearing in the equations in A-2243, are, to a first approximation, given by the following expressions:

$$B_{11} = 2/\beta L$$

$$B_{12} = 3/(\beta L)^2$$

$$B_{22} = 3/(\beta L)^3$$

$$G_{11} = -1/\beta L$$

$$G_{12} = -3/(\beta L)^2$$

$$G_{22} = -6/(\beta L)^3$$

Introducing these expressions for the influence functions B and G into the equations in A-2243 yields expressions identical to those obtained by the application of ring theory. Accordingly, the resultant expressions are subject to all of the limitations inherent in the ring theory, including the limitations due to the assumption that the entire cross-sectional area of the ring $t \times L$ rotates about its centroid without distortion. Nevertheless, in the analysis of very short cylindrical shells characterized by lengths not greater than $1/2\beta$, the expressions may be used without introducing significant error.

A-2260 PRINCIPAL STRESSES DUE TO BENDING

The principal stresses developed at the surfaces of a cylindrical shell at any axial location x due to uniformly distributed edge loads (Fig. A-2120-1) are given by the equations:

$$(18) \sigma_1 = \sigma_t(x) = Ew(x)/(R + t/2) \pm 6vM(x)/t^2$$

$$(19) \sigma_2 = \sigma_l(x) = \pm 6M(x)/t^2$$

$$(20) \sigma_3 = \sigma_r = 0$$

In these equations, where terms are preceded by a double sign $\pm$, the upper sign refers to the inside surface of the cylinder and the lower sign refers to the outside surface.

Page 204

ARTICLE A-3000 ANALYSIS OF SPHERICAL SHELLS

A-3100 INTRODUCTION

A-3110 SCOPE

(a) In this Article equations are given for stresses and deformations in spherical shells subjected to internal or external pressure.

(b) Equations are also given for bending analysis of partial spherical shells under the action of uniformly distributed edge forces and moments.

A-3120 NOMENCLATURE AND SIGN CONVENTION

(a) The symbols and sign convention adopted in this Article are defined as follows:

p	= uniform pressure internal or external, psi
M	= meridional bending moment per unit length of circumference, in.-lb/in.
H	= force per unit length of circumference, perpendicular to center line of sphere, lb/in.
N	= membrane force, lb/in.
Q	= radial shearing force per unit of circumference, lb/in.
S	= stress intensity, psi
R_m	= radius of midsurface of spherical shell, in.
R	= inside radius, in.
t	= thickness of spherical shell, in.
E	= modulus of elasticity, psi
ν	= Poisson's ratio
D	= $Et^3/12(1 - \nu^2)$, flexural rigidity, in.-lb

$$\beta = [3(1 - \nu^2)/R_m^2 t^2]^{1/4}, \text{ in.}^{-1}$$

TERM

ϕ	= meridional angle measured from center line of sphere, deg.
ϕ_o	= meridional angle of reference edge where loading is applied, deg.
ϕ_L	= meridional angle of second edge, deg.
α	= meridional angle measured from the reference edge, rad
x	= length of arc, in., for angle α , measured from reference edge of hemisphere

	$= \pi R_m \alpha / 180$
λ	$= \beta R_m$
Y	$=$ ratio of outside radius to inside radius
Z	$=$ ratio of outside radius to an intermediate radius
U	$=$ ratio of inside radius to an intermediate radius
w	$=$ radial displacement of midsurface, in.
δ	$=$ lateral displacement of midsurface, perpendicular to center line of spherical shell, in.
θ	$=$ rotation of midsurface, rad
o	$=$ used as a subscript to denote a quantity at the reference edge of sphere
l	$=$ used as a subscript to denote meridional direction
t	$=$ used as a subscript to denote circumferential direction
K_1	$= 1 - [(1 - 2\nu)/2\lambda] \cot(\phi_o - \alpha)$
K_2	$= 1 - [(1 + 2\nu)/2\lambda] \cot(\phi_o - \alpha)$
k_1	$= 1 - [(1 - 2\nu)/2\lambda] \cot \phi_o$
k_2	$= 1 - [(1 + 2\nu)/2\lambda] \cot \phi_o$
A_o	$= \sqrt{1 + k_1^2}$
$B(\alpha)$	$= [(1 + \nu^2)(K_1 + K_2) - 2K_2]$
$C(\alpha)$	$= \sqrt{\sin \bar{\phi}_o / \sin(\bar{\phi} - \bar{\alpha})}$
$F(\alpha)$	$= \sqrt{\sin \bar{\phi}_o / \sin(\bar{\phi} - \bar{\alpha})}$
γ_o	$= \tan^{-1}(-k_1)$
σ_r	$=$ radial stress component, psi
σ_t	$=$ tangential (circumferential) stress component, psi
σ_l	$=$ longitudinal (meridional) stress component, psi

(b) The sign convention is listed below and shown in Fig. A-3120-1 by the positive directions of the pertinent quantities:

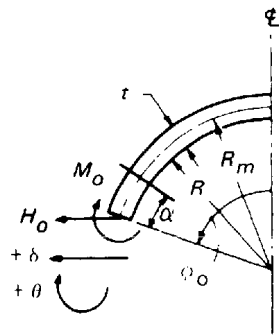
(p) pressure, positive radially outward

(δ) lateral displacement, perpendicular to λ of sphere, positive outward

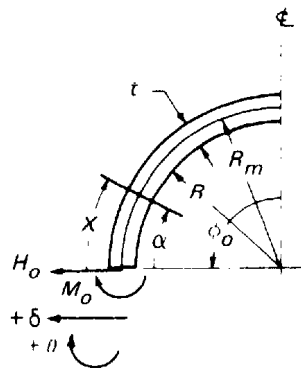
(θ) rotation, positive when accompanied by an increase in the radius or curvature, as caused by a positive moment

(M), (M_o) moment, positive when causing tension on the inside surface

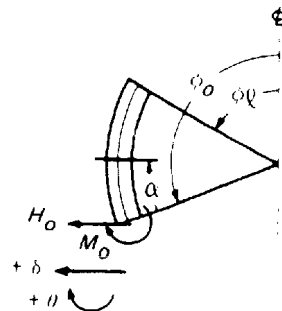
(H), (H_o) force perpendicular to λ , positive outward



(a) Spherical Segment, for Values of ϕ_0 :
 $162/\lambda \leq \phi_0 \leq 180 \text{ deg.} - 162/\lambda$



(b) Hemisphere for $\phi_0 = 90 \text{ deg.}$



(c) Frustum, for Values of ϕ_0 :
 $\phi_0 \leq 180 \text{ deg.} - 162/\lambda$ and $|\phi_0 - \phi_e| \geq 160/\lambda$

FIG. A-3120-1

[98]

FIG. A-3120-1

(N_p), (N_t) membrane force, positive when causing tension

A-3200 STRESS INTENSITIES, BENDING ANALYSIS, DISPLACEMENTS, AND EDGE LOADS

A-3210 PRINCIPAL STRESSES AND STRESS INTENSITIES RESULTING FROM INTERNAL OR EXTERNAL PRESSURE

In this Subarticle equations are given for principal stresses and stress intensities resulting from uniformly distributed internal or external pressure in complete or partial spherical shells. The effects of discontinuities in geometry and loading are not included and should be evaluated independently. The stresses resulting from all effects must be combined by superposition.

A-3220 PRINCIPAL STRESSES AND STRESS INTENSITIES

A-3221 Principal Stresses Resulting From Internal Pressure

The principal stresses at any point in the wall of a spherical shell as a result of internal pressure are given by the following equations:

$$(1) \sigma_l = \sigma_t = p(Z^3 + 2)/2(Y^3 - 1)$$

$$(2) \sigma_2 = \sigma_t = p(Z^3 + 2)/2(Y^3 - 1)$$

$$(3) \sigma_3 = \sigma_r = p(1 - Z^3)/(Y^3 - 1)$$

A-3222 Stress Intensities Resulting From Internal Pressure

A-3222.1 General Primary Membrane Stress Intensity.

The general primary stress intensity in a spherical shell as a result of internal pressure is given by the following equation:

$$(4) S = 0.75p(Y^3 + 1)/(Y^3 - 1)$$

A-3222.2 Maximum Value of Primary Plus Secondary Stress Intensity.

The maximum value of the primary plus secondary stress intensity in a spherical shell

Page 206

as a result of internal pressure occurs at the inside surface and is given by the equation:

$$(5) S = 1.5p(Y^3)/(Y^3 - 1)$$

A-3223 Principal Stresses Resulting From External Pressure

The principal stresses at any point in the wall of a spherical shell resulting from external pressure are given by the following equations:

$$(6) \sigma_l = \sigma_t = -pY^3(U^3 + 2)/2(Y^3 - 1)$$

$$(7) \sigma_2 = \sigma_t = -pY^3(U^3 + 2)/2(Y^3 - 1)$$

$$(8) \sigma_3 = \sigma_r = pY^3(U^3 - 1)/(Y^3 - 1)$$

A-3224

A-3224.1 General Primary Membrane Stress Intensity.

The general primary membrane stress intensity in a spherical shell as a result of external pressure is given by the equation:

$$(9) S = 0.75p(Y^3 + 1)/(Y^3 - 1)$$

A-3224.2 Maximum Value of Primary Plus Secondary Stress Intensity.

The maximum value of the primary plus secondary stress intensity in a spherical shell as a result of external pressure occurs at the inside surface and is given by the equation:

$$(10) S = 1.5p(Y^3)/(Y^3 - 1)$$

NOTE: The equations in A-3223 and A-3224 may be used only if the applied external pressure is less than the critical pressure which would cause instability of the spherical shell. The value of the critical pressure must be evaluated in accordance with the rules given in NB-3133.4.

A-3230 BENDING ANALYSIS FOR UNIFORMLY DISTRIBUTED EDGE LOADS

A-3231 Scope and Limitations of Equations Given

(a) The equations in A-3230 describe the behavior of partial spherical shells of the types shown in Fig. A-3120-1 when subjected to the action of meridional bending moments M_o , in.-lb/in. of circumference, and forces H_o , lb/in. of circumference, uniformly distributed at the reference edge and acting at the mean radius of the shell. The effects of all other loading must be evaluated independently and combined by superposition.

(b) The equations listed in this paragraph become less accurate and should be used with caution when R_m/t is less than 10 or the opening angle limitations shown in Fig. A-3120-1 are exceeded.

A-3232 Displacement, Rotation, Moment, and Membrane Force in Terms of Loading Conditions at Reference Edge

The displacement δ , the rotation θ , the bending moments M_p, M_r , and the membrane forces N_p, N_t at any location of sphere are given in terms of the edge loads M_o and H_o by the following equations:

$$\begin{aligned}
\delta = M_o & \left\{ \frac{2\lambda^2}{Etk_1} F(\alpha)e^{-\lambda\alpha} [\cos(\lambda\alpha) - K_2 \sin(\lambda\alpha)] \right\} \\
& + H_o \left\{ \frac{R_m \lambda}{Etk_1} A_o \sin\phi_o F(\alpha)e^{-\lambda\alpha} [\cos(\lambda\alpha + \gamma_o) \right. \\
& \left. - K_2 \sin(\lambda\alpha + \gamma_o)] \right\} \quad (11)
\end{aligned}$$

$$\begin{aligned}
\theta = M_o & \left\{ \frac{4\lambda^3}{R_m Etk_1} C(\alpha)e^{-\lambda\alpha} \cos(\lambda\alpha) \right\} \\
& + H_o \left\{ \frac{2\lambda^2}{Etk_1} A_o \sin\phi_o C(\alpha)e^{-\lambda\alpha} \cos(\lambda\alpha + \gamma_o) \right\} \quad (12)
\end{aligned}$$

$$\begin{aligned}
M_l = M_o & \left\{ \frac{1}{k_1} C(\alpha)e^{-\lambda\alpha} [K_1 \cos(\lambda\alpha) + \sin(\lambda\alpha)] \right\} \\
& + H_o \left\{ \frac{R_m}{2\lambda k_1} A_o \sin\phi_o C(\alpha)e^{-\lambda\alpha} [K_1 \cos(\lambda\alpha \right. \\
& \left. + \gamma_o) + \sin(\lambda\alpha + \gamma_o)] \right\} \quad (13)
\end{aligned}$$

$$\begin{aligned}
M_t = M_o & \left\{ \frac{C(\alpha)}{2vk_1} e^{-\lambda\alpha} [B(\alpha) \cos(\lambda\alpha) + 2v^2 \sin(\lambda\alpha)] \right\} \\
& + H_o \left\{ \frac{R_m}{4v\lambda k_1} A_o \sin\phi_o C(\alpha) e^{-\lambda\alpha} [B(\alpha) \cos(\lambda\alpha \right. \\
& \left. + \gamma_o) + 2v^2 \sin(\lambda\alpha + \gamma_o)] \right\}
\end{aligned} \tag{14}$$

$$\begin{aligned}
N_t = -M_o & \left\{ \frac{2\lambda}{R_mk_1} C(\alpha) e^{-\lambda\alpha} \sin(\lambda\alpha) \cot(\phi_o - \alpha) \right\} \\
& - H_o \left[\frac{1}{K_1} A_o \cot(\phi_o - \alpha) (\sin \phi_o) C(\alpha) e^{-\lambda\alpha} \right. \\
& \left. \sin(\lambda\alpha + \gamma_o) \right]
\end{aligned} \tag{15}$$

$$\begin{aligned}
N_t = M_o & \left\{ \frac{2\lambda^2}{R_mk_1} C(\alpha) e^{-\lambda\alpha} \left[\cos(\lambda\alpha) \right. \right. \\
& \left. \left. - \left(\frac{K_1 + K_2}{2} \right) \sin(\lambda\alpha) \right] \right\} \\
& + H_o \left\{ \frac{\lambda}{k_1} A_o \sin\phi_o C(\alpha) e^{-\lambda\alpha} \left[\cos(\lambda\alpha + \gamma_o) \right. \right. \\
& \left. \left. - \left(\frac{K_1 + K_2}{2} \right) \sin(\lambda\alpha + \gamma_o) \right] \right\}
\end{aligned} \tag{16}$$

(14 - 16)

A-3233 Displacement and Rotation of Reference Edge in Terms of Loading Conditions at Reference Edge

A-3233.1 At Reference Edge Where $\alpha = 0$ and $\phi = \phi = \phi_o$

The equations for the displacement and rotation (A-3232) simplify to Eqs. (17) and (18) below:

$$\delta_o = M_o \frac{2\lambda^2 \sin \phi_o}{Etk_1} + H_o \frac{R_m \lambda \sin^2 \phi_o}{Et} \left(\frac{1}{k_1} + k_2 \right) \quad (17)$$

$$\theta_o = M_o \frac{4\lambda^3}{R_m Etk_1} + H_o \frac{2\lambda^2 \sin \phi_o}{Etk_1} \quad (18)$$

(17 - 18)

A-3233.2 When Shell Is a Full Hemisphere.

In the case where the shell under consideration is a full hemisphere Eqs. (17) and (18) above reduce to the following:

$$\delta_o = M_o \frac{2\lambda^2}{Et} + H_o \frac{2R_m \lambda}{Et} \quad (19)$$

$$\theta_o = M_o \frac{4\lambda^3}{R_m Et} + H_o \frac{2\lambda^2}{Et} \quad (20)$$

(19 - 20)

A-3234 Principal Stresses in Spherical Shells Resulting From Edge Loads

The principal stresses at the inside and outside surfaces of a spherical shell at any location, resulting from edge loads M_o and H_o are given by Eqs. (21), (22), and (23) below.

$$\sigma_1 = \sigma_l(\alpha) = \frac{N_l}{t} \pm \frac{6M_l}{t^2} \quad (21)$$

$$\sigma_2 = \sigma_t(\alpha) = \frac{N_t}{t} \pm \frac{6M_t}{t^2} \quad (22)$$

$$\sigma_3 = \sigma_r(\alpha) = 0 \quad (23)$$

(21 - 23)

In these equations, where terms are preceded by a double sign $\pm$, the upper sign refers to the inside surface of the shell and the lower sign refers to the outside surface.

A-3240 ALTERNATE BENDING ANALYSIS OF A HEMISPHERICAL SHELL SUBJECTED TO UNIFORMLY DISTRIBUTED EDGE LOADS

A-3241 Nature of Equations Given

If a less exacting but more expedient analysis of hemispherical shells is required, equations derived for cylindrical shells may be used in a modified form. The equations in A-3242 describe the behavior of a hemispherical shell as approximated by a cylindrical shell of the same radius and thickness when subjected to the action of uniformly distributed edge loads M_o and H_o at $\alpha = 0$, $x = 0$, and $\phi_o = 90$ deg.

Page 208

A-3242 Displacement, Rotation, Moment, and Shear Forces in Terms of Loading Conditions at

Edge

$$\delta_o = H_o / 2\beta^3 D + M_o / 2\beta^2 D \quad (24)$$

$$\theta_o = H_o / 2\beta^2 D + M_o / \beta D \quad (25)$$

$$\delta(x) = \frac{H_o \sin^2 \phi}{2\beta^3 D} f_1(\beta x) + \frac{M_o \sin \phi}{2\beta^2 D} f^2(\beta x) \quad (26)$$

$$\theta(x) = \frac{H_o \sin \phi}{2\beta^2 D} f_3(\beta x) + \frac{M_o}{\beta D} f_1(\beta x) \quad (27)$$

$$M(x) = \frac{H_o \sin \phi}{\beta} f_4(\beta x) + M_o f_3(\beta x) \quad (28)$$

(24 - 28)

$$Q(x) = H_o \sin \phi f_2(\beta x) - 2\beta M_o f_4(\beta x) \quad (29)$$

(29)

where f_1, f_2, f_3 , and f_4 are defined in A-2000, and

$$x = \alpha R_m = \frac{\pi R_m}{180 \text{ deg.}} (90 \text{ deg.} - \phi)$$

A-3243 Principal Stresses in Hemispherical Shell Due to Edge Loads

The principal stresses in a hemispherical shell due to edge loads M_o and H_o , at the inside and outside surfaces of a hemispherical shell at any meridional locations, are given by Eqs. (30), (31), and (32) below:

$$(30) \sigma_1 = \sigma_t(x) = \pm 6M(x)/t^2$$

$$(31) \sigma_2 = \sigma_l(x) = E\delta(x)/R_m \pm \nu 6M(x)/t^2$$

$$(32) \sigma_3 = \sigma_r = 0$$

In these equations, where terms are preceded by a double sign $\pm$, the upper sign refers to the inside surface of the hemisphere and the lower sign refers to the outside surface.

Page 209

ARTICLE A-4000 DESIGN CRITERIA AND EQUATIONS FOR TORISPHERICAL AND ELLIPSOIDAL HEADS

A-4100 INTRODUCTION

A-4110 SCOPE

The equations defining the curves in Fig. NC-3224.6-1 are summarized in this Article. The analysis is for pressure on the concave portion of the head and does not include effects of thermal gradients and loadings other than pressure.

A-4120 NOMENCLATURE

The nomenclature adopted in this Article is defined as follows:

t	= minimum required thickness of head, in.
r	= inside knuckle radius of torispherical head, in.
L	= inside crown radius of torispherical head, in.
D	= inside diameter of a head skirt, or inside length of the major axis of an ellipsoidal head, in.
P	= internal design pressure, psi
S	= membrane stress intensity limit from Section II, Part D, Subpart 1, Tables 2A and 2B multiplied by the stress intensity factors in Table NC-3217-1, psi

A-4130 METHOD USED TO DETERMINE DESIGN PRESSURE

The maximum internal pressure capacity or required thickness of a torispherical and ellipsoidal pressure vessel head is determined from the controlling criterion of primary membrane stress, elastic-plastic collapse load, buckling collapse, and fatigue. For thick heads, where $P/S > 0.08$ (approximately $t/L = 0.04$ to 0.05), primary membrane stress dominates. For thin heads, where $t/L > 0.002$, buckling collapse is the limiting condition. For the intermediate thickness heads, where $t/L > 0.002$ up to t/L , where $P/S < 0.08$ (approximately $t/L = 0.04$ to 0.05), elastic-plastic collapse pressure and fatigue due to pressurization cycles are the determining conditions. At the present time, only design of the intermediate thickness heads is considered in this Division.

A-4140 MATHEMATICAL EXPRESSIONS FOR CURVES IN FIG. NC-3224.6-1

The equation for computing A for given set of parameters r/D and P/S is as follows:

$$(1) A = a_1 + a_2x + a_3x^2 + (b_1 + b_2x + b_3x^2)y + (c_1 + c_2x + c_3x^2)y^2$$

where

$$(2) x = r/D$$

$$(3) y = \text{logarithm } P/S$$

Constants a_1 through c_3 are given in A-4141 for natural logarithms and in A-4142 for common base logarithms.

A-4141 Natural Logarithms

$$(4) y = \ln (P/S)$$

$$(5) t/L = e^A$$

and

$$a_1 = -1.2617702$$

$$b_1 = 0.66298796$$

$$c_1 = 0.26878909 \times 10^{-4}$$

$$a_2 = -4.5524592$$

$$b_2 = -2.2470836$$

$$c_2 = -0.42262179$$

$$a_3 = 28.933179$$

$$b_3 = 15.682985$$

$$c_3 = 1.8878333$$

A-4142 Common Base Logarithms

$$(6) y = \log_{10}(P/S)$$

$$(7) t/L = 10^A$$

and

$$a_1 = -0.5479782$$

$$b_1 = 0.66298796$$

$$c_1 = 0.61890975 \times 10^{-4}$$

$$a_2 = -1.9771079$$

$$b_2 = -2.2470836$$

$$c_2 = -0.97312263$$

$$a_3 = 12.565520$$

$$b_3 = 15.682985$$

$$c_3 = 4.3468967$$

A-4150 SAMPLE PROBLEM

Consider a torispherical head having the parameters $L = 84$ in.; $D = 90$ in.; $r = 5.5$ in.; $P = 200$ psi; and for material SA-515 Grade 70, $S = 23,300$ psi. With these data and using Eq. (1) in A-4140 and the common logarithms and constants of A-4142:

$$P/S = 0.00858369$$

$$P/S = 0.06111111 = x$$

$$y = \log (P/S) = -2.066325925$$

and

$$y^2 = 4.269702828$$

$$A = -2.013430932$$

Solving Eq. (1) of A-4140:

$$t/L = 10^A = 0.009695474$$

$$t = 0.814 \text{ in.}$$

Direct reading of Fig. NC-3224.6-1 gives the following:

$$t/L = 0.0097$$

$$t = 0.814 \text{ in.}$$

ARTICLE A-5000 ANALYSIS OF FLAT CIRCULAR HEADS

A-5100 INTRODUCTION

A-5110 SCOPE

(a) In this Article equations are given for stresses and displacements in flat circular plates used as heads for pressure vessels.

(b) Equations are also given for stresses and displacements in these heads due to forces and edge moments uniformly distributed along the outer edge, and uniformly distributed over a circle on one face. The radius of this circle is intended to match the mean radius of an adjoining element, such as a cylinder, cone, or spherical segment.

A-5120 NOMENCLATURE AND SIGN CONVENTION

The symbols and sign conventions adopted in this Article are defined as follows:

p	= pressure, psi
M	= radial bending moment, in.-lb/in. of circumference
Q	= radial force, lb/in. of circumference
σ_r	= radial stress, psi
σ_l	= longitudinal stress, psi
σ_t	= tangential (circumferential) stress, psi
w	= radial displacement, in.
θ	= rotation, rad
R	= outside radius of plate, in.
r	= radial distance from center of plate, in.
x	= longitudinal distance from midplane of plate, in.
t	= thickness of plate, in.
t_s	= thickness of connecting shell at the head junction, in.
E	= elastic modulus, psi
ν	= Poisson's ratio
F	= geometry constant, given in Table A-5240-1
$\ln$	= $\log_e$

Tensile stresses are positive. The positive directions of the coordinates, radial forces, moments, and displacements are shown in Fig. A-5120-1. The pressure is assumed to act on the surface where $x = t/2$.

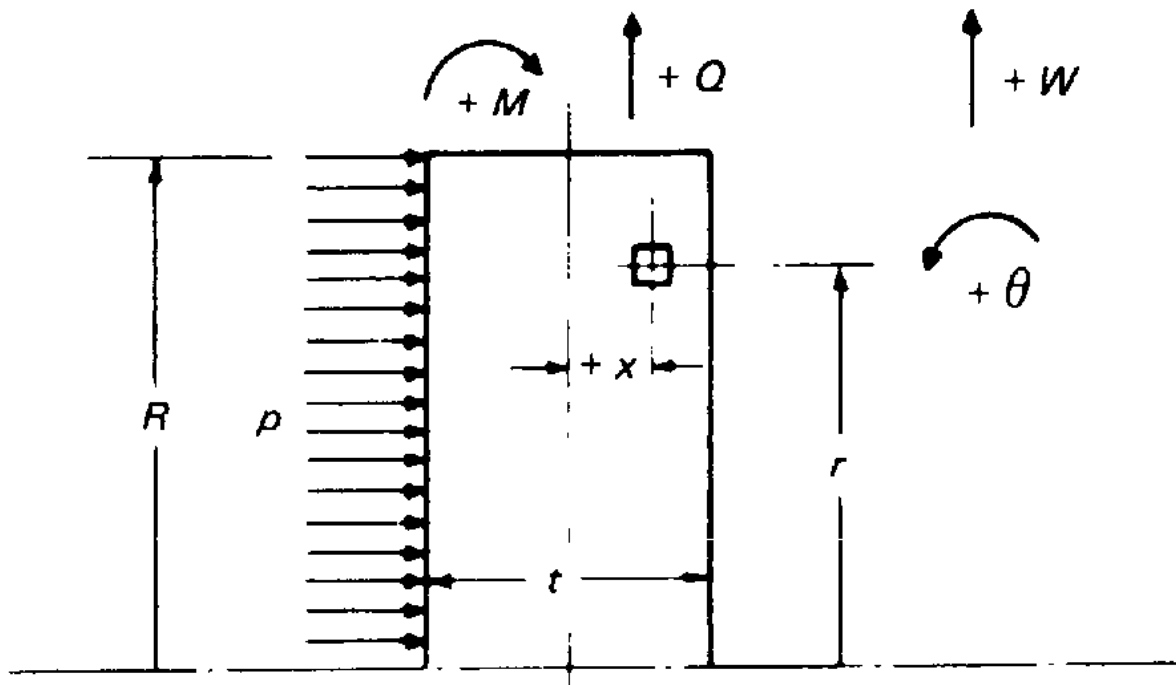


FIG. A-5120-1

FIG. A-5120-1

A-5200 LOADS, DISPLACEMENTS, AND GEOMETRY CONSTANTS

A-5210 PRESSURE AND EDGE LOADS ON CIRCULAR FLAT PLATES

A-5211 Values for Which Equations Are Given

In this Subarticle equations are given for the principal stress and the deformations of flat plates under axisymmetric loading conditions.

A-5212 Pressure Loads on Simply Supported Flat Plates

The principal stresses and deformations for a flat plate, simply supported at its periphery and loaded in the manner shown on Fig. A-5120-1 are given for a radial location r at any point x in the cross section by Eqs. (1) through (6) below.

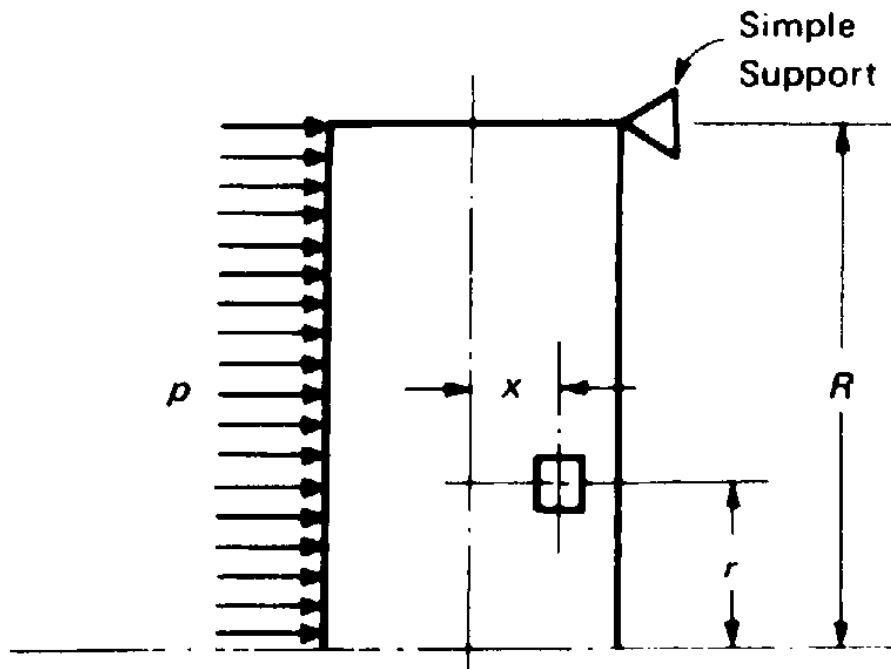


FIG. A-5212-1

FIG. A-5212-1

Radial bending stress:

$$\sigma_r = p \frac{3(x)}{4t^3} [(3 + \nu) (R^2 - r^2)] \quad (1)$$

(1)

Tangential bending stress:

$$\sigma_r = p \frac{3(x)}{4t^3} [(3 + \nu) R^2 - (1 + 3\nu) r^2] \quad (2)$$

(2)

Longitudinal stress:

$$(3) \sigma_l = (p/t)(x - t/2)$$

Rotation of the midplane:

$$\theta = -p \frac{3(1 - \nu)}{4t^3 E} [r^3 (1 + \nu) - rR^2 (3 + \nu)] \quad (4)$$

(4)

Rotation of the midplane at the outer edge:

$$(5) \theta = +p [3(1 - \nu)/2E](R/t)^3$$

Radial displacement:

$$(6) w = +(x)\theta$$

A-5213 Edge Loads on Flat Plates

The principal stresses and deformations of a flat plate subjected to uniformly distributed edge loads, as shown on Fig. A-5213-1 are given for radial location r at any point x in the cross section by the following equations:

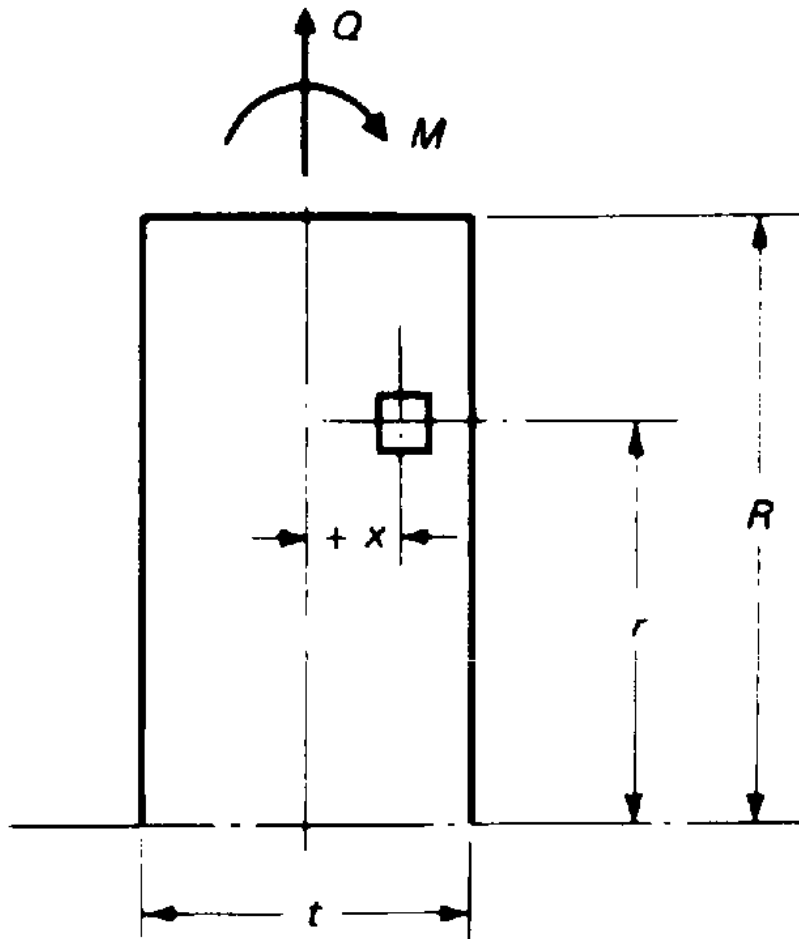


FIG. A-5213-1

FIG. A-5213-1

Radial and tangential stresses:

$$\sigma_r = \sigma_t = \frac{Q}{t} - \frac{12(x)}{t^3} M \quad (7)$$

(7)

Rotation of the midplane:

$$\theta = \frac{-12(1 - \nu)(r)}{Et^3} M \quad (8)$$

(8)

Radial displacement:

$$w = \frac{(1 - \nu)(r)}{Et} Q + (x) \theta \quad (9)$$

(9)

A-5220 FLAT PLATE PRESSURE VESSEL HEADS

A-5221 Methods of Attachment

Flat plates used as pressure vessel heads are attached to a vessel shell in the manner shown by the typical examples in Fig. A-5221-1

formed by the head and the shell may be analyzed according to the principles of discontinuity analysis described in A-6000. In the following paragraph, equations are given for the quantities necessary to perform a discontinuity analysis.

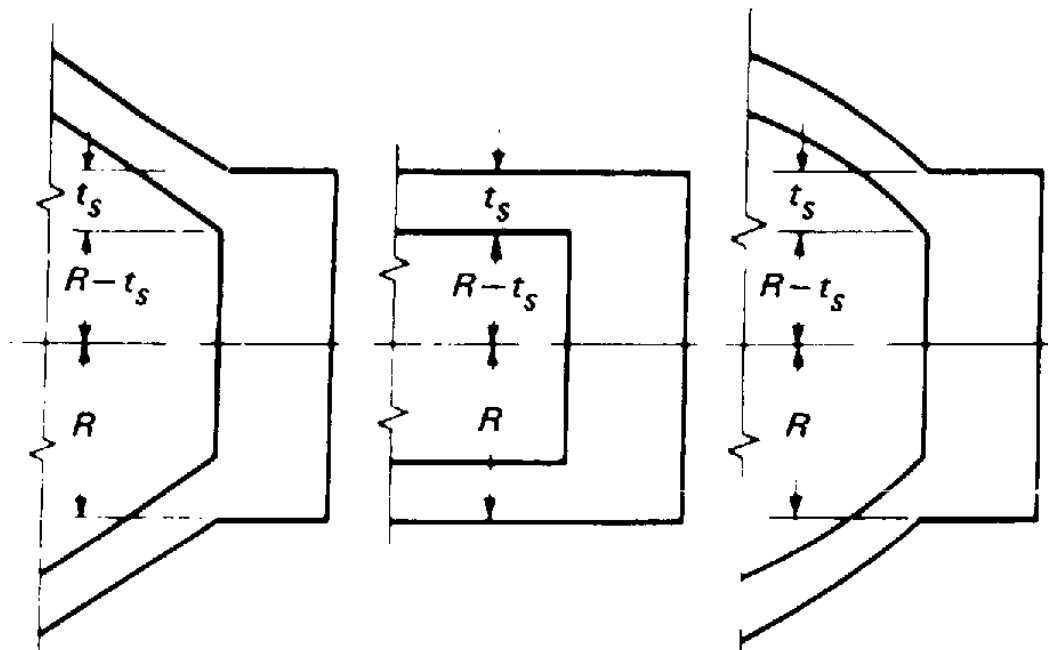


FIG. A-5221-1

FIG. A-5221-1

A-5222 Displacements and Principal Stresses in a Flat Head

The head is assumed to be separated from the adjoining shell element and under the action of the pressure load. Figure A-5222-1 illustrates this condition. The effects of the adjacent shell are represented by the pressure reaction force, the discontinuity force Q , and the discontinuity moment M . These act at the assumed junction point a . The pressure acts on the left-hand face over a circular area defined by the inside radius of the adjacent shell. The support point lies on this same face at the midradius of the adjacent shell. The equations in this paragraph are given in terms of the head dimensions R and t and multiplying factors F_1 to F_4 . These factors reflect the extent of the pressure area and the location of the junction point. The numerical values for F_1 to F_4 are given in Table A-5240-1. These are functions of the ratio of the shell thickness t_s to the head radius R .

A-5223 Displacements of a Flat Head

A-5223.1 Displacements Due to Pressure.

For a plate simply supported at a point a , the rotational displacement θ_p and the radial displacement w_p of point a , due to pressure p acting over the area defined by the radius $(R - t_s)$, are given by Eqs. (10) and (11) below:
(10 - 11)

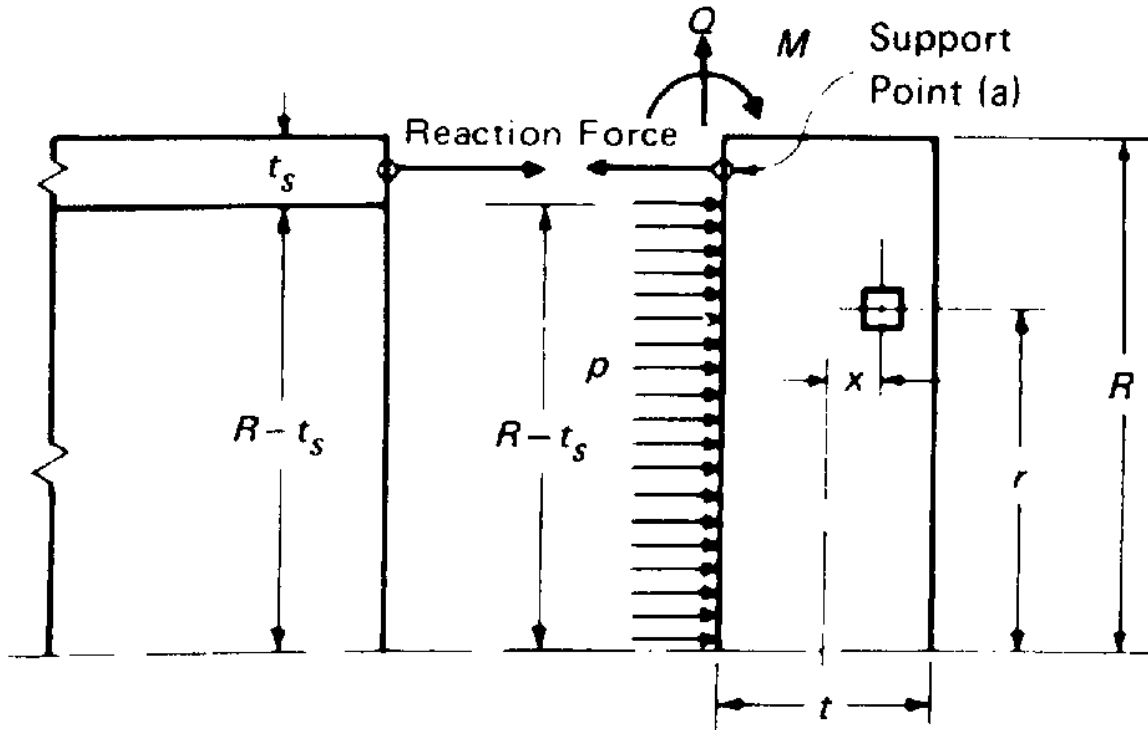


FIG. A-5222-1

FIG. A-5222-1

A-5223.2 Displacements Due to Radial Force and Moment.

The rotational displacements θ and the radial displacement w of point a , due to a uniformly distributed radial force Q and moment M acting at point a , are given by Eqs. (12) and (13) below:

$$\theta = \frac{-F_3}{ER(t/R)^2} Q + \frac{-2F_3}{ER^2(t/R)^3} M \quad (12)$$

$$w = \frac{2F_3}{3E(t/R)} Q + \frac{F_3}{ER(t/R)^2} M \quad (13)$$

(12 - 13)

A-5224 Principal Stresses in a Flat Head

When the values of the discontinuity force Q and the moment M have been determined by a discontinuity analysis, the principal stresses in a flat plate can be calculated in the following subparagraphs.

A-5224.1 Radial Stress Due to Pressure.

For a plate simply supported at point a , the radial stress σ_r for a radial location r less than $(R - t_s)$ at any point x , due to pressure p acting over the area defined by the radius $(R - t_s)$, is given by the following equation:

Page 214

$$\sigma_r = \frac{(x)p}{t(t/R)^2} \left[(F_2) - \frac{3(3 + \nu)r^2}{4R^2} \right] \quad (14)$$

(14)

A-5224.2 Tangential and Axial Stresses Due to Pressure.

For these same conditions, the tangential stress σ_t and the axial stress σ_z are given by Eqs. (15) and (16) below:

$$\sigma_t = \frac{(x)p}{t(t/R)^2} \left[(F_2) - \frac{3(1 + 3\nu)r^2}{4R^2} \right] \quad (15)$$

$$\sigma_t = (p/t)(x - t/2) \quad (16)$$

(15 - 16)

A-5224.3 Radial and Tangential Stresses Due to Radial Force and Moment.

The radial stress σ_r and the tangential stress σ_t for any radial location at any point x in the cross section, due to uniformly distributed radial force Q and a uniformly distributed moment M acting at point a , are given by the equation:

$$\sigma_r = \sigma_t = \frac{F_4}{t} \left[1 - \frac{6(x)}{t} \right] Q - \frac{12F_4(x)}{t^3} M \quad (17)$$

(17)

A-5240 GEOMETRY CONSTANTS

The geometry constants F_1 through F_4 are functions of Poisson's ratio and t_s/R . These are given in Eqs. (18) through (21) below:

$$F_1 = \frac{3(1 - \nu)(2 - f^2)(1 - f)^2 [8 - f(4 - f)(1 - \nu)]}{16(2 - f)} \quad (18)$$

$$F_2 = \frac{3}{8}(1 - f)^2 \left\{ (1 - \nu)(2 - f^2) + 4(1 + \nu) \right. \\ \left. \times \left[1 + 2 \ln \frac{2 - f}{2 - 2f} \right] \right\} \quad (19)$$

(18 - 19)

$$F_3 = \frac{3}{8}(1 - \nu)(2 - f)[8 - f(4 - f)(1 - \nu)] \quad (20)$$

$$F_4 = \frac{1}{8}[8 - f(4 - f)(1 - \nu)] \quad (21)$$

(20 - 21)

TABLE A-5240-1

t_s/R	F_1	F_2	F_3	F_4
0.00	1.0500	2.4750	4.2000	1.0000
0.02	1.0112	2.4149	4.1290	0.9930
0.04	0.9729	2.3546	4.0589	0.9861
0.06	0.9349	2.2943	3.9897	0.9793
0.08	0.8974	2.2338	3.9213	0.9725
0.10	0.8604	2.1734	3.8538	0.9658
0.12	0.8238	2.1129	3.7871	0.9592
0.14	0.7878	2.0524	3.7213	0.9527
0.16	0.7523	1.9919	3.6562	0.9462
0.18	0.7173	1.9315	3.5920	0.9398
0.20	0.6830	1.8712	3.5286	0.9335

TABLE A-5240-1

In these equations

$$f = t_s/R$$

Table A-5240-1 lists these functions for various values of t_s/R . These tabular values have been computed using 0.3 for Poisson's ratio.

A-5250 STRESS INTENSITIES IN A FLAT PLATE

The principal stresses due to pressure p , discontinuity force Q , discontinuity moment M , and other coincident loadings should be combined algebraically and the stress differences determined according to the procedures of NB-3215. The calculated stress intensity values should not exceed the stress limits given in NB-3220.

Page 215

ARTICLE A-6000 DISCONTINUITY STRESSES

A-6100 INTRODUCTION

A-6110 SCOPE

(a) Pressure vessels usually contain regions where abrupt changes in geometry, material, or loading occur. These regions are known as *discontinuity areas* and the stresses associated with them are known as *discontinuity stresses*. The discontinuity

stresses are required to satisfy the compatibility of deformations of these regions.

(b) This Article describes a general procedure for analyzing the discontinuity stresses. A numerical example is included to illustrate the procedure.

(c) To determine the principal stresses at a discontinuity, it is necessary to evaluate the stresses caused by (1) pressure; (2) mechanical loads; (3) thermal loads; and (4) discontinuity loads. The stress intensities are then obtained by superposition of the stresses according to the rules given in NB-3220.

A-6120 INFORMATION REQUIRED

In order to perform a discontinuity analysis, the following information must be known:

- (a) the dimensions of the vessel;
- (b) the material properties (E , α , ν) of the component parts of the vessel (A-7120);
- (c) mechanical loads, such as pressure, dead weight, bolt loads, and pipe loads;
- (d) temperature distribution in the component parts.

A-6200 METHOD OF AND PROCEDURE FOR DISCONTINUITY ANALYSIS

A-6210 METHOD

(a) The analysis of a pressure vessel containing discontinuity areas can be performed in a standard manner similar to the analysis of any statically indeterminate structure. The analysis is initiated by separating the vessel into shell elements of simple geometry, such as rings and cylinders, of which the structural behavior is known. The pressure, mechanical, and thermal loads acting on the structure are applied to the shell elements with a system of forces required to maintain the static equilibrium of each element. These loads and forces cause individual elements deformations, which in general are not equal at the adjoining edges. The deformations at an element edge are defined as:

- (1) radial displacement
- (2) rotation of the meridian tangent

A redundant moment and shear force must generally exist on the edges of the elements, in order to have compatibility of deformations, and restore continuity in the structure.

(b) At each juncture discontinuity, two equations can be written which express the equality of the combined deformations due to all the applied loads and the redundant forces and moments. One equation will express the equality of rotation, the other equation the equality of displacement of the adjacent elements. The resulting system of simultaneous equations can be solved to obtain the redundant moment and shear force at each juncture.

A-6220 PROCEDURE

A-6221 Basic Steps

The basic steps to follow for determining the redundant shear and moment that may exist at a pressure vessel discontinuity are given in (a) through (f) below.

- (a) Separate the vessel into individual shell elements at locations of discontinuity.
- (b) Calculate the edge deformations of each element, caused by a unit shear force and a unit moment at each edge. These values are known as influence coefficients. The deformations due to local flexibilities may be considered in the calculation of these influence coefficients.

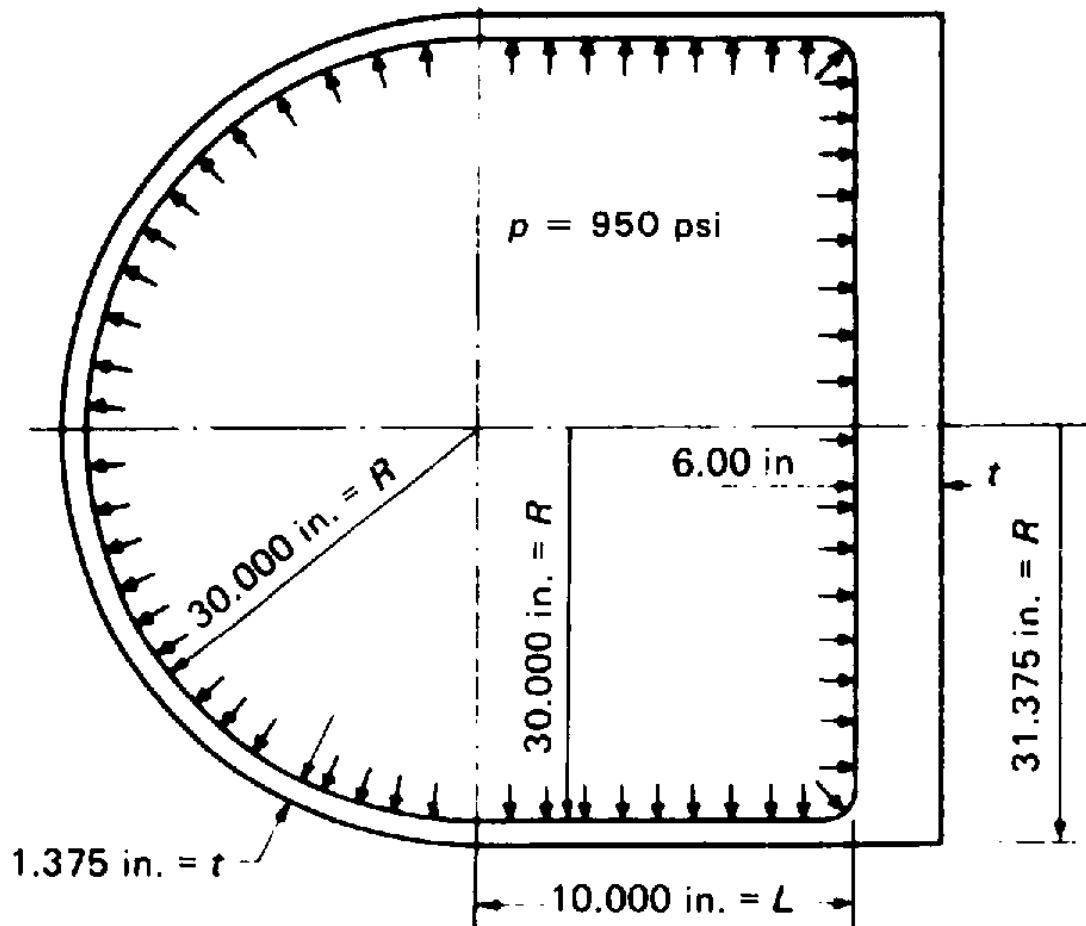


FIG. A-6230-1

FIG. A-6230-1

- (c) Calculate the edge deformations of each element, caused by loads other than redundant loads.
- (d) Calculate the edge deformations of each element, caused by the temperature distributions.
- (e) At each juncture of two elements equate the total radial displacements and the total rotations of each element.
- (f) Solve the final system of simultaneous equations for the redundant shears and moments.

[98]

A-6222 Stresses

When the values of the redundant shear forces and moments have been determined, the stresses resulting from the redundant loadings may be computed by conventional methods. The final stresses for each element are determined by combining these stresses with the stresses which would exist in the individual shell elements of A-6230, Step 1.

[98]

[98]

A-6230 EXAMPLE ILLUSTRATING APPLICATION OF A-6221

Given

A pressure vessel as shown in Fig. A-6230-1. It is constructed of SA-533, Grade B, Class 1 steel and subjected to an internal pressure of 950 psi at 300°F. The vessel consists of the following:

(a) a hemispherical head with:

inside radius $R = 30$ in.

thickness $t = 1.375$ in.

(b) a cylindrical shell with:

inside radius $R = 30$ in.

thickness $t = 1.375$ in.

length $L = 10$ in.

(c) a flat head with:

outside radius $R = 31.375$ in.

thickness $t = 6$ in.

The material properties assumed are:

$$E = 29 \times 10^6 \text{ psi}$$

$$\nu = 0.3$$

Required

To calculate the discontinuity stresses at the locations of structural discontinuity.

Solution

Step 1. Separate the vessel at locations of discontinuity into individual elements.

Step 2. Calculate the influence coefficients.

(a) *Element A, Hemispherical Head.* From A-3233.2, the lateral displacement and rotation at juncture O due to edge loads Q_o and M_o are given as:

$$w_{AO} = \delta_{AO} = -\frac{2R_m\lambda}{Et} Q_o + \frac{2\lambda^2}{Et} M_o$$

$$\theta_{AO} = -\frac{2\lambda^2}{Et} Q_o + \frac{4\lambda^3}{R_m Et} M_o$$

NOTE: For this case of a hemispherical shell the lateral force H and the radial force Q are equal. Similarly the lateral displacement δ and the radial displacement w are equal.

Substituting the given dimensions and material properties gives:

$$w_{AO} = \delta_{AO} = (-9.346755Q_o + 1.849564M_o) \times 10^{-6}$$

$$\theta_{AO} = (-1.849564Q_o + 0.731995M_o) \times 10^{-6}$$

(b) *Element B, Cylindrical Shell (See Fig. A-6230-2).* From A-2243, the radial displacements and rotations at the edges O and L due to edge loadings Q_o, M_o, Q_L , and M_L are given as follows:

$$w_{BO} = (B_{11}/2\beta^3 D)Q_o + (B_{12}/2\beta^2 D)M_o \\ + (G_{11}/2\beta^3 D)Q_L + (G_{12}/2\beta^2 D)M_L$$

$$-\theta_{BO} = (B_{12}/2\beta^2 D)Q_o + (B_{22}/\beta D)M_o \\ + (G_{12}/2\beta^2 D)Q_L + (G_{22}/2\beta D)M_L$$

$$w_{BL} = (G_{11}/2\beta^3 D)Q_o + (G_{12}/2\beta^2 D)M_o \\ + (B_{11}/2\beta^3 D)Q_L + (B_{12}/2\beta^2 D)M_L$$

$$\theta_{BL} = (G_{12}/2\beta^2 D)Q_o + (G_{22}/2\beta D)M_o \\ + (B_{12}/2\beta^2 D)Q_L + (B_{22}/\beta D)M_L$$

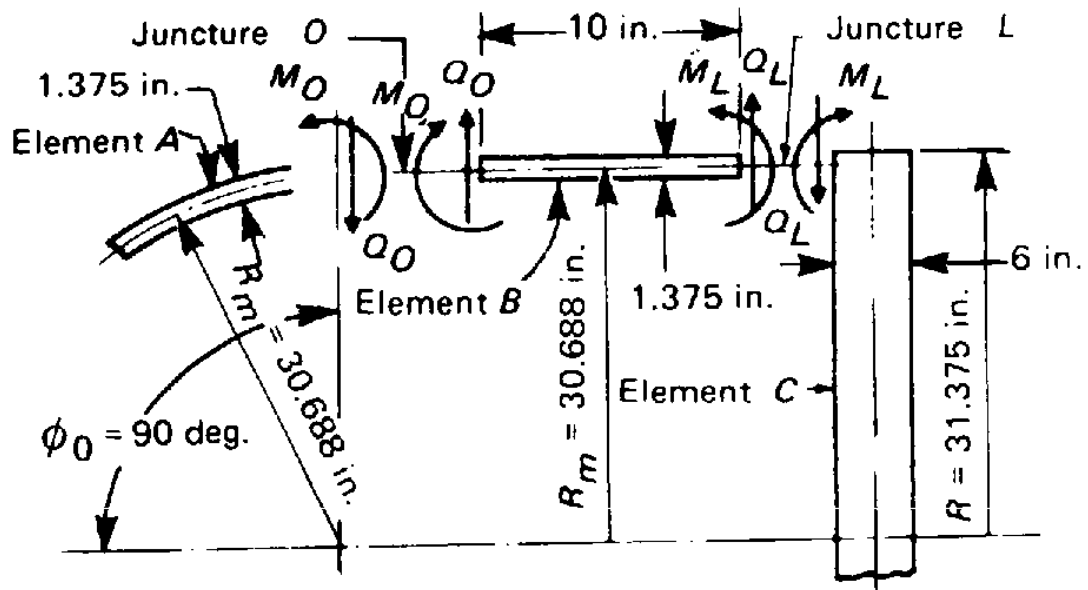


FIG. A-6230-2

FIG. A-6230-2

Substituting given dimensions and material properties gives:

$$w_{BO} = (10.697309Q_o + 2.114906M_o \\ - 3.812809Q_L - 1.025641M_L) \times 10^{-6}$$

$$-\theta_{BO} = (2.114906Q_o + 0.792367M_o \\ - 1.025641Q_L - 0.123127M_L) \times 10^{-6}$$

$$w_{BL} = (- 3.812809Q_o - 1.025641M_o \\ + 10.697309Q_L + 2.114906M_L) \times 10^{-6}$$

$$\theta_{BL} = (- 1.025641Q_o - 0.123127M_o$$

$$+ 2.114906 Q_L + 0.792367 M_L) \times 10^{-6}$$

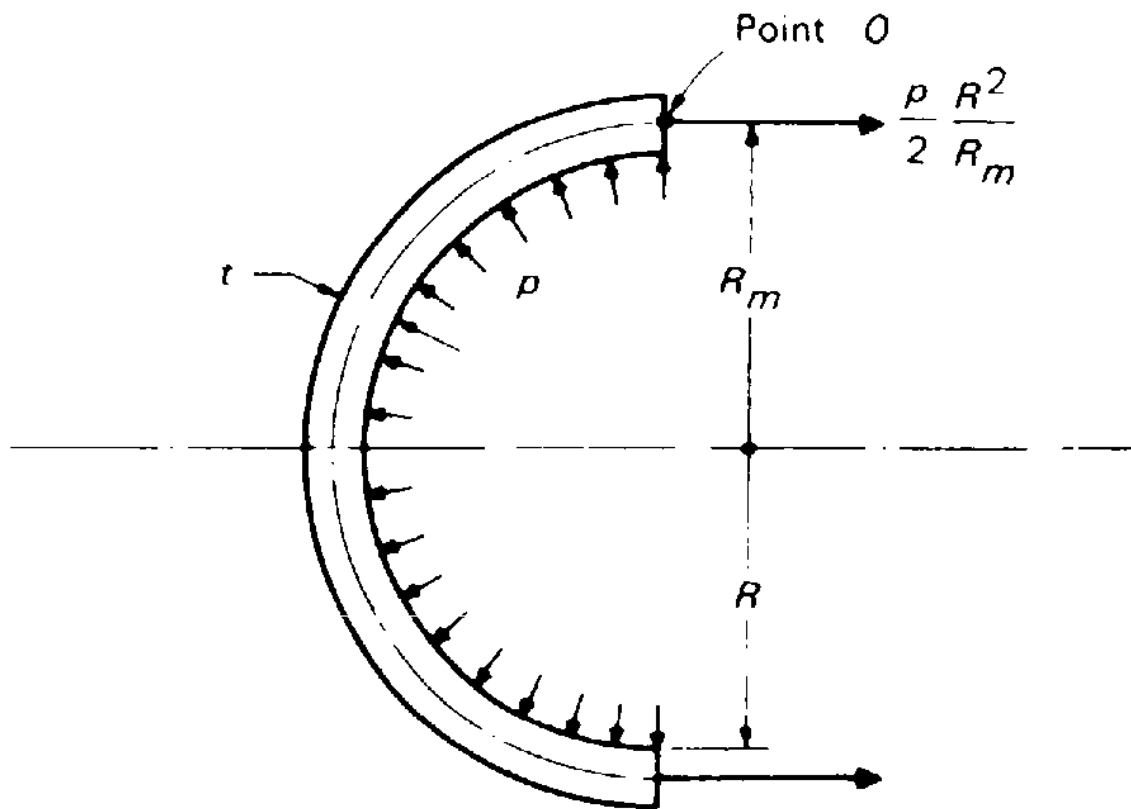


FIG. A-6230-3

FIG. A-6230-3

(c) *Element C, Flat Head.* From A-5223.2, the radial displacement and rotation at juncture L due to edge loadings Q_L and M_L are given as follows:

$$w_{CL} = -\frac{2F_3}{3E(t/R)} Q_L + \frac{F_3}{ER(t/R)^2} M_L$$

$$\theta_{CL} = \frac{F_3}{ER(t/R)^2} Q_L - \frac{2F_3}{ER^2(t/R)^3} M_L$$

Substituting given dimensions and material properties gives:

$$w_{CL} = [-0.486330Q_L + 0.121583M_L] \times 10^{-6}$$

$$\theta_{CL} = [0.121583Q_L - 0.040530M_L] \times 10^{-6}$$

Step 3. Calculate the edge deformations due to the internal pressure.

(a) *Element A, Hemispherical Shell (See Fig. A-6230-3).* The lateral displacement of point O at the midsurface ($r=R_m$) of a hemispherical shell subjected to internal pressure is given by the expression:

$$w_o = \delta_o = p \frac{R^3}{2E(R_o^3 - R^3)R_m^2} [2R_m^3(1 - 2\nu) + R_o^3(1 + \nu)]$$

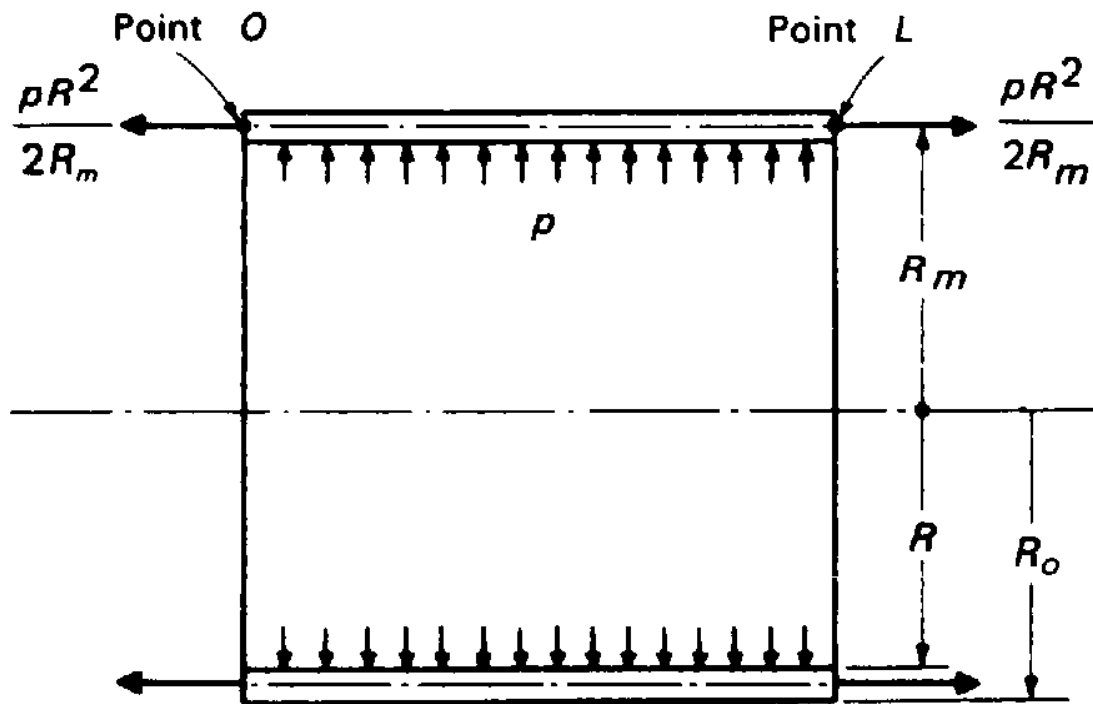


FIG. A-6230-4

FIG. A-6230-4

Substituting the dimensions, pressure, and material properties gives:

$$W_{AO(\text{pressure})} = 7647 \times 10^{-6}$$

NOTE: An alternative expression may be used for the displacement of a thin hemispherical shell:

$$w = (1 - \nu)(pR^2/2Et)$$

There is no rotation resulting from the internal pressure and membrane forces as shown:

$$\theta_{AO(\text{pressure})} = 0$$

(b) *Element B, Cylindrical Shell (See Fig. A-6230-4).* The radial displacement of the midsurface of a closed end cylindrical shell subjected to internal pressure is given by the expression:

$$w = p \frac{R^2}{E(R_o^2 - R^2)R_m} [R_m^2(1 - 2\nu) + R_o^2(1 + \nu)]$$

Substituting the dimensions, pressure, and material properties gives:

—

$$w_{BO(\text{pressure})} = w_{BL(\text{pressure})} = 18,857 \times 10^{-6}$$

NOTE: An alternative expression may be used for displacement of a thin cylindrical shell:

$$w = [1 - (\nu/2)] (pRR_m/Et)$$

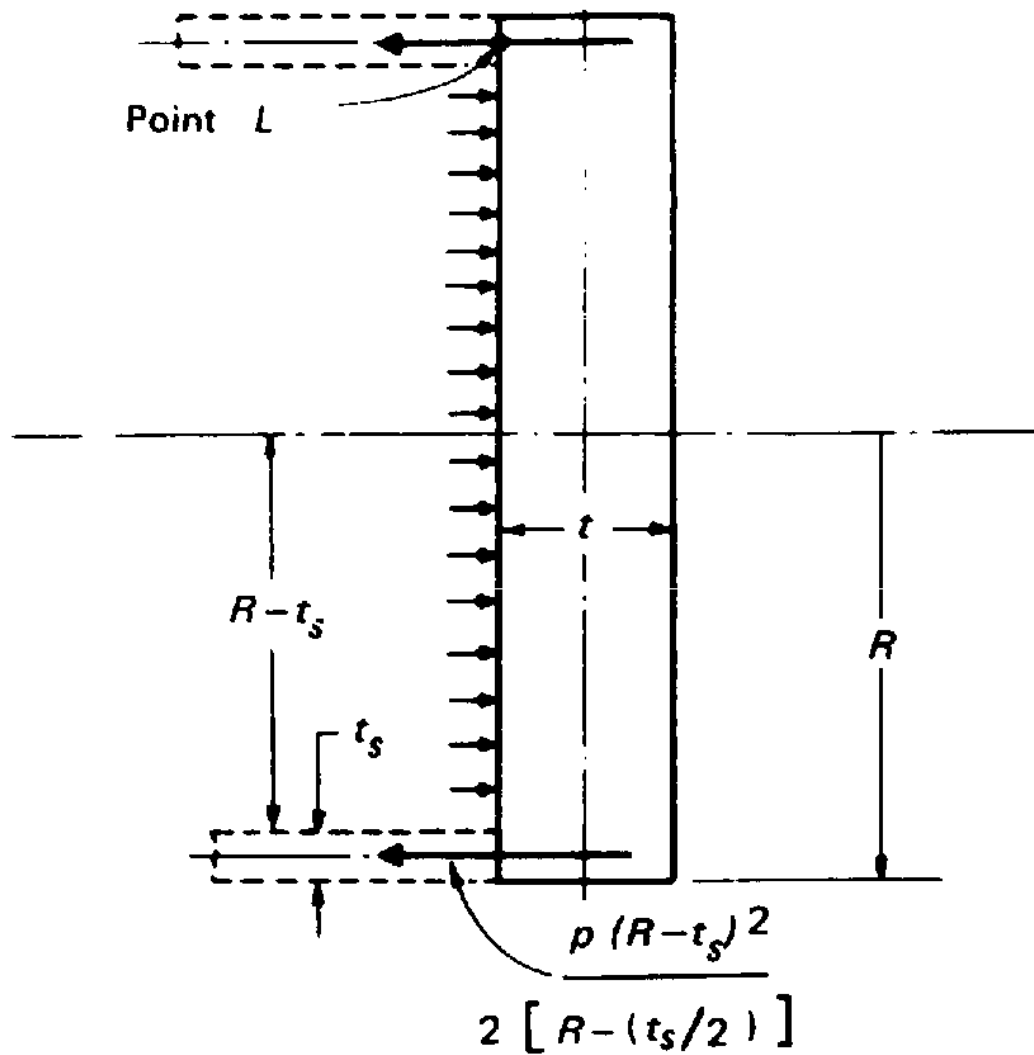


FIG. A-6230-5

FIG. A-6230-5

There is no rotation resulting from internal pressure and the membrane forces as shown:

$$\theta_{BO(\text{pressure})} = \theta_{BL(\text{pressure})} = 0$$

(c) *Element C, Flat Head* (See Fig. A-6230-5). The rotation of a flat head at point L due to internal pressure is given by Eq. (10) in A-5223.1:

$$\theta = \frac{F_1}{E(t/R)^3} p$$

Substituting the dimensions, pressure, and material properties gives:

$$\theta_{CL(\text{pressure})} = 4523 \times 10^{-6}$$

The radial displacement at juncture L is given by Eq. (11) in A-5223.1:

$$w_{CL(\text{pressure})} = -\frac{t}{2} \theta_{CL} = -13,570 \times 10^{-6}$$

Step 4. Calculate the free deformations of the edges of each element caused by temperature distributions.

In this example all parts of the vessel are at the same temperature and are of the same material; therefore, temperature deformations need not be considered.

Page 219

Step 5. Equate the total lateral displacements and rotations of adjacent elements at each juncture.

(a) *Juncture O*

$$w_{AO(\text{total})} = w_{BO(\text{total})}$$

$$(-9.346755Q_o + 1.849564M_o + 7647) \times 10^{-6}$$

$$= (10.697309Q_o + 2.114906M_o - 3.812809Q_L$$

$$- 1.025641M_L + 18,857) \times 10^{-6} \quad (1)$$

$$\theta_{AO(\text{total})} = \theta_{BO(\text{total})}$$

$$(-1.849564Q_o + 0.731995M_o + 0) \times 10^{-6}$$

$$= (-2.114906Q_o - 0.792367M_o + 1.025641Q_L$$

$$+ 0.123127M_L + 0) \times 10^{-6} \quad (2)$$

(1 - 2)

(b) *Juncture L*

$$w_{BL(\text{total})} = w_{CL(\text{total})}$$

$$(-3.812809Q_o - 1.025641M_o + 10.697309Q_L$$

$$+ 2.114906M_L + 18,857) \times 10^{-6}$$

$$= (-0.486330Q_L + 0.121583M_L - 13,570) \times 10^{-6} \quad (3)$$

$$\theta_{BL(\text{total})} = \theta_{CL(\text{total})}$$

$$(-1.025641Q_o - 0.123127M_o + 2.114906Q_L$$

$$+ 0.792367M_L + 0) \times 10^{-6} = (0.121583Q_L$$

$$-0.040530M_L + 4523) \times 10^{-6} \quad (4)$$

(3 - 4)

Combining like terms and multiplying through by 10^6 results in the following system of simultaneous equations which express compatibility at the junctures:

$$(5) -20.04364Q_o - 0.265342M_o + 3.812809Q_L + 1.025641M_L = 11,210$$

$$(6) 0.265342Q_o + 1.524362M_o - 1.025641Q_L - 0.123127M_L = 0$$

$$(7) -3.812809Q_o - 1.025641M_o + 11.183639Q_L + 1.993323M_L = -32,427$$

(8)

$o \qquad o \qquad L \qquad L$

Step 6. Solve the above equation for Q_o , M_o , Q_L , and M_L . The results are:

$$Q_o = 807 \text{ lb/in.} = -0.807 \text{ kips/in.}$$

$$M_o = -3018 \text{ in.-lb/in.} = -3.018 \text{ in.-kips/in.}$$

$$Q_L = 7259 \text{ lb/in.} = -7.259 \text{ kips/in.}$$

$$M_L = 21,363 \text{ in.-lb/in.} = 21.363 \text{ in.-kips/in.}$$

NOTE: A negative sign indicates that the actual direction of the loading is opposite to that chosen in Step 1.

Step 7. Compute the discontinuity stresses at each juncture due to the redundants Q_o , M_o , Q_L , and M_L . To illustrate the procedure, these stresses will be computed in the cylindrical shell element B at both junctures O and L . From A-2260:

$$\sigma_t(x) = \pm 6M(x)/t^2$$

$$\sigma_t(x) = Ew(x)/(R + t/2) \pm 6vM(x)/t^2$$

$$\sigma_r = 0$$

(a) *Juncture O.* At juncture O , $M(x) = M_o$ and $w(x) = w_o$.

NOTE: When computing $\sigma_t(x)$ only the radial displacement due to the redundant shear forces and moments should be used. The free displacements from Steps 3 and 4 should not be included.

Page 220

$$w_{BO} = (10.697309Q_o + 2.114906M_o - 3.812809Q_L - 1.025641M_L) \times 10^{-6} = -0.009007 \text{ in.}$$

$$Ew_{BO} = -261.20 \text{ kips/in.}$$

$$M_o = -3.018 \text{ in.-kips/in.}$$

(1) Inside surface:

$$\sigma_t = 6(-3.018)/(1.375)^2 = -9.6 \text{ ksi}$$

$$\sigma_t = (-261.20/30.6875) + 6(0.3)(-3.02)/(1.375)^2 = -11.5 \text{ ksi}$$

$$\sigma_r = 0$$

(2) Outside surface:

$$\sigma_t = -6(-3.018)/(1.375)^2 = 9.6 \text{ ksi}$$

$$\sigma_t = (-261.20/30.6875) - 6(0.3)(-3.018)/(1.375)^2 = -5.6 \text{ ksi}$$

$$\sigma_r = 0$$

(b) *Juncture L.* At juncture L , $M(x) = M_L$ and $w(x) = w_L$.

$$w_{BL} = (-3.812809Q_o - 1.025641M_o + 10.697309Q_L + 2.114906M_L) \times 10^{-6} = -0.026299 \text{ in.}$$

$$Ew = -762.67 \text{ kips/in.}$$

BL

$$M_L = 21.363 \text{ in.-kips/in.}$$

(1) Inside surface:

$$\sigma_l = 6(21.363)/(1.375)^2 = 67.8 \text{ ksi}$$

$$\sigma_t = (-762.67/30.6875) + 6(0.3)(21.363)/(1.375)^2 = -4.5 \text{ ksi}$$

$$\sigma_r = 0$$

(2) Outside surface:

$$\sigma_l = -6(21.363)/(1.375)^2 = -67.8 \text{ ksi}$$

$$\sigma_t = (-762.67/30.6875) - 6(0.3)(21.363)/(1.375)^2 = -45.2 \text{ ksi}$$

$$\sigma_r = 0$$

NOTE: $E = 29 \times 10^6$ psi.

(c) The discontinuity stresses in the hemispherical shell may be computed by using the expressions given in A-3232 and A-3234.

(d) The discontinuity stresses in the flat head may be computed using the expressions given in A-5224.

Step 8. Compute the total stresses. The total stresses may be computed in any element at any juncture by combining the stresses due to the redundant shear forces and moments as computed in Step 7, with the stresses resulting from all other loadings. In this case the stresses in the cylindrical shell, hemispherical shell, and flat head due to internal pressure may be computed by the expressions given in A-2212, A-3221, and A-5224, respectively. To illustrate the procedure the total stresses in the cylindrical shell at junctures *O* and *L* will be computed. The stresses in the cylindrical shell due to internal pressure may be computed from Eqs. (1), (2), and (3) in A-2212:

$$\sigma_l = p/(Y^2 - 1)$$

$$\sigma_t = p(1 + Z^2)/(Y^2 - 1)$$

$$\sigma_r = p(1 - Z^2)/(Y^2 - 1)$$

(a) *Juncture O*

(1) Inside surface:

Page 221

$$Y = Z = R_o/R = 31.375/30.000 = 1.04583$$

$$p = 950 \text{ psi}$$

$$\sigma_l = 10,132 \text{ psi B } 10.1 \text{ ksi}$$

$$\sigma_t = 21,214 \text{ psi B } 21.2 \text{ ksi}$$

$$\sigma_r = -950 \text{ psi B } -1 \text{ ksi}$$

The stresses due to the redundant shear forces and moments were computed in Step 7 as:

$$\sigma_l = -9.6 \text{ ksi}$$

$$\sigma_t = -11.5 \text{ ksi}$$

$$\sigma_r = 0$$

The total stresses are:

$$\sigma_l = 10.1 + (-9.6) = 0.5 \text{ ksi}$$

$$\sigma_t = 21.2 + (-11.5) = 9.7 \text{ ksi}$$

$$\sigma_r = -0.95 + 0 = -1.0 \text{ ksi}$$

(2) Outside surface:

$$Z = 1$$

$$Y = 1.04583$$

$$\sigma_l = 10,132 \text{ psi} \approx 10.1 \text{ ksi}$$

$$\sigma_t = 20,264 \text{ psi} \approx 20.3 \text{ ksi}$$

$$\sigma_r = 0$$

The stresses due to the redundant shear forces and moments were computed as:

$$\sigma_l = 9.6 \text{ ksi}$$

$$\sigma_t = -5.6 \text{ ksi}$$

$$\sigma_r = 0$$

The total stresses are:

$$\sigma_l = 10.1 + (9.6) = 19.7 \text{ ksi}$$

$$\sigma_t = 20.3 + (-5.6) = 14.7 \text{ ksi}$$

$$\sigma_r = 0 + 0 = 0$$

(b) *Juncture L*

(1) *Inside Surface.* The stresses due to the internal pressure are the same as at juncture O:

$$\sigma_l = 10.1 \text{ ksi}$$

$$\sigma_t = 21.2 \text{ ksi}$$

$$\sigma_r = -1.0 \text{ ksi}$$

The stresses due to the redundant shear forces and moments were computed as:

$$\sigma_l = 67.8 \text{ ksi}$$

$$\sigma_t = -4.5 \text{ ksi}$$

$$\sigma_r = 0$$

The total stresses are:

$$\sigma_t = 10.1 + (67.8) = 77.9 \text{ ksi}$$

$$\sigma_t = 21.2 + (-4.5) = 16.7 \text{ ksi}$$

$$\sigma_r = -0.95 + 0 = -1.0 \text{ ksi}$$

(2) *Outside Surface.* The stresses due to the internal pressure are the same as at juncture *O*:

Page 222

$$\sigma_t = 10.1 \text{ ksi}$$

$$\sigma_t = 20.3 \text{ ksi}$$

$$\sigma_r = 0$$

The stresses due to redundant shear forces and moments were computed as:

$$\sigma_t = -67.8 \text{ ksi}$$

$$\sigma_t = -45.2 \text{ ksi}$$

$$\sigma_r = 0$$

The total stresses are:

$$\sigma_t = 10.1 + (-67.8) = -57.7 \text{ ksi}$$

$$\sigma_t = 20.3 + (-45.2) = -24.9 \text{ ksi}$$

$$\sigma_r = 0 + 0 = 0$$

Step 9

(a) When evaluating the stresses in accordance with NB-3222.2, the stress intensities at each location should be computed from the total principal stresses determined in Step 8.

(b) When evaluating the stresses in accordance with NB-3222.4(b), it is necessary to consider the influence of local stress concentrations upon the principal stresses determined in Step 8 before computing the stress intensities.

[98]

Page 223

ARTICLE A-7000 THERMAL STRESSES

A-7100 INTRODUCTION

A-7110 OCCURRENCE OF THERMAL STRESSES AND DISPLACEMENTS

(a) Thermal stresses occur in a system, or part of a system, when thermal displacements (expansions or contractions) which would otherwise freely occur are partially or completely restrained.

(b) Thermal displacements may be induced by temperature distributions caused by heat transfer and internal heat generation.

[98]

A-7120 INFORMATION NECESSARY TO CALCULATE THERMAL STRESSES

(a) In order to calculate thermal stresses, the information stipulated in (1), (2), and (3) below must usually be known for each member comprising the system:

(1) the dimensions;

(2) the temperature distribution T as a function of a suitable coordinate system;

(3) the material properties: modulus of elasticity E , Poisson's ratio ν , and coefficient of thermal expansion α , where E and α are temperature dependent quantities (Tables TE and TM of Section II, Part D, Subpart 2 provide these values).

(b) Frequently, it is accurate enough to consider E and α for each material as constant at their instantaneous values for the average temperature of the temperature range under consideration. If the lower limit of the temperature range is ambient, the instantaneous value of α for the average temperature coincides with the mean coefficient of thermal expansion.

(c) During transient conditions, the temperature distribution and thermal stresses vary with time. The analysis, therefore, requires consideration of the thermal stresses as a function of time during the transient.

[98]

A-7130 METHOD OF CALCULATION

If closed form expressions for the thermal stresses are not available, the procedure of (a) through (e) below may be used for computing the thermal stress for a specified time θ .

(a) Express the temperature distribution T for each component as a function of the space coordinates t , l , and r .

(b) Divide the system, which may be of irregular shape or of complex geometry, into free bodies of simple shape, such as rings, cylinders, and spherical shells.

(c) Calculate the free body stresses and deformations for each component resulting from the temperature distribution.

(d) Calculate the discontinuity thermal stresses by means of discontinuity analysis as described in A-6000.

(e) Superimpose the stresses determined in (c) and (d) above to obtain the combined thermal stresses.

Page 224

ARTICLE A-8000 STRESSES IN PERFORATED FLAT PLATES

A-8100 INTRODUCTION

A-8110 SCOPE

(a) This Article contains a method of analysis for flat perforated plates when subjected to directly applied loads or loadings resulting from structural interaction with adjacent members. This method applies to perforated plates which satisfy the conditions of (1) through (5) below.

(1) The holes are in an array of equilateral triangles.

(2) The holes are circular.

(3) There are 19 or more holes.

(4) The ligament efficiency is greater than 5% ($\eta \geq 0.05$).

(5) The plate is thicker than twice the hole pitch ($t/P \geq 2$). If only in-plane loads or thermal skin stresses are considered, this limitation does not apply.

(b) Credit may be taken for the stiffening effect of the tubes in the perforations. The extent to which the tubes stiffen the perforated plate depends on the materials, the manufacturing processes, operating conditions, and degree of corrosion. This stiffening effect may be included in the calculations by including part or all of the tube walls in the ligament efficiency used to obtain the effective elastic constants of the plate. Such stiffening may either increase or decrease stresses in the plate itself and in the attached shells.

(c) Credit may be taken for the staying action of the tubes where applicable.

A-8120 NOMENCLATURE

h	= nominal width of ligament at the minimum cross section, in.
P	= nominal distance between hole center lines, pitch, in.
t	= thickness of plate exclusive of cladding or corrosion allowance, in.
η	= ligament efficiency = h/P
ν^*	= effective Poisson's ratio for perforated plate (Fig. A-8131-1)
E^*	= effective Young's modulus for perforated plate (Fig. A-8131-1), psi
R^*	= the effective radius of the perforated plate, in. = $r_o + 1/4 (P - h)$
r_o	= radial distance from center of plate to center of outermost hole, in.
p_1, p_2	= pressures acting on surfaces of the plate, psi
Δp	= differential pressure across the plate
σ_r	= radial stresses in the equivalent solid plate, psi
σ_θ	= tangential stress in the equivalent solid plate, psi
β	= biaxiality ratio σ_r/σ_θ or σ_θ/σ_r (σ_1/σ_2 or σ_2/σ_1), where $-1 \leq \beta \leq 1$
σ_{ave}	= larger absolute value of σ_r or σ_θ [A-8142.1(b)]
$\bar{\sigma}_r$	= radial stress averaged through the depth of the equivalent solid plate, psi
σ_1, σ_2	= principal stress in the plane of the equivalent solid plate (A-8142.2), psi
σ_{rim}	= nominal circumferential stress in solid rim, psi
σ_{skin}	= thermal skin stress, psi
r	= designation of radial location in plate
ρ	= radius of holes in the plate, in.
K	= stress multiplier for stresses averaged across the width of the ligament but not through the thickness (Fig. A-8142-1)
Y	= stress multiplier for peak ligament stresses (Fig. A-8142-1)

K_m	= ratio of peak stress in reduced ligament to the peak stress in normal ligament
K_{skin}	= stress multiplier for thermal skin stress (Fig. A-8153-1)
K_r	= stress multiplier for circumferential stress in the plate rim (Fig. A-8142-6)
S	= stress intensity (A-8142), psi
w	= radial displacement of plate edge, in.
θ	= rotation of plate edge, rad

Page 225

Q	= radial force acting at edge of plate, lb/in. of circumference
M	= radial moment acting at edge of plate, in.-lb/in. of circumference
W	= total ring load acting on plate (Fig. A-8132.2-1), lb
ν	= Poisson's ratio
E	= Young's modulus for plate material, psi
E_t	= Young's modulus for tube material, psi
T_m	= mean temperature averaged through the thickness of the plate, °F
T_s	= temperature of the surface of the plate, °F
α	= coefficient of thermal expansion, in./in.-°F
t_t	= tube wall thickness, in.
p_s	= pressure on surface where stress is computed, p_1 or p_2 , psi
p_i	= pressure inside tubes, psi
$\ln$	= $\log_e$
c	= radius of ring load (Fig. A-8132.2-1), in.
x	= axis of symmetry of hole pattern through the smaller ligament thickness (Figs. A-8142-3 through A-8142-5)
y	= axis of symmetry of hole pattern, perpendicular to x axis

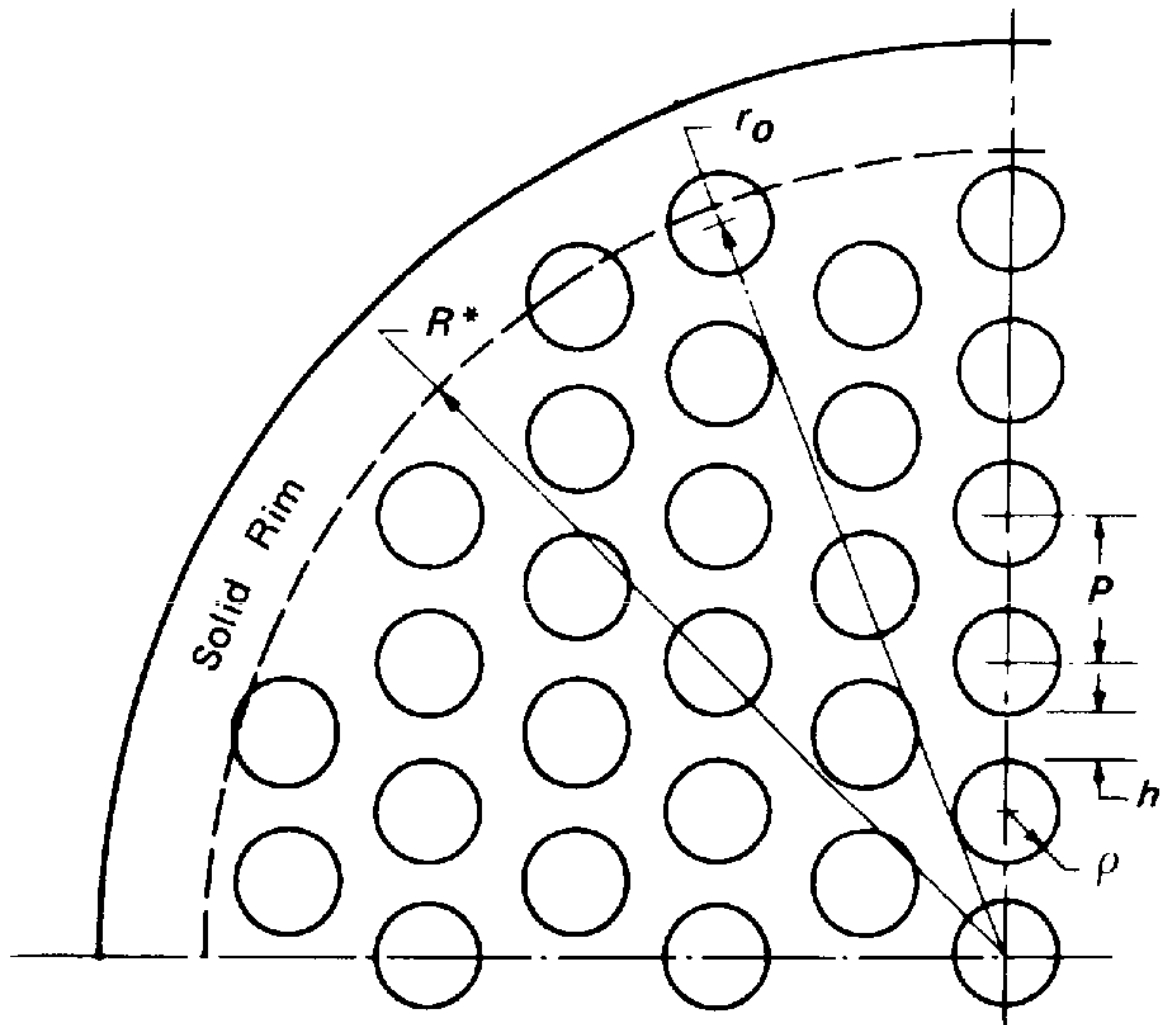


FIG. A-8120-1

FIG. A-8120-1

A-8130 ANALYSIS OF CIRCULAR PERFORATED AREA

[98]

A-8131 Procedure

(a) The analysis method for perforated plates presented in this Article utilizes the concept of the equivalent solid plate. In this method, the perforated plate is replaced by a solid plate which is geometrically similar to the perforated plate but has modified values of the elastic constants.

(b) The elastic modulus E and Poisson's ratio ν are replaced by the effective elastic modulus E^* and effective Poisson's ratio ν^* of the perforated plate, and conventional equations for plates are used to determine the deformations and nominal stresses for the equivalent solid plate. The deformations so computed may be used directly in evaluating interaction effects. The actual values of the stress intensities in the perforated plate are determined by applying multiplying factors to the nominal stresses computed for the equivalent solid plate.

(c) The effective elastic constants are functions of the ligament efficiency η . The values are given in Fig. A-8131-1 for the range of $0.05 \leq \eta \leq 1.0$ in the form of ν^* vs. η for a material with $\nu = 0.3$, and E^*/E vs. η . The stress multipliers are given in Figs. A-8142-1 through A-8142-6. The Y factors presented in Figs. A-8142-3 and A-8142-4 represent the largest values occurring through the thickness at the given angular position.

(d) The region of the perforated plate outside the effective radius R^* is called the plate rim. This unperforated portion of the plate may be considered as a separate connecting member, a ring or cylinder, and the structure may be analyzed in accordance with the procedures of A-6000.

[98]

A-8132 Analysis of Equivalent Solid Plate

In the following subparagraphs, equations are given for the nominal stresses and edge displacements for the equivalent solid circular plate under various axisymmetric load conditions.

A-8132.1 Edge Loads (See Fig. A-8132.1-1)

(a) Stresses at any location on the surface of the equivalent solid plate.

$$\sigma_r = \sigma_\theta = \frac{Q}{t} \pm \frac{6M}{t^2} \quad (1)$$

(1)

When double signs are used, the upper sign applies to the top surface as shown in Fig. A-8132.1-1.

(b) Edge displacements of midplane at R^* :

$$w = \frac{R^*}{E^*t} (1 - \nu^*) Q \quad (2)$$

$$\theta = - \frac{12R^*}{E^*t^3} (1 - \nu^*) M \quad (3)$$

(2 - 3)

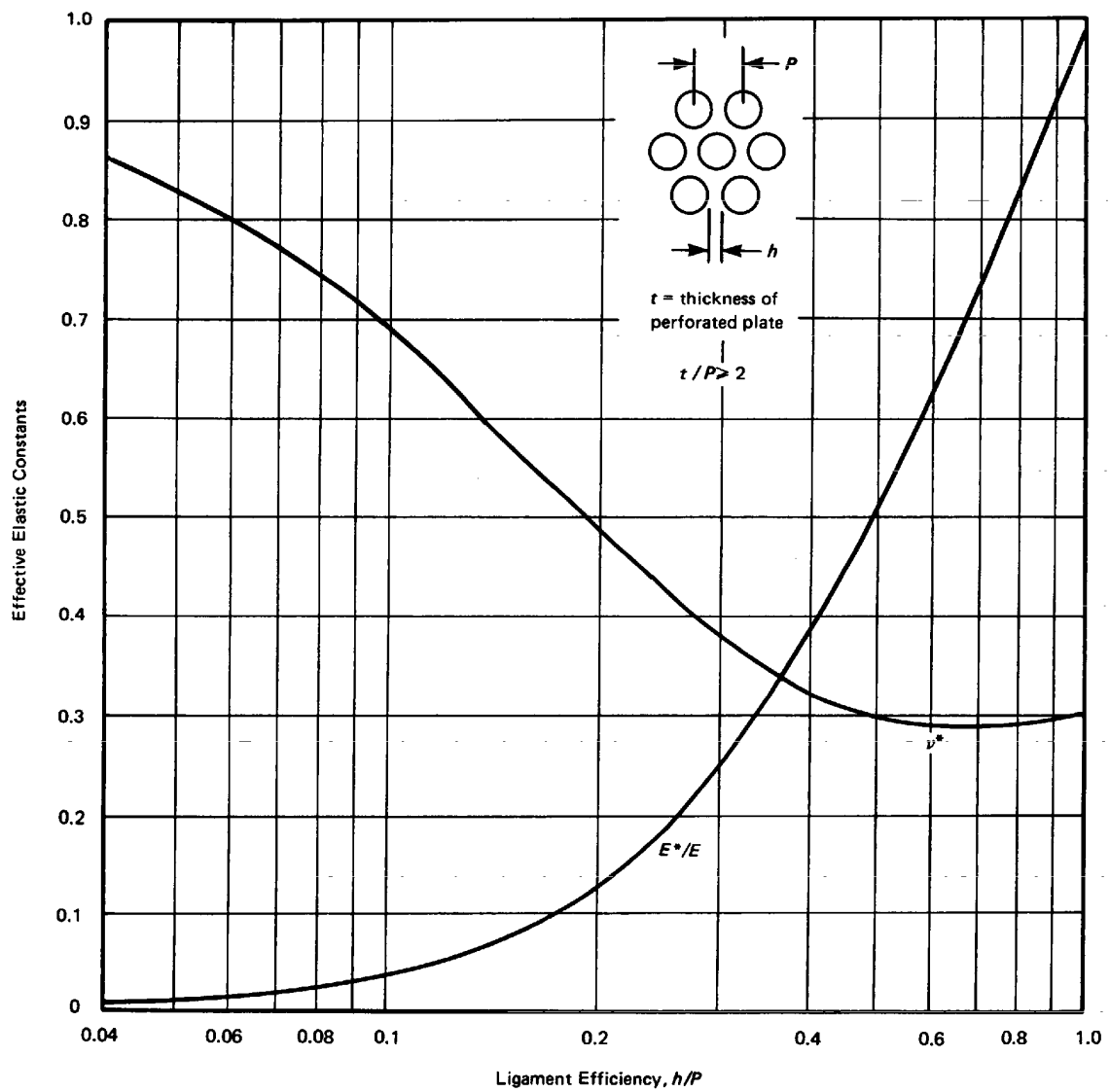


FIG. A-8131-1

FIG. A-8131-1

A-8132.2 Ring Loads Transverse to the Plane of the Plate (See Fig. A-8132.2-1)

(a) Stresses at any radial location r on the surfaces of the equivalent solid plate: for $r \leq c$,

$$\sigma_r = \sigma_\theta = \pm \frac{3W}{2\pi t^2} \left[\frac{1}{2} (1 - \nu^*) - \frac{1}{2} (1 - \nu^*) \times \left(\frac{c}{R^*} \right)^2 + (1 + \nu^*) \ln \frac{R^*}{c} \right] \quad (4)$$

(4)

for $r > c$,

$$\sigma_r = \pm \frac{3W}{2\pi t^2} \left[\frac{1}{2} (1 - \nu^*) \left(\frac{c}{r} \right)^2 - \frac{1}{2} (1 - \nu^*) \times \left(\frac{c}{R^*} \right)^2 + (1 + \nu^*) \ln \frac{R^*}{r} \right] \quad (5)$$

$$\sigma_\theta = \pm \frac{3W}{2\pi t^2} \left[(1 - \nu^*) - \frac{1}{2} (1 - \nu^*) \left(\frac{c}{r} \right)^2 - \frac{1}{2} (1 - \nu^*) \times \left(\frac{c}{R^*} \right)^2 + (1 + \nu^*) \ln \frac{R^*}{r} \right] \quad (6)$$

(5 - 6)

(b) Edge displacements of midplane at $r = R^*$:

$$(7) w = 0$$

$$\theta = \frac{3R^*}{\pi E^* t^3} (1 - \nu^*) \left[1 - \left(\frac{c}{R^*} \right)^2 \right] [W] \quad (8)$$

(8)

A-8132.3 Uniformly Distributed Pressure Loads (See Fig. A-8132.3-1)

(a) Stresses at any location r on the surfaces of the equivalent solid plate:

$$\sigma_r = \pm \frac{3}{8} \left(\frac{R^*}{t} \right)^2 (3 + \nu^*) \left[1 - \left(\frac{r}{R^*} \right)^2 \right] [\Delta p] \quad (9)$$

$$\sigma_\theta = \pm \frac{3}{8} \left(\frac{R^*}{t} \right)^2 \left[(3 + \nu^*) - (1 + 3\nu^*) \left(\frac{r}{R^*} \right)^2 \right] [\Delta p] \quad (10)$$

(9 - 10)

(b) Edge displacement of midplane at $r = R^*$:

$$w = \frac{\nu R^*}{E} \left(\frac{p_1 + p_2}{2} \right) \quad (11)$$

$$\theta = \frac{3}{2} \frac{(R^*)^3}{E^* t^3} (1 - \nu^*) [\Delta p] \quad (12)$$

(11 - 12)

A-8132.4 Pressure in Tubes or Perforations (See Fig. A-8132.4-1)

(a) Stresses at any location in the equivalent solid plate:

$$\sigma_r = \sigma_\theta = \frac{h}{P} \frac{(P - h - 2t_f)}{\left[h + 2 \left(\frac{E_f}{E} \right) t_f \right]} p_i \quad (13)$$

(13)

(b) Edge displacements of midplane at $r = R^*$:

$$w = \frac{R^*}{E} \left[\frac{E}{E^*} (1 - \nu^*) - (1 - \nu) \right] p_i \quad (14)$$

(14)

where E^*/E and v^* should be evaluated for the ligament efficiency:

$$\frac{h}{P} = \frac{h + (2E_t/E)t_t}{P} \quad (15)$$

(15)

using Fig. A-8131-1;

$$\theta = 0$$

A-8140 STRESS INTENSITIES AND STRESS LIMITS FOR PERFORATED PLATES

A-8141 Equations for Stress Intensities

In A-8140 equations are given for the stress intensities in a perforated plate using the stresses determined for the equivalent solid plate.

Page 228

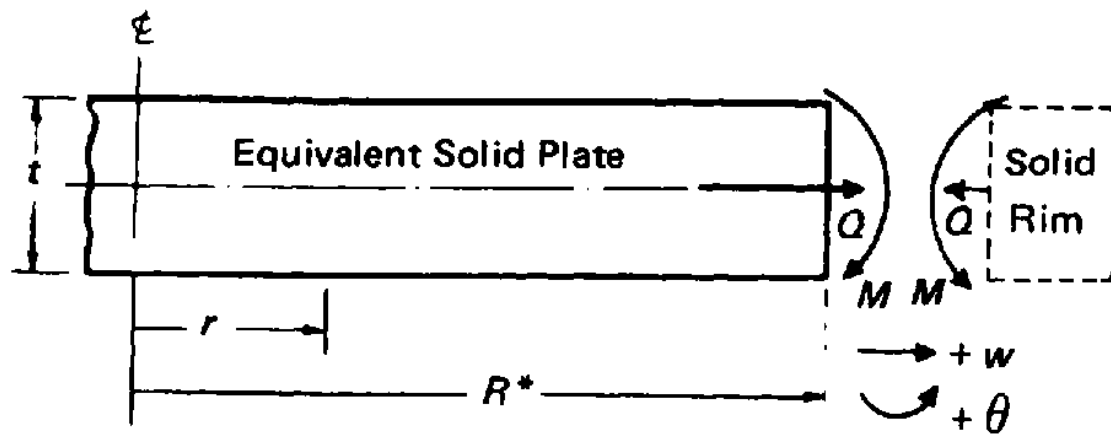


FIG. A-8132.1-1

FIG. A-8132.1-1

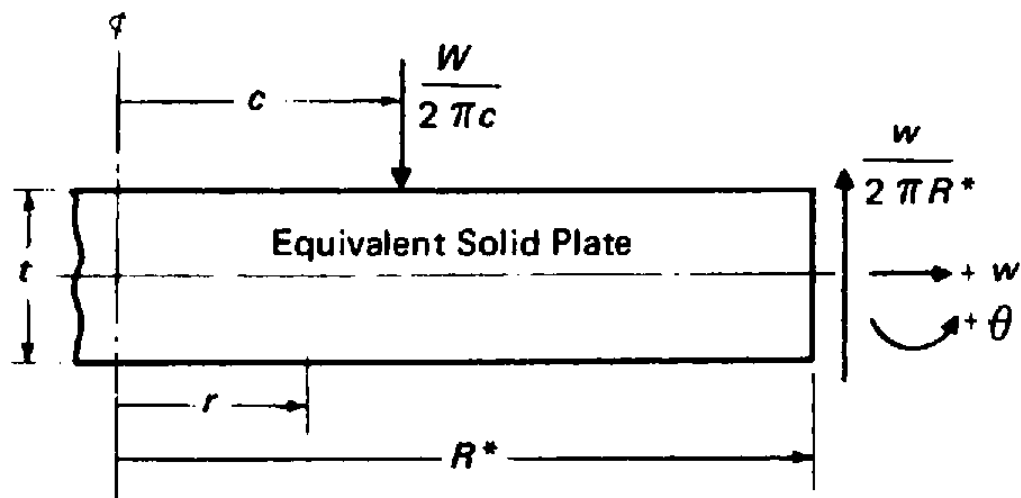


FIG. A-8132.2-1

A-8142 Typical Ligaments in a Uniform Pattern**A-8142.1 Mechanical and Pressure Loads on Circular Plates**

(a) The stress intensity based on stresses averaged across the minimum ligament width and through the thicknesses of the plate is limited according to NB-3221.1 and is computed from the larger of:

$$S = \frac{P}{h} \sqrt{\left(\frac{\Delta p R^*}{t} + \frac{W}{\pi t R^*}\right)^2 + (\bar{\sigma}_r)^2} \quad (16)$$

(16)

or

$$S = \frac{1}{2} \frac{P}{h} \left[\sqrt{\left(\frac{\Delta p R^*}{t} + \frac{W}{\pi t R^*}\right)^2 + (\bar{\sigma}_r)^2} + \bar{\sigma}_r + (2p_i h/P) \right] \quad (17)$$

(17)

where only the positive root is used. The first term under the radical reflects the effect of the transverse shear stress due to the mechanical and pressure loads. It is a maximum in the outermost ligament of the perforated region, but it may be determined for any radius, larger than c , by substituting r for R^* in the expression. For $r < c$, the $W/\pi t R^*$ term should be omitted. $\bar{\sigma}_r$ is the stress resulting from applied in-plane loading averaged through the thickness of the equivalent solid plate. It includes the stresses due to pressure in the tubes or perforations given in A-8132.4. No bending stresses are included.

(b) The stress intensity based on stresses averaged across the minimum ligament width but not through the thickness of the plate is limited according to NB-3221.3 and is computed from

$$(18) S = K (P/h) \sigma_{ave}$$

where

K

= stress multiplier from Fig. A-8142-1

σ_{ave}

= larger value of σ_r or σ_θ , psi, caused by mechanical loading and structural interaction with adjacent members, computed as the sum of the surface stresses in the equivalent solid plate, using the applicable formulas in A-8130

However, supporting interactions from adjacent members may only be considered if the primary plus secondary stresses in such members are limited to $1.5S_m$. Effects of temperature are not included.

A-8142.2 Combined Mechanical and Thermal Effects

(a) The range of the stress intensity based on stresses averaged across the minimum ligament width but not through the thickness of the plate is limited according to NB-3222.2 and is computed from

$$(19) S = K (P/h) \sigma_I$$

where

K

= stress multiplier from Fig. A-8142-1

σ_I

= larger absolute value of σ_r or σ_θ , psi, caused by mechanical loading or structural interaction with adjacent members, computed as the sum of the surface stresses in the equivalent solid plate using the applicable equations in A-8130 and A-8150

The effects of temperature are included in the consideration of the structural interaction with adjacent members.

(b) The peak stress intensity due to all loadings is limited by cumulative fatigue considerations as described in NB-3222.4 and is given by:

$$(20) S = Y_{\max} (P/h) \sigma_I + p_s$$

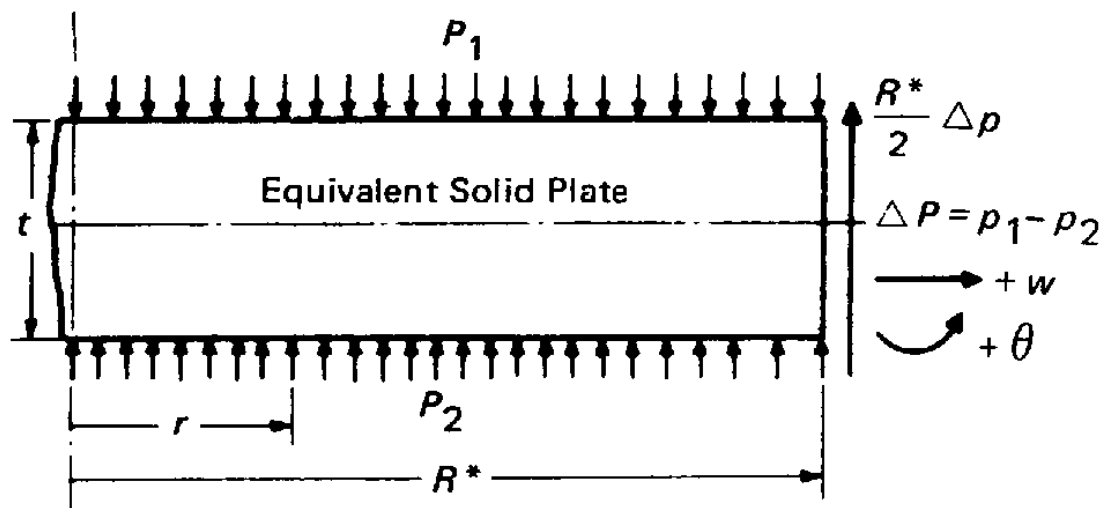


FIG. A-8132.3-1

FIG. A-8132.3-1

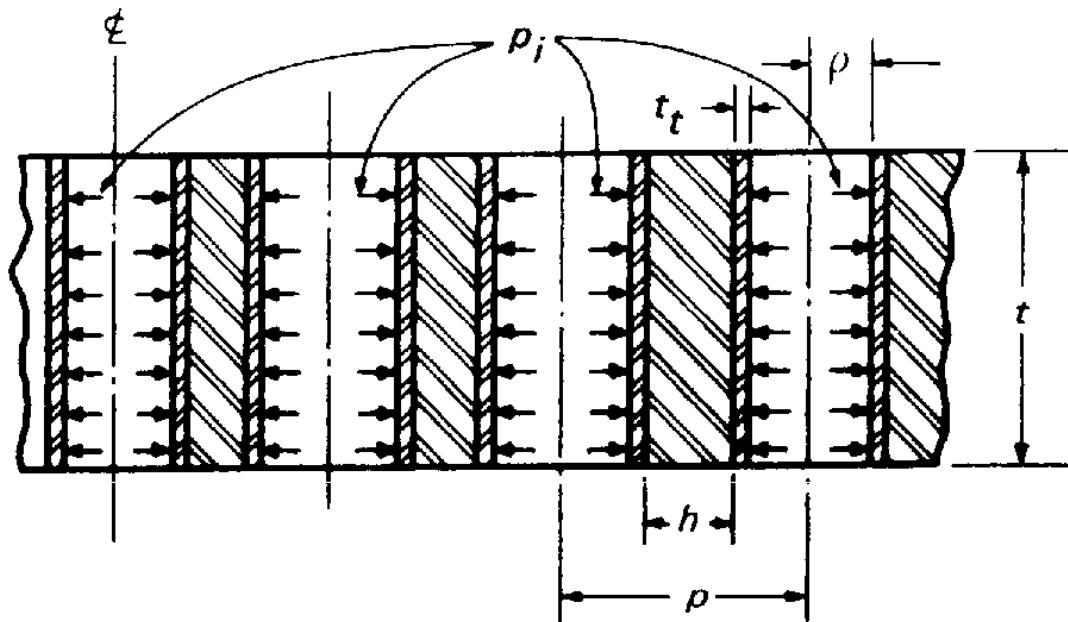


FIG. A-8132.4-1

FIG. A-8132.4-1

where

p_s

= pressure on the surface where the stress is being computed, psi

σ_1

= principal stress being the largest absolute value in the plane of the equivalent solid plate, psi

σ_2

= principal stress having the smallest absolute value in the plane of the equivalent solid plate, psi (Equivalent solid plate stresses due to various loads shall be superimposed in order to obtain σ_1 and σ_2 before any multipliers are applied, and the signs of σ_1 and σ_2 should be maintained.)

$Y_{\max}$

= stress multiplier given in Fig. A-8142-2 as a function of the biaxiality ratio $\beta = \sigma_2/\sigma_1$

The solid curves in Fig. A-8142-2 give the maximum stress multipliers for the worst angular orientation of σ_1 and σ_2

with respect to the axes of symmetry x and y of the hole pattern. In some cases, the worst orientation may not exist anywhere in the plate, and the use of lower stress multipliers is justified. An important case concerns the thermal stress produced by a temperature gradient across the diametral lane in a perforated plate. Such a gradient causes a uniaxial stress oriented parallel to the diametral lane. If the diametral lane is parallel to the y axis as shown in Fig. A-8142-3, the stress multiplier given by the dashed line in Fig. A-8142-2 may be used.

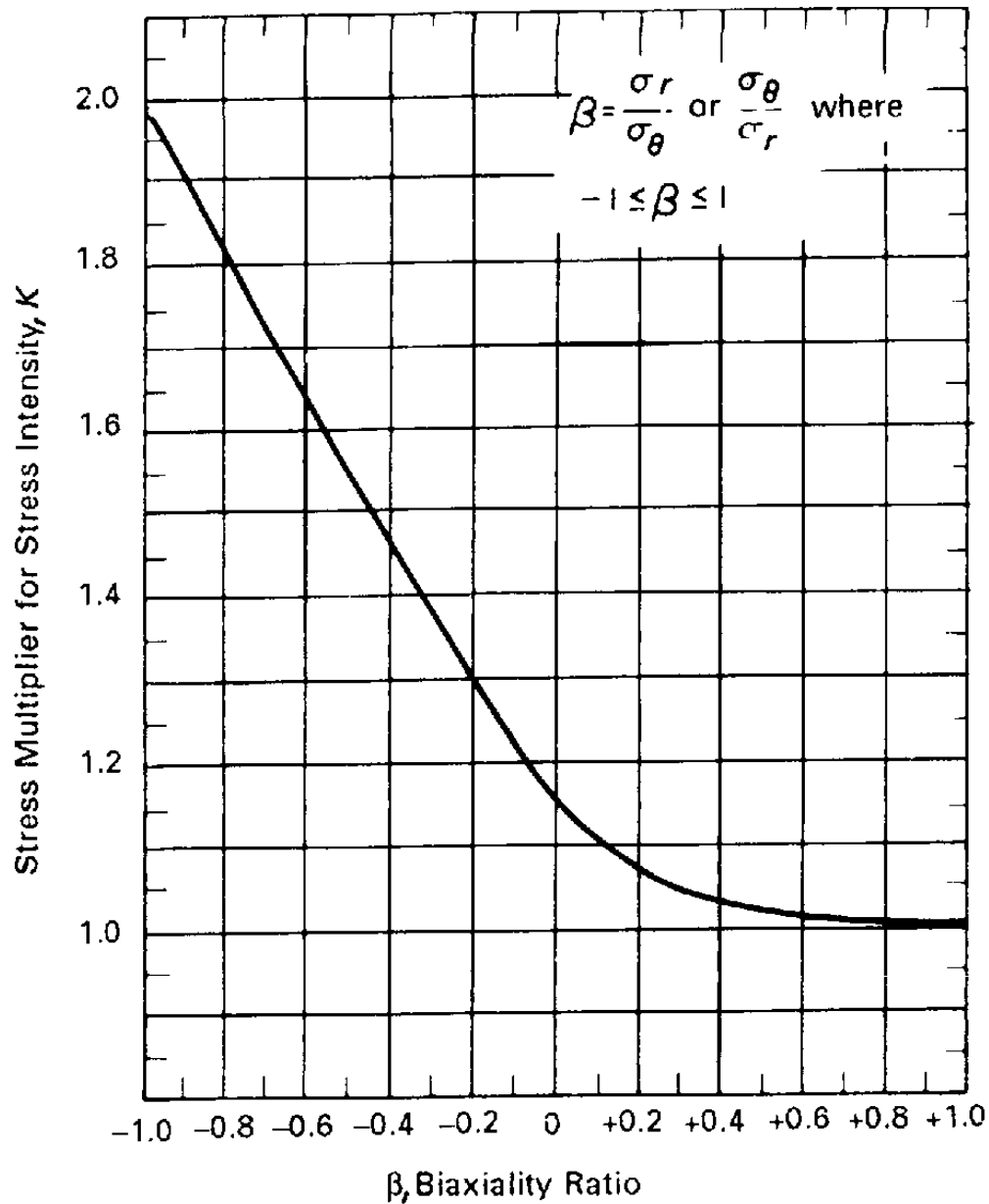


FIG. A-8142-1

FIG. A-8142-1

(c) Equation (20) will give the maximum stress intensity for any loading system. Equation (20) is not adequate for more complex cyclic histories where the angular orientation of the maximum stress intensity varies during the cycle. In such cases, it is necessary to compute the stress history at each angular orientation ϕ using Eq. (21):

$$(21) S_{\phi} = Y_1(P/h)\sigma_1 + Y_2(P/h)\sigma_2 + p_s$$

where

S_{ϕ}

= peak stress intensity at the angular orientation ϕ

Y_1, Y_2

= stress multipliers in Figs. A-8142-3 through A-8142-5 for various orientations of the principal stresses σ_1 and σ_2 computed for the equivalent solid plate

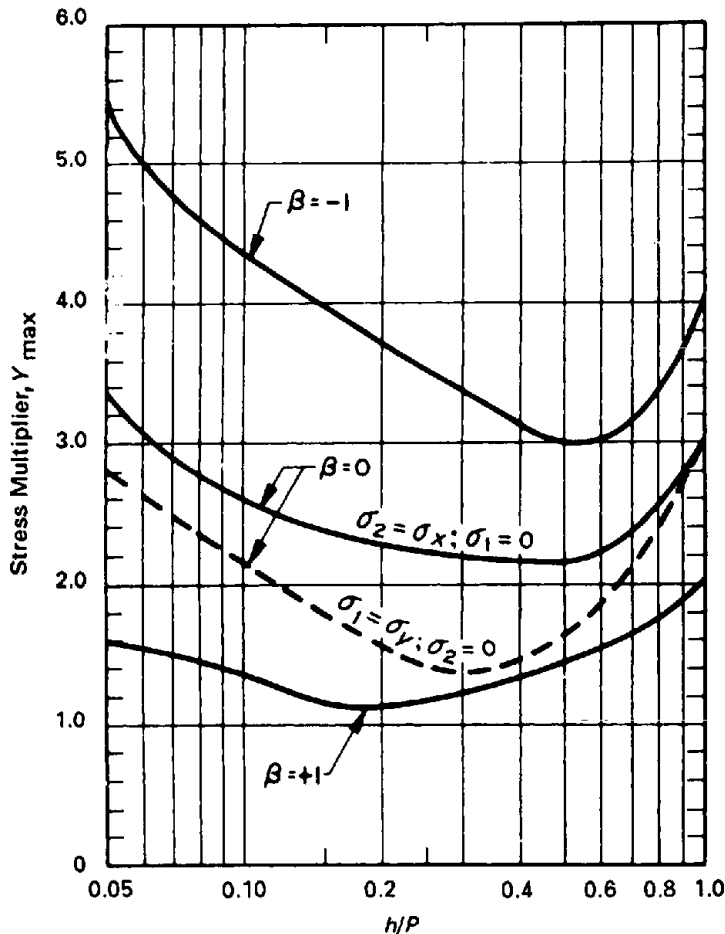


FIG. A-8142-2

FIG. A-8142-2

Note that these figures give stress multipliers for particular angular orientation only. The graph for the angular orientation closest to the actual angular orientation should be used. This is sufficiently accurate since the maximum possible difference between the actual orientation and the nearest orientation given in Figs. A-8142-3 through A-8142-5 is only 7.5 deg. Examples for the computation of S_ϕ are given as follows.

Example 1

The combined stresses in the equivalent solid plate for a perforated plate of 0.05 ligament efficiency were computed at a point as:

$$\sigma_r = 750 \text{ psi}$$

$$\sigma_\theta = -1100 \text{ psi}$$

and σ_r is rotated 12 deg., measured from the y axis of the hole pattern. To determine the value of σ_ϕ at 40 deg. from the y axis, use the following procedure: let $\sigma_1 = \sigma_r$, $\sigma_2 = \sigma_\theta$. Since the angular orientation of 12 deg. is closest to 15 deg., use Fig. A-8142-5 for the stress multipliers. Read at $\phi = 40$ deg. on Scale A: $Y_1 = +1.65$; on Scale B: $Y_2 = -0.70$. Then from Eq. (21) in (c) above, the peak stress intensity is computed as:

$$\begin{aligned} S_\phi &= \frac{1}{0.05} (+1.65)(750) + \frac{1}{0.005} (-0.70)(-1100) \\ &= 40,200 \text{ psi} \end{aligned}$$

Example 2

For the same plate as above at another point, the direction of σ_r coincides with the x axis. Let $\sigma_r = \sigma_2$, $\sigma_\theta = \sigma_1$. Read at $\phi = 40$ deg. from Fig. A-8142-3, $Y_1 = +2.75$ and from Fig. A-8142-4, $Y_2 = -1.80$. Then

$$S_{\phi} = \frac{1}{0.05} (2.75)(-1100) + \frac{1}{0.05} (-1.80)(750)$$

$$= -87,500 \text{ psi}$$

(d) The peak stress intensity at the outermost hole is computed from:

$$(22) S = K_r \sigma_{\text{rim}} + p_s$$

where

K_r

= a stress multiplier from Fig. A-8142-6

σ_{rim}

= the nominal circumferential stress in the rim, psi

The stresses given by Eqs. (20) and (21) in (b) and (c) above and by Eq. (22) are limited by cumulative fatigue considerations, as described in NB-3222.4.

A-8143 Irregular Ligament Patterns or Thin Ligaments in a Nominally Uniform Pattern

For irregular ligament patterns or thin ligaments in a nominally uniform pattern, the stresses are determined as given in the following subparagraphs.

A-8143.1 Average Stress Intensity.

The stress intensity based upon the ligament stresses averaged across the ligament width and through the plate thickness due to pressure plus other mechanical loads is limited to $3.0S_m$ in accordance with Table NB-3217-1. The appropriate value is computed according to A-8142.1(a), where h_a (the actual width of the thin ligament) is used in place of the nominal width h .

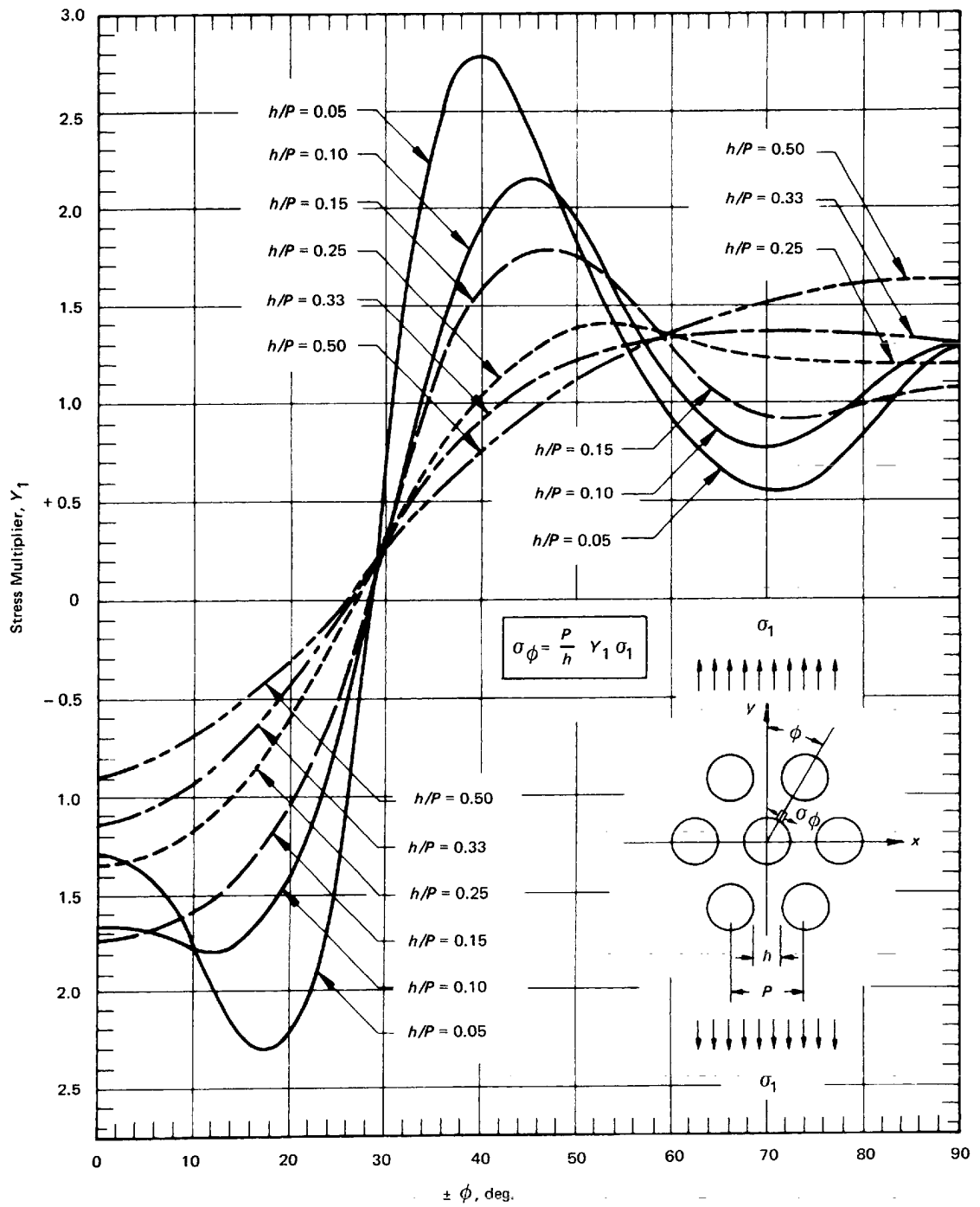


FIG. A-8142-3

FIG. A-8142-3

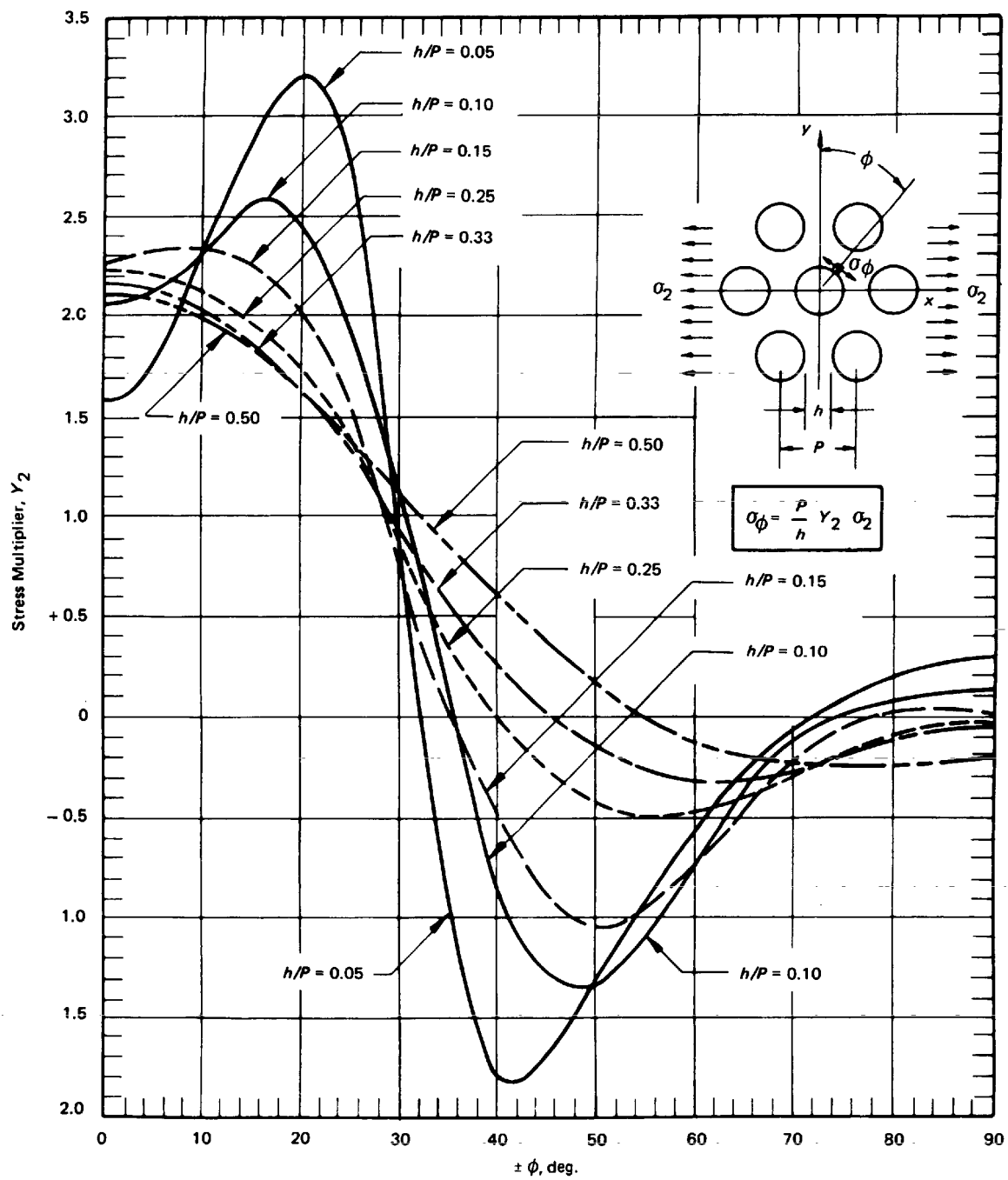


FIG. A-8142-4

FIG. A-8142-4

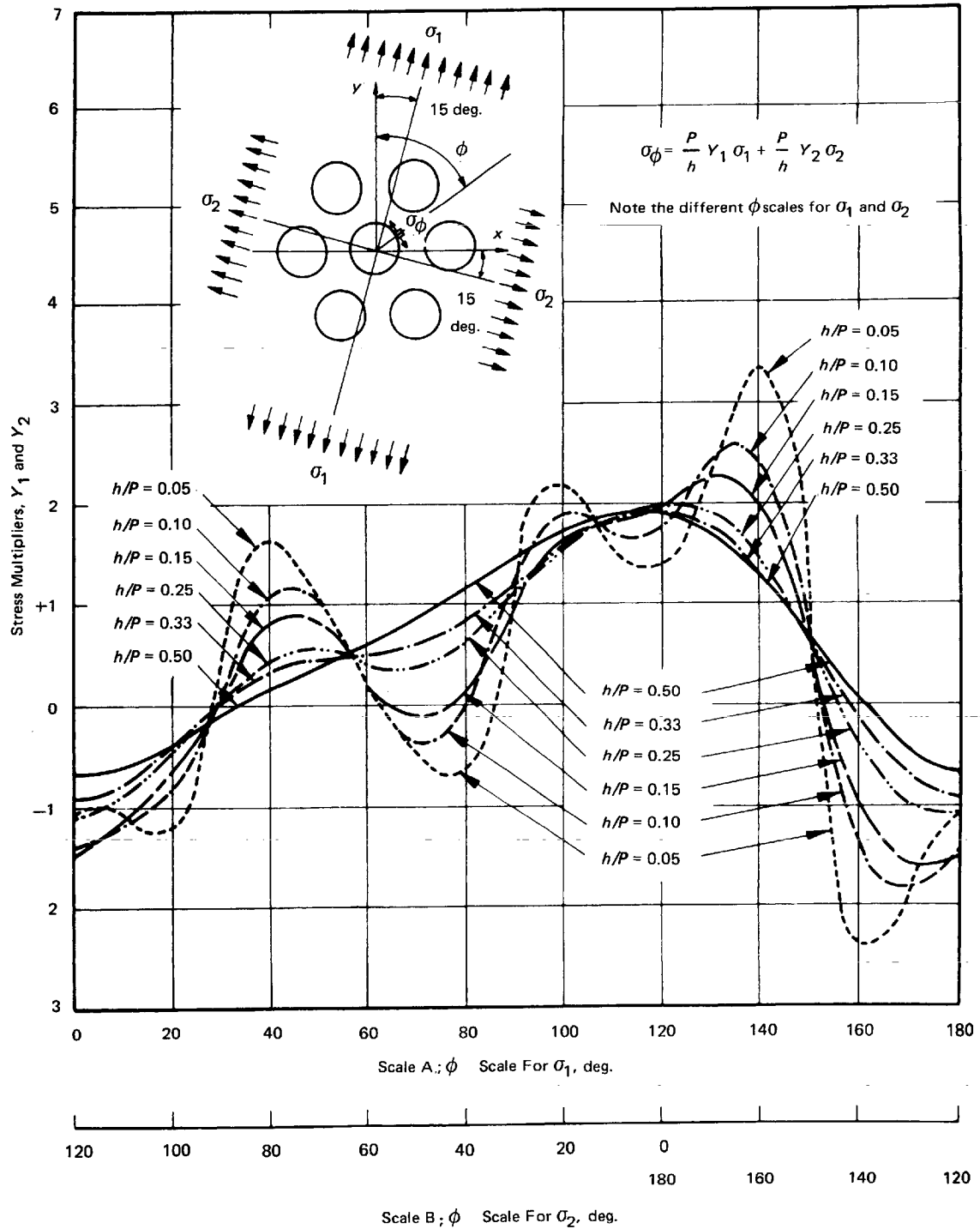


FIG. A-8142-5

FIG. A-8142-5

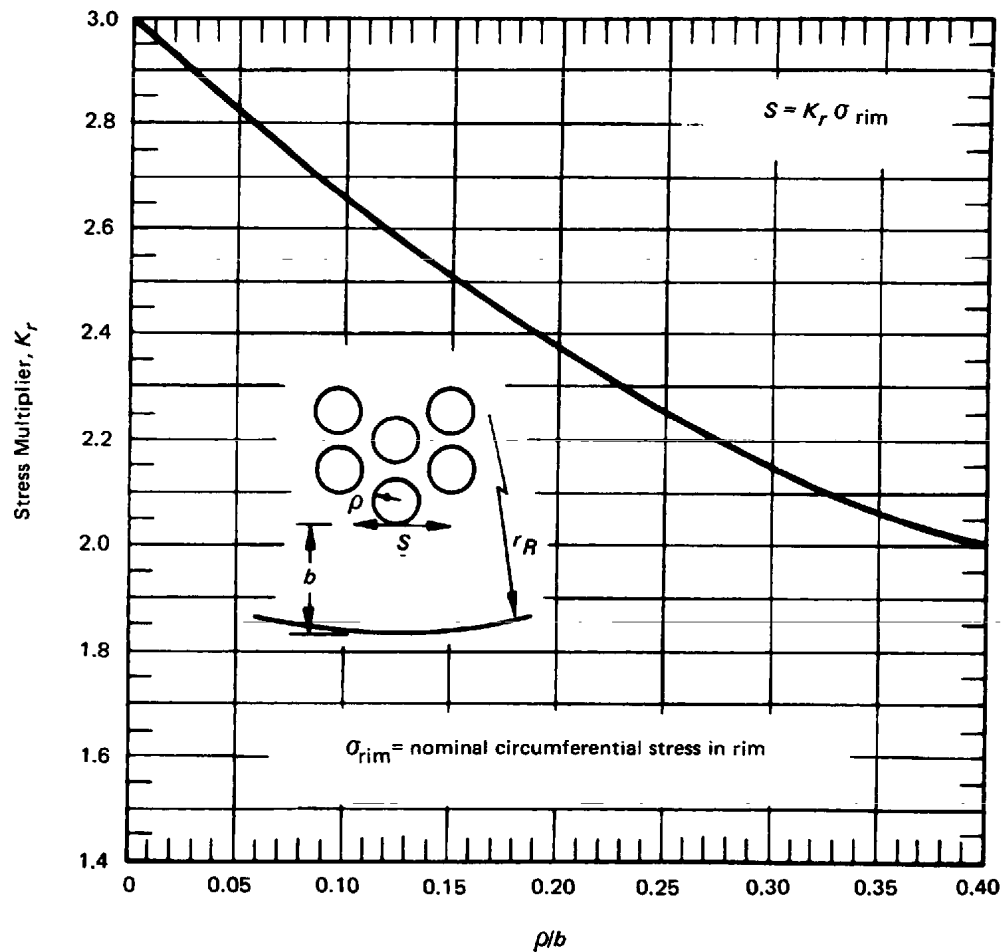


FIG. A-8142-6

FIG. A-8142-6

A-8143.2 Peak Stress Intensity.

The peak stress intensity in the thin ligament due to mechanical loading and structural interaction with adjacent members, including thermal effects, is limited by cumulative fatigue considerations. This peak stress intensity is computed by multiplying the peak stress intensity for a nominal thickness ligament by the K_m value given in Fig. A-8143.2-1.

(a) The peak stress intensity in nominal ligament is calculated as indicated in A-8142.2(b).

A-8150 THERMAL SKIN EFFECT

A-8151 General Considerations

In certain cases, the temperature gradient through the thickness of a perforated plate can be closely approximated by a step change in the metal temperature near the surface of the plate. In such a case, significant thermal stresses develop only in the skin layer of the plate at the surface where the temperature change occurs and the thermal stresses in the remainder of the plate are negligible.

A-8152 Maximum Thermal Skin Stress

The maximum thermal skin stress on the surface of a perforated plate can be computed from the relation:

$$\sigma_{\text{skin}} = K_{\text{skin}} Y_{\text{max}} \left(\frac{P}{h} \right) \left(\frac{E\alpha}{1 - \nu} \right) (T_m - T_e) \quad (23)$$

(23)

where

E, α, ν	= modified material properties
Y_{max}	= stress multiplier from Fig. A-8142-2, for $\beta = +1$
T_m	= mean temperature of the plate, °F
T_s	= temperature of the plate at the surface under consideration, °F
P	= pitch
h	= ligament width, in.

A-8153 Peak Stress Intensities When Thermal Skin Stresses Are Included

(a) When thermal skin stresses are to be combined with other stresses to obtain the peak stress intensity, Eq. (23) of A-8152 may not be used. In such a case the thermal stresses at any location on the surface of the equivalent solid plate are given by:

$$\sigma_r = \sigma_\theta = K_{\text{skin}} \frac{E\alpha}{1 - \nu} (T_m - T_s) \quad (24)$$

(24)

where

K_{skin}

= stress ratio from Fig. A-8153-1

T_m

= mean temperature of the plate, °F

T_s

= surface temperature of the plate, °F

E, ν

= unmodified material properties (since K_{skin} includes the consideration for E^* and ν^*)

(b) The equivalent solid plate stresses given by Eq. (23) can then be combined with other solid plate stresses and the method given in A-8142.2(b) can be used to obtain the peak stress intensity.

Page 236

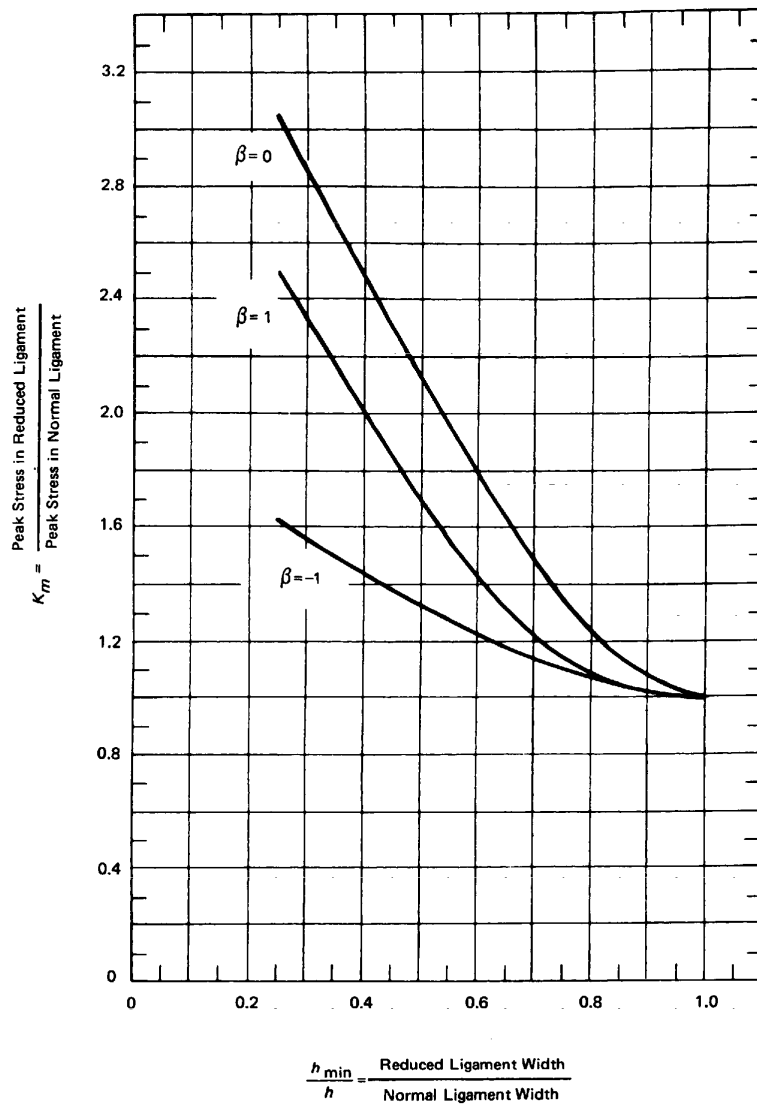


FIG. A-8143.2-1

FIG. A-8143.2-1

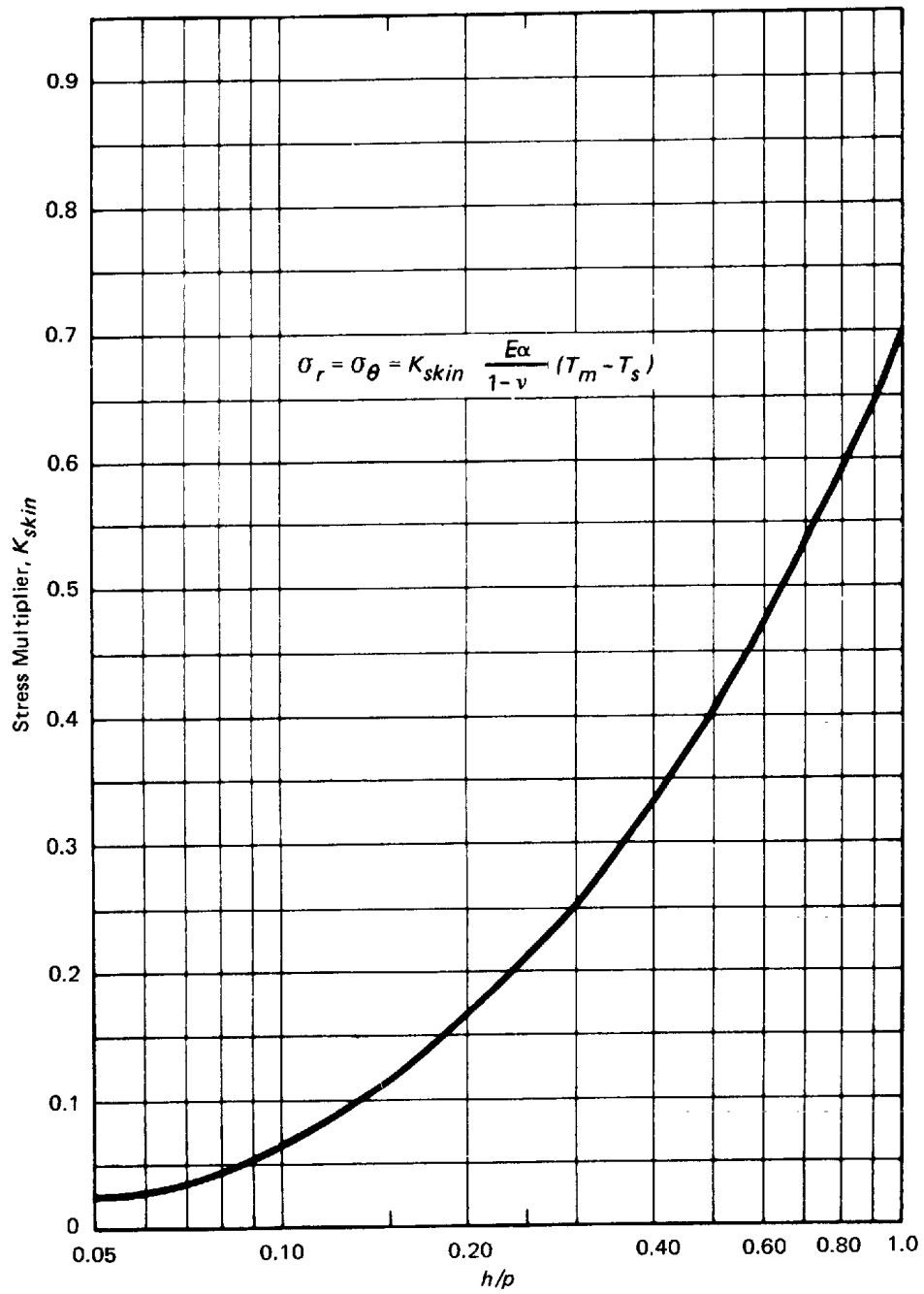


FIG. A-8153-1

ARTICLE A-9000 INTERACTION METHOD

A-9100 INTRODUCTION

A-9110 SCOPE

(a) This Article contains a method for evaluating the adequacy of linear structural elements under combined loads, without determining principal stresses, by use of the stress ratio/interaction curve method. By using an interaction formula for combined stress states the ability of a linear structural element to withstand combined loads can then be determined provided the strength of the element under each individual load is known. The method can be applied to elastic and inelastic problems, including elastic and inelastic stability, and is useful when an exact stress analysis is not practical.

(b) A general interaction formula for three states of stress is given by the following:

$$(1) R_1^p + (R_2^q + R_3^r)^s \leq 1.0$$

where R_1 , R_2 , and R_3 are ratios of either individual stresses, stress resultants, or loads to their respective allowables; and the exponents p , q , r , and s constitute the interaction relationship. These exponents are based upon experimental and/or theoretical considerations. Generally speaking, such an interaction is set up for each individual element in a structure (each beam, column, etc.), and each element will have its own set of exponents for the loads to which it is subjected.

(c) For elastic analysis of compact structures (those in which buckling need not be considered), interaction methods can be used to determine the yield surface. However, classical strength of material methods can also be used to obtain principal stresses, hence an interaction method is not of importance. For ultimate strength, an exact stress analysis is frequently impractical and interaction methods provide a useful alternative. In addition, for structures subject to more than one type of load which can cause instability (e.g., torsional and axial buckling of thin-walled tubes or pipes), interaction methods can again be used.

A-9120 NOMENCLATURE

(a) The definitions of the symbols used in this Article are given below.

A	= cross-sectional area, sq in.
c	= distance from neutral axis to outermost fiber, in.
e	= strain, ksi
f_{ap}	= linearized allowable bending stress (apparent stress), ksi
f_{uk}	= linearized ultimate bending stress, ksi, for section factor K
f_{yk}	= linearized yield bending stress, ksi, for section factor K
I	= moment of inertia, in. ⁴
K	= section factor
m	= applied moment, in.-lb
M	= allowable bending moment, in.-lb
n	= interaction exponent
P	= axial load, lb
Q_m	= first moment of the area between the neutral axis and outer fiber

$$= \int_0^c y da$$

R	= ratio of an individual stress or load to its allowable
S	= stress, ksi
S_o	= trapezoidal intercept stress, ksi
U	= stress field utilization factor
x	= centroidal axis, x direction
x'	= principal axis, x' direction
y	= centroidal axis, y direction
y'	= principal axis, y' direction
y_p	= distance from principal axis to intermediate fiber, in.
ϕ	= angle between centroidal and principal axis, deg.
γ	= plasticity factor

(b) The indices used with the symbols in this Article are defined below.

Page 239

al	= allowable
ap	= apparent
b	= bending
bc	= buckling
c	= compression
pl	= proportional limit
s	= shear
t	= tension
to	= torsion
u	= ultimate
y	= yield
1, 2	= locations across a section

A-9200 INTERACTION EQUATIONS

A-9210 SCOPE

- (a) This Subarticle provides interaction equations based on experimental data for a number of common structural shapes.
- (b) Allowable loads and stresses for the interaction equations presented herein shall be determined in accordance with A-9300.
- (c) Interaction equations for combinations of loads other than those specified herein may be used, provided they are developed in accordance with the rules of A-9400.
- (d) Interaction equations, which may be used for common beam shapes subject to various combinations of loads, are presented in Table A-9210(d)-1. As an alternative to some of the interaction equations given in Table A-9210(d)-1, the curve in Fig. A-9210(d)-1 may be used.
- (e) All structural shapes subject to buckling shall be governed by the requirements of NF-3300.
- (f) Interaction equations which may be used for thin- and thick-walled tubes and pipes, subject to various combinations of loads, are presented in Table A-9210(f)-1 (in the course of preparation).
- (g) Interaction equations which may be used for flat, unperforated plates, subject to various combinations of loads, are presented in Table A-9210(g)-1 (in the course of preparation).

A-9300 ALLOWABLE LOADS AND STRESSES

[98]

A-9310 SCOPE

This Subarticle provides criteria for determining the allowable loads for components or supports subject to the application of one or more loads. The allowable loads are to be based on the allowable stresses set forth in F-1331.2 or F-1341.5, as appropriate, for either elastic or plastic system analysis.

[98]

[98]

A-9311 Material Properties

The material properties used in developing the allowable component or support loads or stresses shall be based on Section II, Part D, Subpart 1, and included and justified in the Design Report.

[98]

A-9312 Strain Rate Effects

Strain rate effects on material properties may be considered if justified in the Design Report.

A-9313 Temperature Effects

Temperature effects on the allowable component or support loads or stresses shall be considered and justified in the Design Report.

[98]

A-9314 Allowable Load

The allowable load of a component or support is defined as the lesser of (a) through (d) below.

- (a) The load at which the most severely stressed fiber reaches the allowable stress defined in F-1331.2 or F-1341.5, as appropriate.

(b) The load at which either strain or deformation exceeds the limits provided by the component or support Design Specification.

(c) The load at which loss of component or support function occurs, as defined by the component or support Design Specification.

(d) The allowable buckling load as defined in F-1370(c).

[98]

A-9320 METHOD

(a) The allowable load of a component or support under the application of a single load may be determined by experimental or analytical methods or both. The allowable loads of a component or support thus determined are to be modified by the effects discussed in A-9312 and A-9313 for use in the interaction equations of A-9200.

(b) An acceptable method of determining the allowable loads of beam shapes in pure bending or in bending

Page 240

in combination with direct loads and shear is the apparent stress method provided in A-9500.

**TABLE A-9210(d)-1
INTERACTION EQUATIONS FOR COMMON BEAM SHAPES**

Type of Load	Interaction Equation ^{2,3}	Remarks
Simple bending	$R_b < 1$	$R_b = m/M$
Complex bending	$R_{bx'} + R_{by'} < 1$	$R_{bx'} = m_x'/M_{x'}$, etc.
Simple shear	$R_s < 1$	$R_s = S_s/S_{sal}$
Complex shear	$\sqrt{R_{sx'}^2 + R_{sy'}^2} < 1$	$R_{sx'} = S_{sx'}/S_{sal}$, etc.; $S_{sx'}$ and $S_{sy'}$ are maximum shear stresses
Simple bending plus shear	$\sqrt{R_b^2 + R_s^2} < 1$	Note (1)
Complex bending plus shear	$\sqrt{R_{bx'}^2 + R_{by'}^2 + R_s^2} < 1$	$R_{bx'} = R_{bx'} + R_{by'}$; R_s = $\sqrt{R_{sx'}^2 + R_{sy'}^2}$; Note (1)
Simple or complex bending plus tension	$R_b' + R_t^n < 1$	$R_t = P_t/P_{tal}$; to determine n use A-9532
Simple or complex bending tension and shear	$\sqrt{(R_b' + R_t^n)^2 + R_s^2} < 1$	Note (1); to determine n use A-9532; see A-9533
Simple or complex bending and compression	$R_b' + R_c < 1$	Notes (1) and (4); $R_c = P_c/P_{cal}$
Simple or complex bending compression and shear	$\sqrt{(R_b' + R_c)^2 + R_s^2} < 1$	Notes (1) and (4); see A-9535

NOTES:

- (1) As an alternate to the given interaction equation, the curve of Fig. A-9210(d)-1 may be used.
- (2) Allowable loads for use in interaction equations should be based on allowable stresses as defined in A-9300.
- (3) All interaction ratios R_i are positive by definition.
- (4) Amplification of bending moment by axial load shall be taken into account.

TABLE A-9210(d)-1 INTERACTION EQUATIONS FOR COMMON BEAM SHAPES

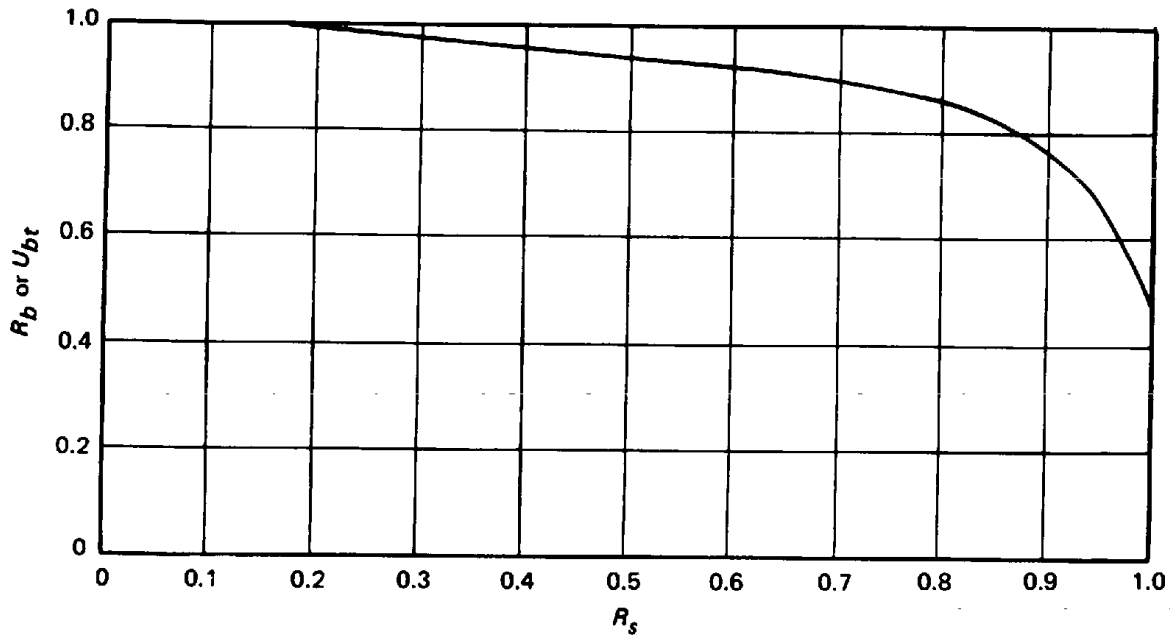


FIG. A-9210(d)-1 INTERACTION CURVE FOR BEAMS SUBJECT TO BENDING AND SHEAR OR TO BENDING, SHEAR, AND DIRECT LOADS

FIG. A-9210(d)-1 INTERACTION CURVE FOR BEAMS SUBJECT TO BENDING AND SHEAR OR TO BENDING, SHEAR, AND DIRECT LOADS

(c) An acceptable method of determining the allowable loads of pipes and tubes in pure bending or in bending in combination with direct loads and shear is provided in A-9600 (in the course of preparation).

A-9400 NEW INTERACTION EQUATIONS

A-9410 SCOPE

Interaction equations other than those provided in A-9200 may be used for the analysis of components or supports, provided they are developed in accordance with the rules of this Section.

A-9420 METHOD

Any new interaction equations to be used shall be included and justified in the Design Report. They may be justified by one of the following:

- (a) common appearance in appropriate technical literature or in industry codes or standards;
- (b) experimental development which includes a variation of all types of loads or stresses that appear in the interaction equations. Such a load or stress variance shall bound the loads or stresses to which the component is subjected;
- (c) theoretical development which includes testing to verify the interaction equations developed.

A-9500 DETERMINATION OF ALLOWABLE BENDING STRENGTH OF BEAMS BY THE APPARENT STRESS METHOD

A-9510 SCOPE

(a) This Subarticle provides a method to calculate the strength of beams in the plastic range under pure bending or under bending combined with direct loads and shear. It is based on the work of Cozzone^{1,2} and utilizes a fictitious stress called an *apparent stress*. This method shall not be used for the analysis of thin-walled tubes or pipes.

(b) The conventional beam theory, based on the assumption that a plane section before bending remains plane after bending, gives a linear distribution of strain and stress in the elastic range up to the proportional limit. Beyond the proportional limit, however, although the strain distribution is assumed to remain linear, the stress distribution corresponds with the stress-strain relationship for the material. An approximation of this distribution has been obtained, which enables the prediction of the effects of shape and material properties on bending in the plastic range. This method has the advantage that strain hardening may be taken into account.

(c) The methods provided herein may also be used for the analysis of beams with cutouts or notches, provided that the geometric properties are based on the net area at the cutout or notch.

(d) The effect of cyclic loading should be evaluated independently, where appropriate.

A-9520 SIMPLE BENDING

[98]

A-9521 Simple Bending - Symmetrical Sections

(a) The method given below may be used when the resultant applied moment vector is parallel to a principal axis which is also an axis of symmetry.

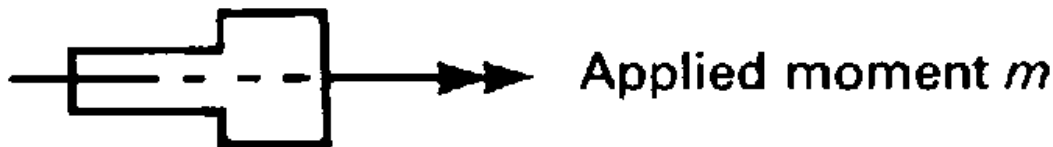


FIGURE - UNTITLED

(b) The section factor K is given by the formula $K = 2Q_m/(I/c)$. If $K > 2.0$, use $K = 2.0$. Section factors are given in Table A-9521(b)-1 for common structural shapes.

(c) The allowable bending moment shall be determined as given in (1) through (3) below.

(1) Using the method outlined in A-9540, derive the relationship between the allowable stress S_{al} and the linearized allowable stress f_{ap} for the proper section factor K . An example calculation for SA-672 A50 material at 600°F is provided in A-9542, with the resulting relationship shown in Fig. A-9542-1.

(2) Using the value of S_{al} set forth in F-1323.3 or F-1324.3, as appropriate, determine the value of f_{ap} for the proper K .

(3) Multiply f_{ap} from (2) above by I/c to obtain the allowable moment M .

[98]

**TABLE A-9521(b)-1
SECTION FACTORS**

Flanges Only			Solid Round	
	  			
$K = 1$	$K = 1 \text{ to } 1.5$	$K = 1.5$	$K = 1.7$	$K = 2.0$

TABLE A-9521(b)-1 SECTION FACTORS

A-9522 Simple Bending - Unsymmetrical Section

(a) Use the following method when the resultant applied moment vector is parallel to a principal axis which is not an axis of symmetry.

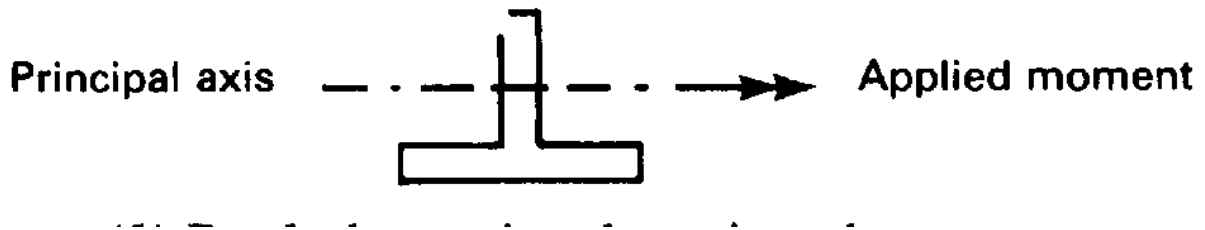


FIGURE - UNTITLED

(1) Break the section down into the two parts on either side of the principal axis. For each part, compute $Q_m I$, and I/c about the principal axis of the original complete section.

(2) Compute $K = Q_m / (I/c)$ for each part. In utilizing the K value for each part, computed as above, it will be the same as for a symmetrical section composed of the given part and its reflection about the principal axis of the original section.

(b) The allowable bending moment shall be determined as given in (1) through (4) below.

(1) Use the method given in A-9521(c) and the K value of the part with the larger c to obtain an f_{ap} value for this part.

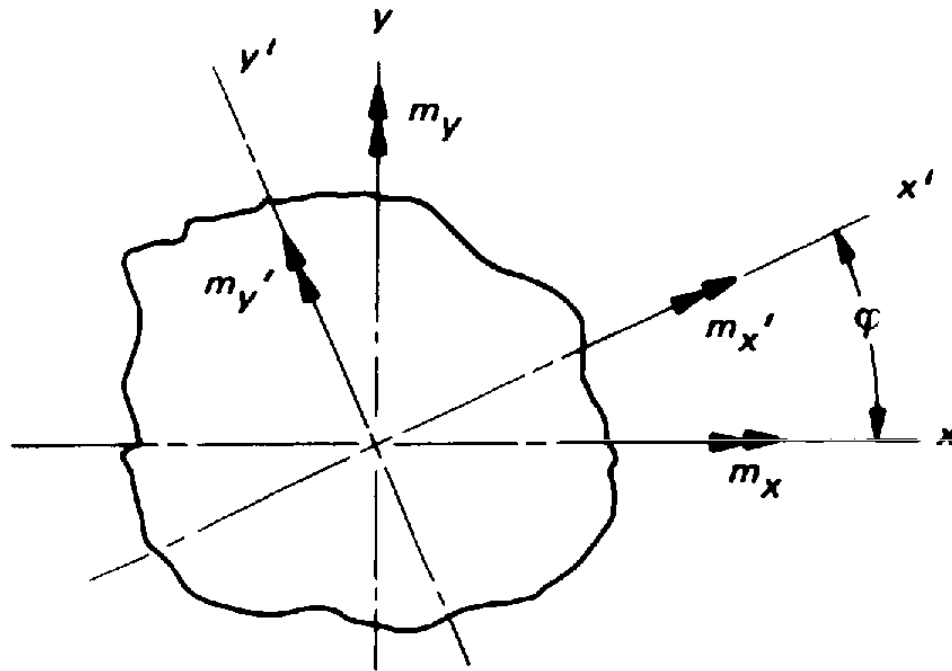
(2) Determine the strain e_{ap} associated with S_{al} from the engineering stress-strain curve.

(3) Obtain the allowable maximum strain e_1 in the part having the smaller c by the following equation:

$$e_1 = (\text{smaller } c / \text{larger } c) e_{ap}$$

Enter this strain e_1 on the stress-strain curve and obtain the corresponding stress from the stress-strain curve. Use this stress value as the allowable stress S_{al} and, with the K value for the part with the smaller c , use the method of A-9521(c) to obtain f_{ap} for this part.

(4)



NOTE: Moment vectors are designated by double-headed arrows and are to be interpreted by the left-hand rule: point left thumb in direction of vector and natural curl of fingers will designate the direction of moment.

FIG. A-9523.1-1 SIGN CONVENTION AND NOMENCLATURE

A-9523.1-1 SIGN CONVENTION AND NOMENCLATURE

A-9523 Complex Bending - Symmetrical and Unsymmetrical Sections

This condition occurs when the resultant applied moment vector is not parallel to a principal axis.

A-9523.1 Sign Convention and Nomenclature.

In Fig. A-9523.1-1, let x and y represent two mutually perpendicular centroidal axes, and let x' and y' represent the principal axes.

[98]

A-9523.2 Resolution of Complex Bending Into Simple Bending.

Any case of complex bending may be resolved into two cases of simple bending about the principal axes of the section. The principal axes are defined as mutually perpendicular centroidal axes

Page 243

about which the moments of inertia are a maximum and minimum, respectively, and about which the product moment of inertia is zero. The procedure is given in (a) through (d) below.

(a) Determine the principal axes x' and y' . If they cannot be determined by inspection, obtain $I_{x'}$, $I_{y'}$, and I_{xy} about any arbitrary pair of centroidal axes.

$$\tan 2\phi = 2I_{xy}/(I_y - I_x)$$

(b) Using the x' axis as a reference, determine the allowable moment $M_{x'}$ as described under simple bending (A-9521 and A-9522).

(c) Using the y' axis as a reference, determine the allowable moment $M_{y'}$ as described under simple bending (A-9521 and A-9522).

(d) For use in the interaction equations of A-9210, moments in the global axis shall be resolved into moments about the principal axes by use of the following relationships:

$$m_{x'} = m_x \cos \phi + m_y \sin \phi$$

$$m_{y'} = m_x \sin \phi + m_y \cos \phi$$

[98]

A-9530 BENDING COMBINED WITH A STRESS FIELD

[98]

A-9531 Interaction - Simple or Complex Bending and Shear

The maximum shear stress in a beam usually occurs at the principal (neutral) axis where the bending stress is zero. The maximum bending stress occurs at an extreme fiber where the shear stress is usually zero.

(a) In the elastic range, the distribution of shear and bending stresses (see Fig. A-9531-1) is usually such that the most critical point in the section is at either the principal axis or the extreme fiber. This is true on a rectangular section since the shear distribution across the section is parabolic and the bending distribution is linear. If the shear distribution has been elliptical, every point in the cross section will be equally critical in combined stress based on circular interaction.

(b) In the plastic range, however, the distribution of the shear stress as well as the bending stress differs from that in the elastic range. This results in intermediate points which frequently become more critical in combined stress than either the shear stress at the principal axis or the bending stress at the extreme fiber.

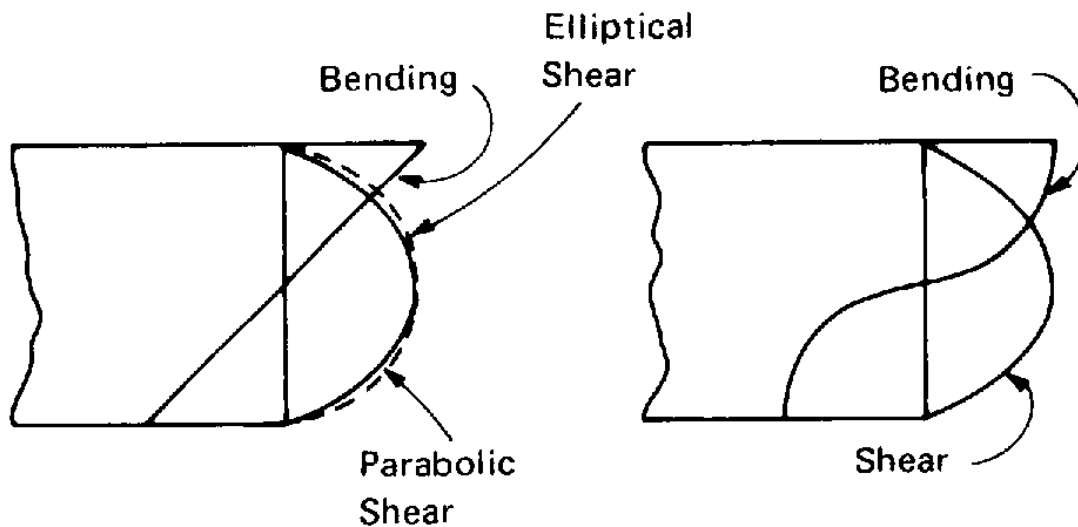


FIG. A-9531-1 BENDING AND SHEAR STRESSES

FIG. A-9531-1 BENDING AND SHEAR STRESSES

(c) To find the most critical point would require the calculation of combined stresses at a series of points across the section. This procedure would not only be laborious but probably incorrect in the conservative direction, since there would undoubtedly be some redistribution of stress away from the most critical point, although the exact nature of this redistribution appears to be extremely difficult to determine. Therefore, the procedure of (1) through (4) below shall be used.

(1) The method used to determine the shear flows for simple or complex bending shall be included and justified in the Design Report.

(2) For complex bending, the maximum principal shear stresses S_{sx} and S_{sy} shall be determined for use in the interaction equations of A-9210.

(3) For simple or complex bending, the allowable shear stress S_{sal} shall be taken as $0.6S_{tal}$.

(4) The allowable moments shall be determined as in A-9521 or A-9522, as appropriate.

[98]

A-9532 Interaction - Simple or Complex Bending and Tension

(a) The allowable moments for simple or complex bending shall be determined from A-9521 or A-9522, as appropriate.

(b) The allowable tensile load P_{al} shall be taken as AS_{al} .

(c)

(c) The interaction exponent n for use in the interaction equations of A-9210(d) shall be determined from (1) through (3) below.

(1) Determine $Ac/2Q_m$ for use in obtaining the interaction exponent. If the section is unsymmetrical, take c for the side for which axial and bending stresses are of opposite sign. For complex bending, obtain both $Ac/2c_x$ and $Ac/2c_y$. In obtaining $Ac/2c_x$ if the section

Page 244

is unsymmetrical about the x' axis, take c_x for the side for which axial stress and stress due to m_x are of opposite sign. Obtain $Ac/2c_y$ in the same manner.

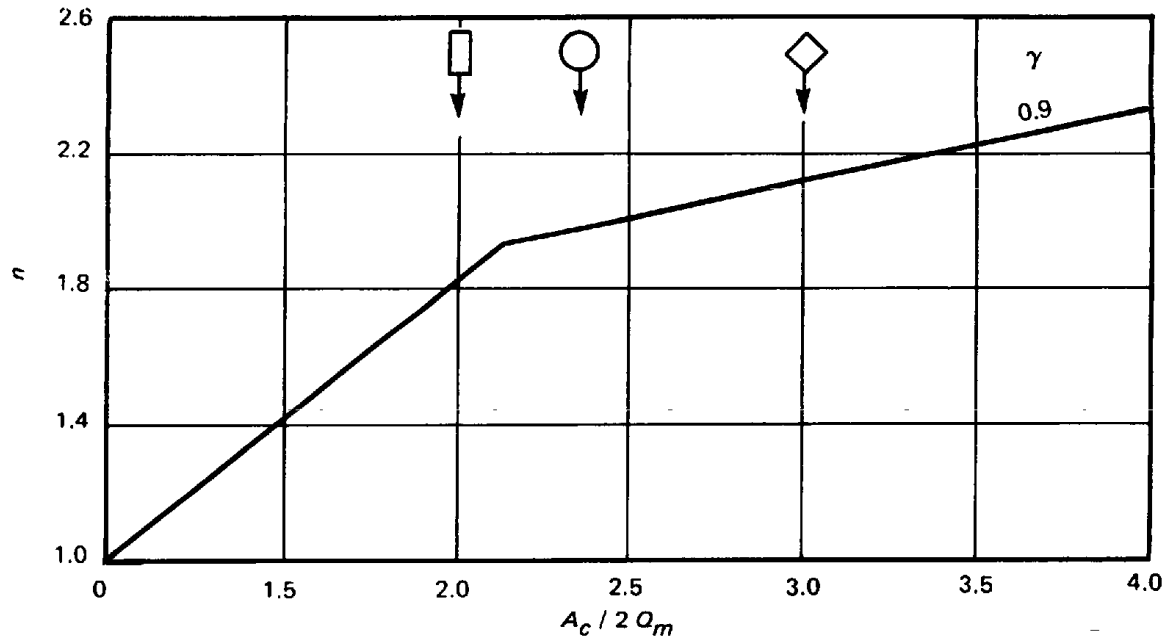


FIG. A-9532(c)(3)-1 INTERACTION EXPONENT

FIG. A-9532(c)(3)-1 INTERACTION EXPONENT

(2) The material plasticity factor for use in obtaining the interaction exponent is $\gamma = 0.90$ for all materials.

(3) Using $Ac/2Q_m$ determined above in (1) and γ determined above in (2), obtain n from Fig. A-9532(c)(3)-1. To determine the interaction exponent for complex bending, obtain both n_x and n_y from Fig. A-9532(c)(3)-1 and determine a combined n using $n = (n_x R_{bx'} + n_y R_{by'}) / R_b$

A-9533 Interaction - Simple or Complex Bending, Tension, and Shear

When bending acts in addition to tension and shear, allowables shall be determined as provided in (a) through (c) below.

(a) Follow the procedure outlined in A-9531 and A-9532 to obtain S_{ab} , P_{ab} , M_x , M_y , and n .

(b) Plot the curve of $R_b + R_t^n = 1$ [Fig. A-9533(b)-1] and the intersection of R_b and R_t . Call this point A. Obtain $a = \overline{OA}$ and $b = \overline{OB}$.

(c) Obtain the bending-tension utilization factor for use in Fig. A-9210(d)-1:

$$U = a/b$$

A-9534 Interaction - Simple or Complex Bending and Compression

(a) When compression acts in addition to simple or complex bending, the applied moment m shall take into account the additional bending caused by the compressive load.

(b) The allowable moments for simple or complex bending shall be determined from A-9520, as appropriate.

(c) The allowable compressive load P_{cal} shall be taken as the lesser of AS_{al} and the allowable buckling load [F-1370(c)].

[98]

A-9535 Interaction - Simple or Complex Bending, Compression, and Shear

When bending acts in addition to compression and shear, the following procedure may be used to determine the interaction relationships for use in A-9210.

(a) Follow the procedure in A-9534 to obtain the applied and allowable moments and the allowable compressive load.

(b) Obtain the bending-compression utilization factor $U_{bc} = R_b + R_c$.

(c) U_{bc} may be used in Fig. A-9210(d)-1 by replacement of U_{bt} by U_{bc} .

[98]

Page 245

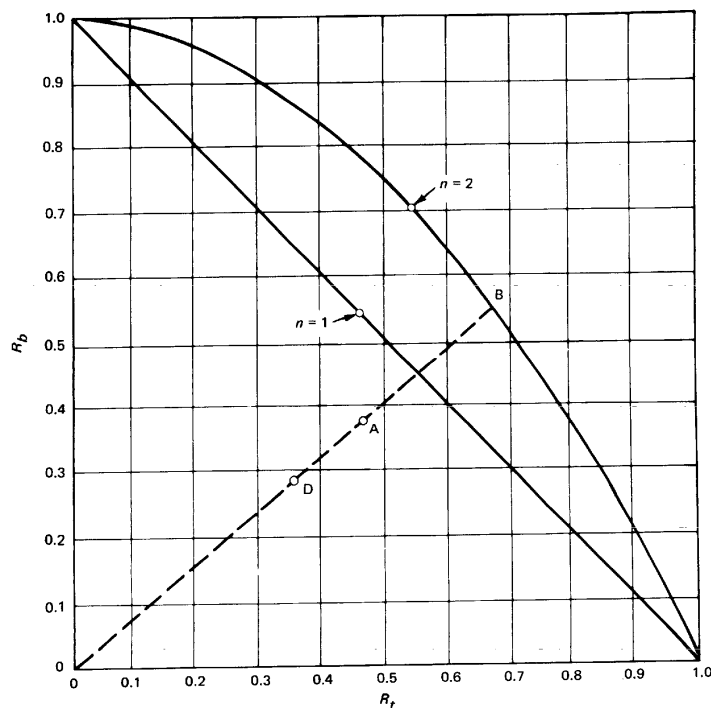


FIG. A-9533(b)-1 INTERACTION CURVE FOR BENDING AND TENSION

FIG. A-9533(b)-1 INTERACTION CURVE FOR BENDING AND TENSION

A-9540 PROCEDURE FOR DETERMINATION OF ALLOWABLE BENDING STRESS

[98]

A-9541 Derivation of Linearized Allowable Bending Stress for Any Material

A fictitious bending stress, called the linearized allowable bending stress f_{ap} , may be used for establishing the bending strength of a material. This method assumes that in the plastic region the nonlinear stress-strain relationship for a particular section and material can be approximated by a trapezoidal shape as shown in Fig. A-9541-1.

The stress S_o is a fictitious stress which is assumed to exist at the neutral axis or at zero strain. The value of S_o is determined by requiring that the internal moment of the engineering stress-strain curve must equal the internal moment of the assumed trapezoidal shape. Thus, the total moment capacity of a symmetrical section may be expressed as follows:

$$\begin{aligned}
 M &= 2S_o \int_0^c y da + (S_{al} - S_o)(I/c) \\
 &= 2S_o Q_m + (S_{al} - S_o)(I/c) \\
 &= (I/c) \{ S_{al} + S_o [2Q_m / (I/c) - 1] \} \\
 &= (I/c) [S_{al} + S_o (K - 1)] \quad (2)
 \end{aligned}$$

(2)

Thus, the linearized allowable stress for any section factor K becomes

$$(3) f_{apk} = S_{al} + (K - 1)S_o$$

and the moment capacity of the section is as follows:

$$(4) M = f_{apk} I/c$$

An alternate method of determining f_{ap} for any section factor is to express it in terms of the linearized allowable bending stress for a 1.5 stress factor:

$$(5) f_{apk} = f_{ap1.5} + (K - 1.5)S_o$$

When the allowable stress S_{al} is equal to the ultimate stress S_y , Eqs. (3) and (5) become

$$(6) f_{uk} = S_u + (K - 1)S_{ou}$$

$$(7) f_{uk} = f_{u1.5} + (K - 1.5)S_{ou}$$

When the allowable stress S_{al} is equal to the yield stress S_y , Eqs. (3) and (5) become

$$(8) f_{yk} = S_y + (K - 1)S_{oy}$$

$$(9) f_{yk} = f_{y1.5} + (K - 1.5)S_{oy}$$

where S_{ou} and S_{oy} are the trapezoidal intercept stresses corresponding to S_u and S_y .

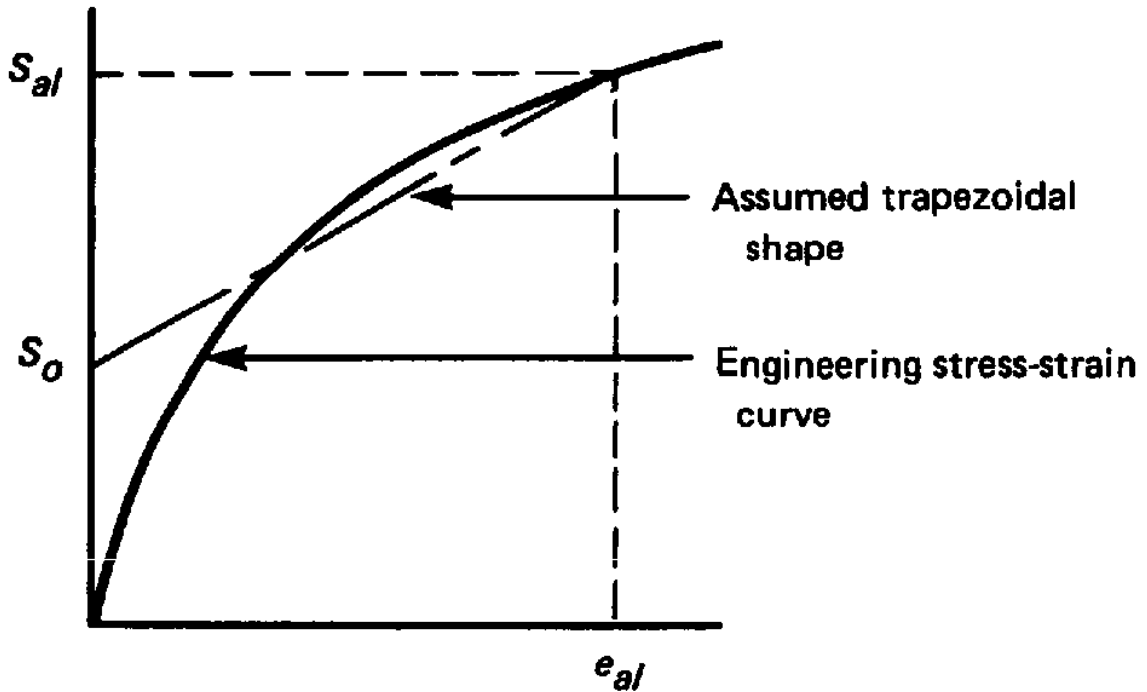


FIG. A-9541-1 TRAPEZOIDAL STRESS-STRAIN RELATIONSHIP

FIG. A-9541-1 TRAPEZOIDAL STRESS-STRAIN RELATIONSHIP

In order to calculate the allowable moment of a given beam cross section by the use of Eqs. (3) and (4), the intercept stress S_o must first be determined using the allowable moment, determined either by test or an exact stress analysis, that corresponds to a known value of K . Such effort would negate the advantage of this method. On the other hand, the values of S_{ou} and S_{oy} have been calculated for about 50 materials³ and are shown in Fig. A-9541-2. These curves may be utilized for the carbon, low, and high alloy steels given in Section II, Part D, Subpart 1. The corresponding values of $f_{u1.5}$ and $f_{y1.5}$ are shown in Fig. A-9541-3.

Once f_{uk} and f_{yk} are determined from Fig. A-9541-3 and Eqs. (6)-(9), f_{ap} for any value of the allowable stress S_{al} may be

determined as shown in (a) through (c) below.

(a) For $S_{al} \leq S_{pl}$, where S_{pl} is the proportional limit stress (Fig. A-9541-4),

$$(10) f_{apk} = S_{al}$$

3Gavalis, R. Bending Strength in the Plastic Range. Machine Design, July 1964.

Page 247

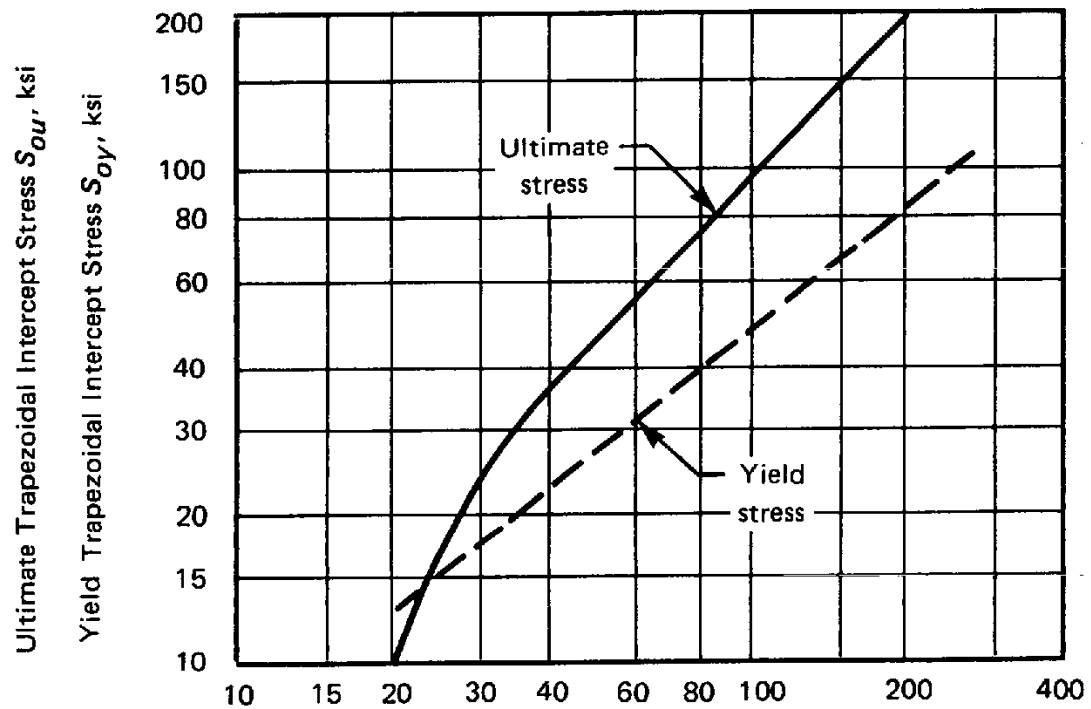


FIG. A-9541-2 ULTIMATE AND YIELD TRAPEZOIDAL INTERCEPT STRESSES

FIG. A-9541-2 ULTIMATE AND YIELD TRAPEZODIAL INTERCEPT STRESSES

Page 248

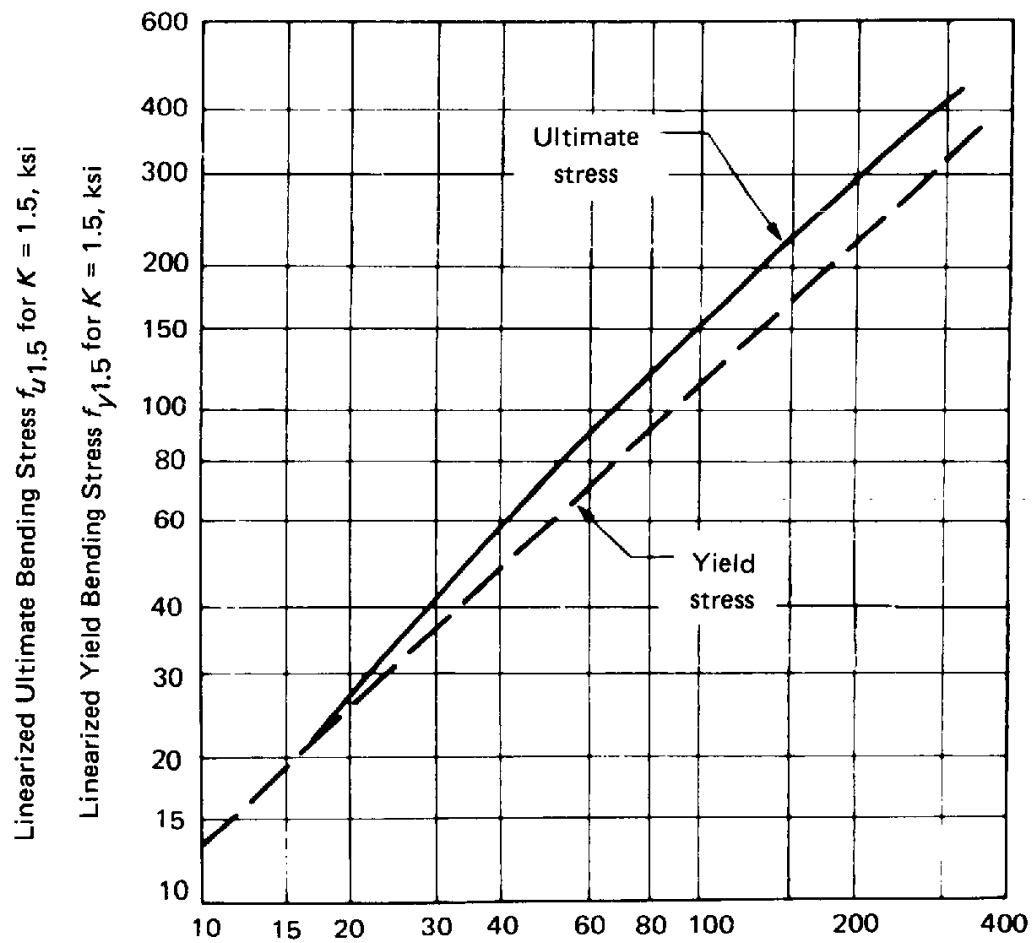


FIG. A-9541-3 LINEARIZED ULTIMATE AND YIELD BENDING STRESSES FOR RECTANGULAR SECTION

FIG. A-9541-3 LINEARIZED ULTIMATE AND YIELD BENDING STRESSES FOR RECTANGULAR SECTION

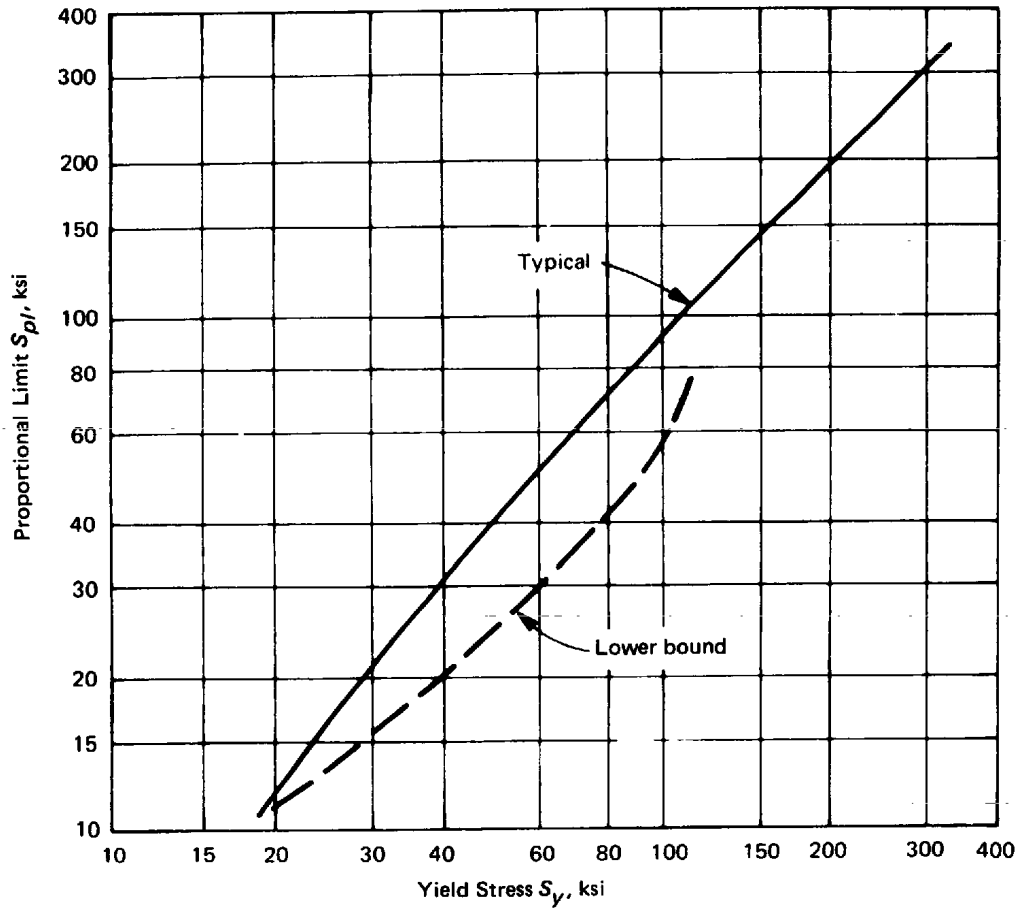


FIG. A-9541-4 PROPORTIONAL LIMIT AS A FUNCTION OF YIELD STRESS

FIG. A-9541-4 PROPORTIONAL LIMIT AS A FUNCTION OF YIELD STRESS

(b) For $S_{pl} \leq S_{al} \leq S_y$

$$(11) f_{apk} = S_{pl} + Z_{1k}(S_{al} - S_{pl})$$

where

$$(12) Z_{1k} = (f_{yk} - S_{pl}) / (S_y - S_{pl})$$

(c) For $S_y < S_{al} \leq S_u$

$$(13) f_{apk} = f_{yk} + Z_{2k}(S_{al} - S_y)$$

where

$$(14) Z_{2k} = (f_{uk} - f_{yk}) / (S_u - S_y)$$

[98]

[98]

A-9542 Example Illustrating the Derivation of Linearized Allowable Bending Stress for SA-672 A50 Material at 600°F (316°C)

The values of S_y and S_u are given:

$$S_y = 20.0 \text{ ksi yield strength at } 600^\circ\text{F (Section II, Part D, Subpart 1, Table Y-1)}$$

$$S_u = 50.0 \text{ ksi ultimate tensile strength at } 600^\circ\text{F (Section II, Part D, Subpart 1, Table U)}$$

The following values of S_{oy} and S_{ou} are found from Fig. A-9541-2:

$$S_{oy} = 11 \text{ ksi}$$

$$S_{ou} = 44 \text{ ksi}$$

Using Eqs. (6) and (8),

$$f_{ul.5} = 50 + 0.5(44) = 72 \text{ ksi}$$

$$f_{yl.5} = 20.0 + 0.5(11) = 25.5 \text{ ksi}$$

or, using Fig. A-9541-3,

$$f_{ul.5} = 72 \text{ ksi}$$

$$f_{yl.5} = 25 \text{ ksi}$$

Using Eqs. (7) and (9), the value of f_{uk} and f_{yk} , for any K , is determined. For example, if $K = 1.9, 1.7, 1.3$, and 1.1 , then

$$f_{ul.9} = 72.0 + 0.4(44.0) = 89.6 \text{ ksi}$$

$$f_{ul.7} = 72.0 + 0.2(44.0) = 80.8 \text{ ksi}$$

$$f_{ul.3} = 72.0 + (-0.2)(44.0) = 63.2 \text{ ksi}$$

$$f_{ul.1} = 72.0 + (-0.4)(44.0) = 54.4 \text{ ksi}$$

$$f_{yl.9} = 25.5 + 0.4(11.0) = 29.8 \text{ ksi}$$

$$f_{yl.7} = 25.5 + 0.2(11.0) = 27.6 \text{ ksi}$$

$$f_{yl.3} = 25.5 + (-0.2)(11.0) = 23.2 \text{ ksi}$$

$$f_{yI.I} = 25.5 + (-0.4)(11.0) = 21.0 \text{ ksi}$$

From Fig. A-9541-4, $S_{pl} = 13.0$ ksi. Using the above data, Fig. A-9542-1 may be obtained for $K = 1.9$, 1.5 , and 1.1 .

From F-1323.3, the allowable stress is the lesser of $1.2S_y$ and $0.7S_u$:

$$1.2S_y = 1.2(20) = 24 \text{ ksi}$$

$$0.7S_u = 0.7(50) = 35.0 \text{ ksi}$$

Therefore, $S_{al} = 24.0$ ksi and

$$S_y = 20 \text{ ksi}$$

$$S_u = 50 \text{ ksi}$$

$$\therefore S_y < S_{al} < S_u$$

From Eq. (14), with $K = 1.5$,

$$Z = (72 - 25.5)/(50 - 20) = 1.55$$

From Eq. (13),

$$f_{qp} = 25.5 + 1.55(24 - 20)$$

$$= 31.7 \text{ ksi}$$

Alternatively, from Fig. A-9542-1, $f_{qp} = 31.5$ ksi.

[98]

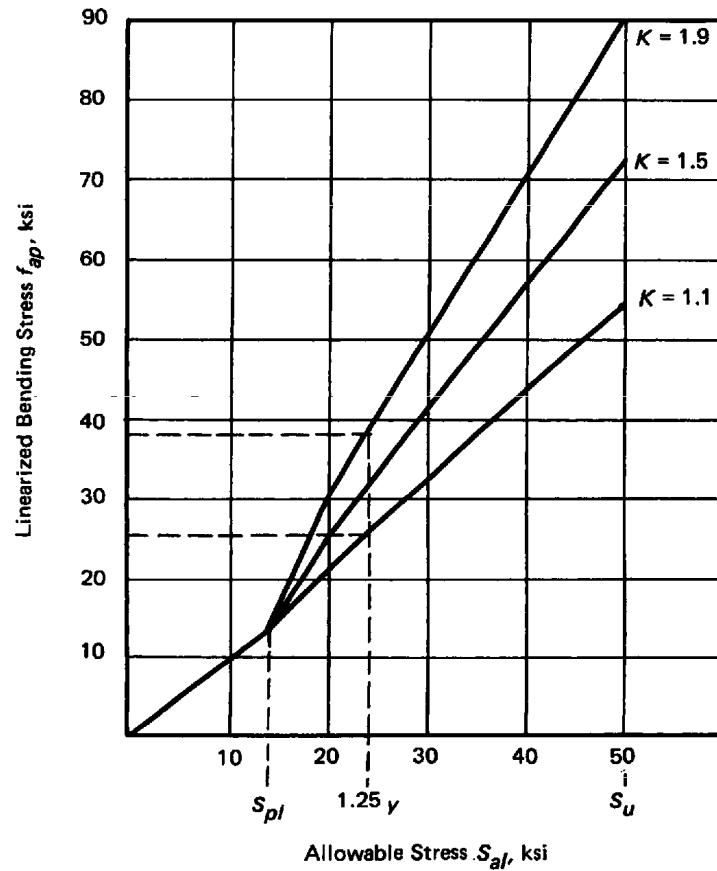


FIG. A-9542-1 LINEARIZED BENDING STRESS VERSUS ALLOWABLE STRESS FOR SA-672 A50 MATERIAL AT 600°F

FIG. A-9542-1 LINEARIZED BENDING STRESS VERSUS ALLOWABLE STRESS FOR SA-672 A50 MATERIAL AT 600°F

July 1, 1998
 American Society Of Mechanical Engineers
 SEC III D1 NMA APP B

ARTICLE B-1000 INTRODUCTION AND SCOPE

B-1100 INTRODUCTION

B-1110 OBJECTIVE

(a) The objective of this Appendix is to provide a guide for the preparation of the Design Specification required by this Section. The writer of the Design Specification is not restricted as to what can be included therein except that, as a minimum, the information required by this Section must be included. Additional, but not less restrictive, requirements which modify the rules of this Section to make them complete for a specific component or to provide more specific or restrictive requirements should be identified.

(b) It is recognized that in order to prepare a document that provides a complete basis for construction of an item for a nuclear power plant, a number of considerations outside the scope of this Section may need to be addressed. Some of these which are addressed in this Appendix are:

- (1) load combinations;
- (2) operability;
- (3) regulatory requirements.

The additional guidance provided in this Appendix for these considerations is not required by this Section, is not a part of the certification process, and should not be interpreted as extending the duties of the Inspector.

B-1120 FORMAT

B-1120.1 General.

Design Specifications should be as uniform throughout the nuclear industry as is reasonably attainable. The format of this Appendix is presented as a guide to uniformity and is divided into major categories as follows:

- (a) *Generic Requirements* applicable to all components (B-2000);
- (b) *Specific Requirements* applicable to each component (B-3000 through B-10000, inclusive).
- (c) Included in both the Generic and Specific Requirements are those considerations outside the scope of this Section (operability¹ and regulatory² requirements) which have an effect on construction but which are not required by this Section to be a part of the certified Design Specification.

B-1120.2 Nomenclature, Definitions, and Symbols.

Nomenclature, definitions, and symbols should be in agreement with those established in the applicable Article. Should a conflict exist between Articles, the Design Specification should be clear as to what is intended in each case.

B-1200 SCOPE OF CERTIFIED DESIGN SPECIFICATION

The certified Design Specification should contain in sufficient detail the information which this Section requires to be provided. Operability¹ and regulatory² requirements which are beyond the jurisdiction of this Section are not covered by the Code required certification of the Design Specification (NCA-1110).

¹ Applicable operability requirements are contained in the Subarticles designated 200 in this Appendix, such as B-2200, B-3200, etc.

² Applicable regulatory requirements are contained in the Subarticles designated 300 in this Appendix, such as B-2300, B-3300, etc.

ARTICLE B-2000 GENERIC REQUIREMENTS

B-2100 CERTIFIED DESIGN SPECIFICATION REQUIREMENTS

The information in this Article addresses those portions of the certified Design Specification which are generic in nature and therefore applicable to the construction of all Section III items.

B-2110 GENERAL

B-2110.1 Contents of the Certified Design Specification

(a) NCA-3252 provides the minimum requirements for the contents of the certified Design Specification.

(b) With respect to NCA-3252(a), it is important to recognize that the boundary defines an interface between two items that are dependent on each other for the transmittal of loads. In order to properly design the item on either side of the boundary, the effect of the attached item is required. The effect may be furnished directly by supplying the forces and moments that are transmitted across the boundary or, alternatively, by providing sufficient information to enable the designer to determine the interaction across the boundary. This Section provides rules to accomplish this in NCA-3254.

(c) Any Code Cases applicable to the construction of an item should be included in the Design Specification.

B-2110.2 Certification.

NCA-3255 provides the requirements for certification of the Design Specification. The required certification is not applicable to supplementary, regulatory, or operability requirements which are outside of the scope of this Section.

B-2110.3 Permanent Records.

NCA-4134.17 provides the requirements for the continued maintenance and retention location for permanent records.

B-2110.4 Handling, Storage, and Shipping.

The Design Specification should include any special measures to control handling, storage, and shipping of the component (NCA-4134.13).

B-2110.5 Identification of Enforcement Authorities.

The Design Specification should include identification of enforcement authorities at locations of component installation with whom Data Reports must be filed.

B-2110.6 Filing.

NCA-3256 provides the requirements for filing of the Design Specification.

B-2110.7 Review of Design Report.

NCA-3260 provides the requirements for review of the Design Report.

B-2111 Classification

B-2111.1 Responsibility.

NCA-2110 provides the requirements for classification of equipment.

B-2111.2 Multiple Code Class Components.

NCA-2133 provides the requirements for multiple Code Class components.

B-2111.3 Optional Use of Code Classes.

NCA-2134 provides the requirements for optional use of Code Classes.

B-2111.4 Special Requirements.

NCA-2160 provides the requirements for contractual arrangements that are beyond the scope of this Section.

B-2112 Design Basis and Service Limits

B-2112.1 Plant and System Service Conditions.

The definition of plant and system service conditions, and the determination of their significance to the design and operability of components and supports of a nuclear power system, may be derived from systems safety criteria documents for specific types of nuclear power systems and may be found in the requirements of regulatory authorities having jurisdiction at the site [NCA-2141(b)].

Page 257

B-2112.2 Design Loadings.

The Design Specification shall include the Design Pressure [NCA-2142.1(a)], the Design Temperature [NCA-2142.1(b)], and the Design Mechanical Loads [NCA-2142.1(c)].

B-2112.3 Establishment of Component and Component Support Design and Service Limits

(a) For Class 1, MC, and CS components, and for Class 2 and 3 piping and its supports, Design and Service Loads should be specified and appropriate Service Limits designated [NCA-2142(a)].

(b) For Class 2 and 3 components and supports, other than piping and its supports, two options are available as follows:

(1) Design and Service Loads may be specified and appropriate Service Limits designated.

(2) Service Loadings are not required to be identified when the Design Pressure, Design Temperature, and Design Mechanical Loads result in stresses that are at least as high, relative to allowable values, as any which may occur for any Service Loading [NCA-2142(a)].

B-2112.4 Test Loadings.

NCA-2142.3 provides the rules for consideration of Test Loadings.

B-2113 N Certificate Holder's Responsibilities

B-2113.1 Manufacturers of Small Pumps and Valves and of Component Standard Supports.

Manufacturers of small pumps and valves (4 in. NPS and smaller) and component standard supports (including snubbers) who elect to provide their own Design Specification are responsible for compliance with the requirements of NCA-3256(b).

B-2113.2 Compliance With N Certificate Holder's Responsibilities.

When the completed Code item involves work by more than one organization, the Design Specification shall be provided to the organization having overall responsibility.

B-2120 DESIGN

B-2121 Loadings

The Owner or Owner's designee shall identify the loadings and designate the appropriate Design and Service Limits for each component or support. The loadings that should be taken into account in designing a component include, but are not limited to, the following:

- (a) internal and external pressure, including static head;
- (b) weight of the component and normal contents under service and test conditions;
- (c) superimposed loads, such as other components, operating equipment, insulation, or corrosion resistant or erosion resistant linings and piping;
- (d) vibrations and earthquake loads;
- (e) reactions of supporting lugs, rings, saddles, or other types of supports;
- (f) temperature effects;
- (g) restrained thermal expansion;
- (h) anchor and support movement effects;
- (i) environmental loads, such as wind and snow;
- (j) dynamic effects of fluid flow.

B-2122 Design Loads

B-2122.1 Design Pressure.

NCA-2142.1(a) and NB/NCND/NE-3112.1 provide the required definitions for Design Pressure.

B-2122.2 Design Temperature.

NB/NCND/NE/NF/NG-3112 and NCA-2142.1(b) provide the requirements for Design Temperature. The Design Temperature shall be used in computations involving the Design Pressure and coincidental Design Mechanical Loads. The actual metal temperature at the point under consideration shall be used in all computations where the use of the actual service pressure is required. Where a component is heated by tracing, induction coils, jacketing, or by internal heat generation, the effect of such heating shall be incorporated in the establishment of the Design Temperature.

B-2122.3 Design Mechanical Loads

(a) The specified Design Mechanical Loads should be selected so that when combined with the effects of Design Pressure, they represent the most severe coincident loadings for which the Level A Service Limits on primary stress are applicable.

(b) The determination of *most severe coincident loadings* may result in specification of pairs of Design Conditions since the one most severe combination may not be readily predicted. The specification may specify the maximum Design Mechanical Load for any situation which, when taken with the Design Pressure, would result in the worst combination of Design Conditions even though they may not be coincident.

(c) The Design Mechanical Loads that are considered are somewhat dependent on the component, its location, its attachment to other components, and for a Class 2 or 3 component, whether Service Loadings are to be specified (refer to B-2112.3 and NCA-2142).

Page 258

B-2123 Service Loads

In order to properly specify Service Limits for the various types of loadings, the Owner or Owner's designee should recognize the basis for the establishment of those Limits. These are given in NCA-2142.2.

B-2123.1 Service Limits A and B

(a) For Class 1, MC, and CS components and for Class 2 vessels designed to NC-3200, Service Limits A and B are provided in order to evaluate the effect of system operating loads on the fatigue life of the component. For a fatigue

analysis the loads applicable to the component being considered should be described in terms of quantities that the designer may use [NB-3222.4(e)]. The variation with respect to time of pressure, temperature, flow rate, etc., as well as the number of times these changes occur in the life of the component, is needed. In this regard, a service cycle is defined in NB-3213.15 as: "... the initiation and establishment of new conditions followed by a return to the conditions which prevailed at the beginning of the cycle." Thus, as an example, the conditions associated with plant startup do not constitute a service cycle. Startup and shutdown together constitute a service cycle, and if there are n_1 startups in the Design Specification, there should be the same number of shutdowns.

(b) Figure B-2123-1 is an illustration of the time - dependent load information which the designer needs. (Note that it provides only the startup portion of a service cycle.)

(c) For Class 2 and 3 piping and its supports, it is not necessary to define each service cycle in detail. What is needed is the maximum range of conditions and the number of occurrences to which the piping will be subjected. For example, the minimum temperature conditions could be 40°F (4°C) while the maximum is 456°F (236°C). If all other service cycles did not impose a temperature condition less than the minimum or greater than the maximum, they would not have to be specified. An exception to this would be ranges of temperatures that occurred more than 7000 times which resulted in significant stresses.

(d) For all other Class 2 and 3 components and component supports, it is not necessary to define each service cycle in detail since no fatigue analysis is required. It is important for the designer to know the maximum loading condition on the component for these Service Limits.

B-2123.2 Service Limit C.

Service Limit C is provided in order to evaluate the effect of plant operating loads on the structural integrity of a component for situations which are not anticipated to occur for a sufficient number of times to affect fatigue life and for which large deformations in areas of structural discontinuities are not objectionable. Since the occurrence of stress associated with this Limit may result in removal of the component from service for inspection or repair, the Owner should review the selection of this Limit for compatibility with established system safety criteria.

B-2123.3 Service Limit D.

Service Limit D is provided in order to evaluate the effect of plant operating loads on the structural integrity of a component for situations in which gross general deformations, loss of dimensional stability, and damage requiring repair, excluding loss of pressure retaining function, are not objectionable. Since the occurrence of stress associated with this Limit may require removal of the component from service, the Owner should review the selection of this Limit for compatibility with established system safety criteria.

B-2124 Test Loads

Loads due to tests beyond those allowed by this Section should be classified in the appropriate Service Limit in accordance with NCA-2142.3(b) [NCA-2142.4(d)-2].

B-2125 Load Combinations

In order to provide a complete definition of service loads, the combination of specific events must be considered. Since these combinations are a function of specific systems which make up a part of a specific type nuclear facility, this Section does not directly address this other than to provide different Stress Limits for various loadings. Specific guidance is provided in the approved Safety Analysis Report (SAR) for the plant.

B-2126 Deformation Limits

The Code does not provide specific deformation limits other than those that would be associated with a given allowable stress. If control of deformation is a requirement, the deformation limits should be provided.

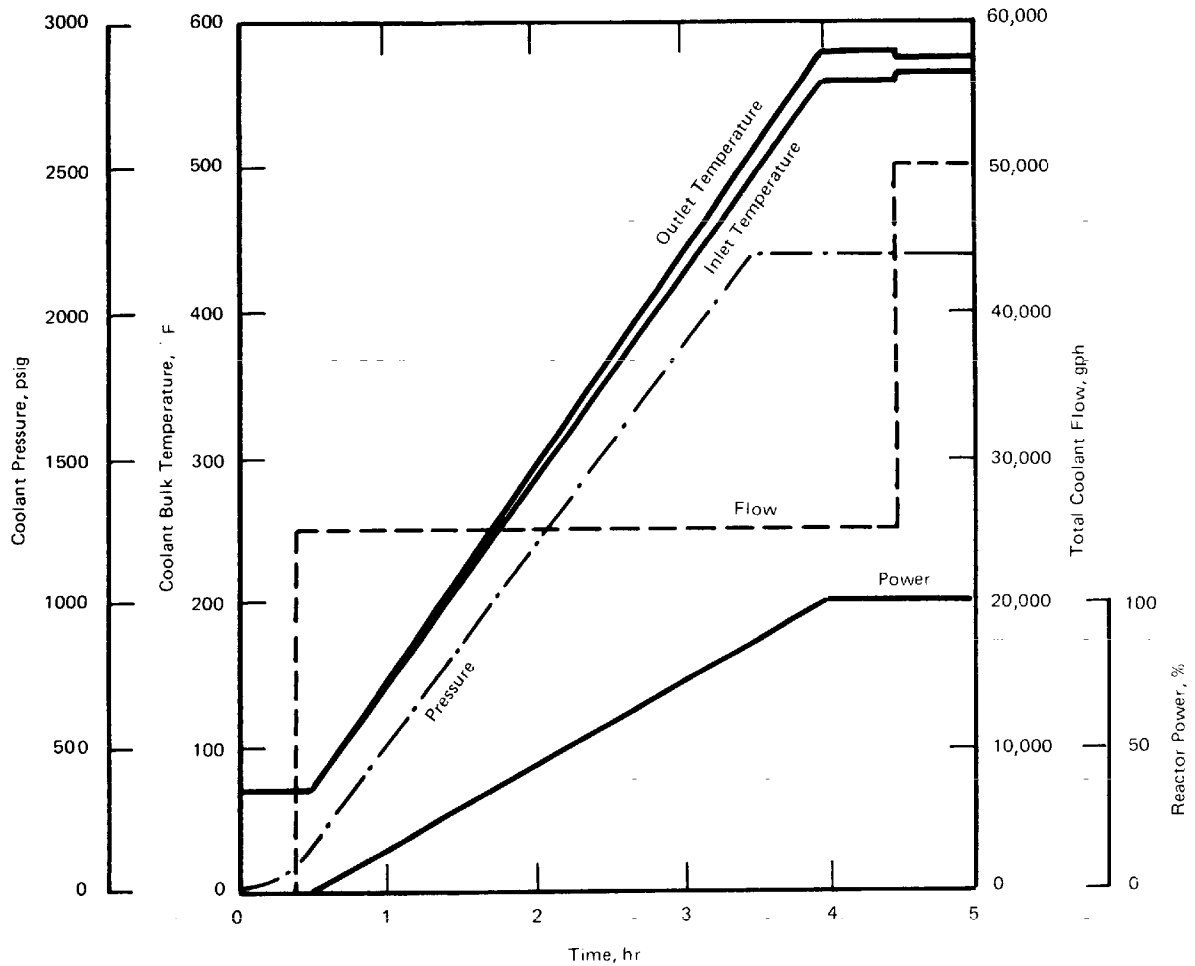


FIG. B-2123-1 TIME-DEPENDENT LOAD INFORMATION

FIG. B-2123-1 TIME-DEPENDENT LOAD INFORMATION

B-2130 MATERIALS

B-2131 General Requirements

The Design Specification should provide information relative to materials as listed in (a) through (g) below:

- (a) any hydrostatic testing or service temperature limits;
- (b) any reductions to design stress intensity values, allowable stress, or fatigue curves necessitated by environmental conditions;
- (c) any restrictions on cladding materials;

- (d) materials which are acceptable from the standpoints of environment and location;
- (e) any restrictions on heat treating;
- (f) any requirements with respect to cleanliness;
- (g) impact test requirements (B-2132);
- (h) any corrosion or erosion allowances;
- (i) postweld heat treatment times applied to the material or item after it is completed must be specified (NB/NC/ND/NE/NF/NG-4622).

B-2132 Impact Tests

For those cases where impact testing is optional, the Design Specification should state whether or not impact testing of the pressure retaining material of the component or the support material is required. The test temperature should be specified and the tests become part of the appropriate Subsection.

B-2140 FABRICATION

The Design Specification should specify any unusual restrictions on fabrication processes or techniques that would be deleterious to the suitability of the component in the expected service environment.

B-2150 TESTING

B-2151 Pneumatic Test

The Design Specification should identify if a pneumatic test should be used in lieu of hydrostatic testing for those components and appurtenances required to be pressure tested in accordance with the rules of this Section (NB-6111, NB-6112, NE-6112).

B-2152 Restriction on Testing

Any restrictions on the use of the test fluid should be provided (NB-6112, NE-6112). When selecting a fluid for the test, it should be determined that the test fluid does not have deleterious effects and that the test fluid may be safely used at the pressure and temperature specified for the test.

B-2153 Bellows Type Expansion Joints

Any requirements that supplement hydrostatic or pneumatic testing of bellows type expansion joints should be included.

B-2154 Leak Tightness

Leak tightness requirements for areas, such as permanent seals, seats, and gasketed joints for pressure retaining components or appurtenances, should be included (NB-6215).

B-2155 Additional Testing

If testing in addition to pressure testing is required, the loads due to such testing should be classified in accordance with NCA-2142.2(b) (NCA-2145).

B-2160 OVERPRESSURE PROTECTION

B-2161 General Requirements

B-2161.1 Scope.

For steady state or transient conditions of pressure and coincident temperature that are in excess of design or service

loadings and their combinations and associated limits specified in the Design Specifications, system overpressure protection is required for vessels, piping, pumps, and valves in service and subjected to the consequences of the application of these conditions (refer to NB/NC/ND-7110).

B-2161.2 Integrated Overpressure Protection.

It should be recognized that the overpressure protection of pressure retaining components in a system require consideration of the pressure transients which may be imposed on the systems during all service loadings and testing conditions described in the component Design Specifications [refer to NB-7120(a)].

B-2162 Design Secondary Pressure

The design secondary pressure shall be specified in the Design Specification [refer to NB-7111(d) and NC/ND-7112].

Page 261

B-2163 Maximum Anticipated Pressure and Temperature

The Design Specification should identify the maximum anticipated pressure and coincident temperature among any systems components under the operating conditions of the system as a consequence of any transients occurring either within the system or in associated systems which may affect the system for which overpressure protection is intended (refer to NB/NC/ND-7300). Service conditions such as at startup and shutdown may require protection against nonductile failure [NB-3211(d)] at pressures lower than the component design pressure.

B-2164 Pressure Relief Valve Operating Requirements

B-2164.1 Blowdown Requirements.

The Design Specification may specify blowdown requirements with a greater tolerance than the values stated in NB/NC/ND-7500.

B-2164.2 Popping Point Tolerance.

The Design Specification may specify a popping point tolerance greater than the value stated in NB/NC/ND-7500.

B-2165 Pressure Relief Valve Operating Characteristics (Refer to ANSI N278.1)

As applicable, the following pressure relief valve operating characteristics should be specified in the Design Specification when overpressure protection is dependent upon these factors:

- (a) set pressure;
- (b) set pressure range;
- (c) set pressure tolerance;
- (d) discharge capacity with due allowance for the effect of the back pressure on the capacity;
- (e) accumulation;
- (f) blowdown;
- (g) static and dynamic back pressure, minimum and maximum;
- (h) response time (maximum time delay between attainment of set pressure or reception of the energizing signal by the solenoid and valve lift).

B-2166 Rupture Disk Devices

Rupture disk device burst pressure tolerance and manufacturing design range should be specified in the Design Specification.

B-2200 OPERABILITY

B-2210 INTRODUCTION

Operability requirements are outside the scope of this Section (NCA-2142); however, the Owner or Owner's designee is required to identify any such requirements in the Design Specifications (NCA-3252).

B-2220 ACTIVE PUMPS OR VALVES

The Design Specification should indicate if the specified pump or valve must perform a mechanical motion during the course of accomplishing a system safety function during or following the specified plant event. Such a pump or valve is designated as an active component.

B-2300 REGULATORY REQUIREMENTS

In the process of preparing a Design Specification, it is important to refer to and rely on the requirements contained in SAR documents since they provide the basis for complying with existing regulatory requirements. Conflicts between a Design Specification and the SAR could lead to construction of items not in compliance with the license requirements. A reference list of regulatory documents is provided in B-11000 which may be used in determining the applicable requirements to be included in a Design Specification.

Page 262

ARTICLE B-3000 SPECIFIC VESSEL REQUIREMENTS

B-3100 CERTIFIED DESIGN SPECIFICATION REQUIREMENTS

The Design Specification for vessels should include requirements indicated in B-2000, Generic Requirements.

Page 263

ARTICLE B-4000 SPECIFIC PUMP REQUIREMENTS

B-4100 CERTIFIED DESIGN SPECIFICATION REQUIREMENTS

In addition to the Design Specification requirements indicated in B-2000, Generic Requirements, the Design Specification for pumps should include the other requirements of B-4110 and B-4120.

B-4110 GENERAL REQUIREMENTS

Covered by B-2110.

B-4120 DESIGN

B-4121 Loads From Connected Piping

The forces and moments produced by the connected piping on each pump inlet and outlet should be included (NB/NC/ND-3415).

B-4122 Earthquake Loadings

NB/NC/ND-3417 provide the requirements for consideration of earthquake loading.

B-4200 OPERABILITY REQUIREMENTS FOR PUMPS

B-4210 GENERAL REQUIREMENTS

B-4211 Applicability

The inclusion of functional operability requirements in the Design Specifications should be based on the functional requirements of the pump being specified. These requirements should be specified only if the pumps are considered to be active pumps.

B-4220 DESIGN

The Design Specification should include all applicable and pertinent information considered important to the functional operability of the pump.

B-4230 QUALIFICATION

B-4231 Methods

The method of pump qualification, if any, for functional operability should be defined in the Design Specification. Qualification by analysis, test, or combinations thereof should be specified. Available codes or standards which cover these areas should be referred to and used to the maximum extent possible.

B-4232 Analysis

Acceptable methods of analysis should be identified. The following areas, as a minimum, should be addressed:

- (a) required analysis;
- (b) load combinations, including deadweight, thermal loads, nozzle loads, seismic loads, etc.;
- (c) allowable stresses for the various loading conditions.

B-4233 Testing

Acceptable methods of testing should be identified. The following areas, as a minimum, should be addressed:

- (a) required tests and test sequences;
- (b) imposed loads and pump function during tests;
- (c) acceptance criteria.

Page 264

B-4240 FUNCTIONAL OPERABILITY PRODUCTION TESTS

Any special functional operability tests to be conducted on production pumps should be specified in the Design Specification.

B-4250 DOCUMENTATION

Documentation requirements for functional qualification or production tests should be specified.

B-4300 REGULATORY REQUIREMENTS

Regulatory requirements are covered in B-2300 and a reference list is given in B-11000.

Page 265

ARTICLE B-5000 SPECIFIC VALVE REQUIREMENTS

B-5100 CERTIFIED DESIGN SPECIFICATION REQUIREMENTS

In addition to the Design Specification requirements indicated in B-2000, Generic Requirements, the Design Specification for valves should include the other requirements of B-5110 and B-5120.

B-5110 GENERAL REQUIREMENTS

Covered by B-2110.

B-5120 DESIGN

B-5121 Class 1 Valves

B-5121.1 Pipe Reactions for Valves Designed to Alternative Design Rules.

NB-3512.2 provides the requirements concerning pipe reactions.

B-5121.2 Earthquake Loadings.

NB-3524 provides the requirements concerning earthquake loadings.

B-5121.3 Level C Service Limits.

NB-3526 provides the requirements concerning valve function during loading for which Level C Service Limits are specified.

B-5121.4 Pipe Reaction Stress.

NB-3526.2 provides the requirements concerning pipe reaction stress computation for Level C Service Limits.

B-5121.5 Level D Service Limits.

NB-3527 provides the requirements concerning valve function during loadings for which Level D Service Limits are specified.

B-5121.6 Hydrostatic Tests.

NB-3531.2(c) provides the requirements concerning alternative test pressures, seat leakages, and test durations.

B-5121.7 Body Contours at Weld Ends.

NB-3544.8 provides the requirements concerning alternative body contours at weld ends of valves.

B-5121.8 Bypass Piping.

The Design Specification shall state which organization is responsible for the bypass piping design, if the responsible organization is not the piping system designer [NB-3546.3(b)].

B-5122 Class 2 Valves

B-5122.1 Alternative Rules.

The Design Specification shall specify whether the alternative rules of NC-3513 are permitted to be used.

B-5122.2 Hydrostatic Tests.

NC-3514 provides the requirements concerning alternative test pressures, seat leakages, and test durations.

B-5123 Class 3 Valves

B-5123.1 Alternative Rules.

The Design Specification shall specify whether the alternative rules of ND-3513 are permitted to be used.

B-5123.2 Hydrostatic Tests.

ND-3514 provides the requirements concerning alternative test pressures, seat leakages, and test durations.

B-5200 OPERABILITY REQUIREMENTS FOR VALVES

B-5210 INTRODUCTION

Operability requirements are outside the scope of this Section (NCA-2142); however, the Owner or Owner's designee is required to identify any valve operability requirements in the Design Specification [NB-3526(b) and NB-3527].

B-5220 DESIGN

The Design Specification should include all applicable and pertinent information required. A document pertaining to this information is ANSI N278.1. Additional

Page 266

information not covered in ANSI N278.1, but considered important to the functional operability of the valve should also be included. NB-3524, NC-3520, and ND-3520 provide guidance for analysis of valves with extended masses.

B-5230 QUALIFICATION

B-5231 Methods

The method of valve qualification, if any, for functional operability should be defined in the Design Specification. Qualification by analysis, test, or combinations thereof should be specified. Available Codes or Standards which cover these areas should be referenced and used to the maximum extent possible.

B-5232 Analysis

Acceptable methods of analysis should be identified. The following areas, as a minimum, should be addressed:

- (a) required analysis;
- (b) load combinations, including seismic, end loads, mechanical loads, etc.;
- (c) allowable stresses for the various loading conditions.

B-5233 Testing

Acceptable methods of testing shall be identified. The following areas, as a minimum, should be addressed:

- (a) required tests and test sequence
- (b) imposed loads and valve function during tests
- (c) acceptance criteria Y

B-5240 FUNCTIONAL OPERABILITY PRODUCTION TESTS

Any special functional operability tests to be conducted on production valves shall be specified in the Design Specification.

B-5250 DOCUMENTATION

Documentation requirements for functional qualification or production tests or both should be specified in the Design Specification.

B-5300 REGULATORY REQUIREMENTS

Regulatory requirements are covered in B-2300 and a reference list is given in B-11000.

ARTICLE B-6000 SPECIFIC PIPING REQUIREMENTS

B-6100 CERTIFIED DESIGN SPECIFICATION REQUIREMENTS

In addition to the Design Specification requirements indicated in B-2000, Generic Requirements, the Design Specification for piping should include the other requirements of B-6110 and B-6120.

B-6110 GENERAL REQUIREMENTS

Covered by B-2110.

B-6120 DESIGN

B-6121 Seismic

For piping, the loadings, movements, anchor motions, and number of cycles due to seismic events should be given. The associated Service Loadings which occur with, or as a result of, the specified seismic events should be stated.

B-6122 Other Dynamic Loads

Dynamic loadings, such as those resulting from sudden valve or pump operation, should be given. As a minimum, the information needed to determine this loading should be given (such as pressures, temperatures, flow rates, valve operating times).

B-6123 Peak Pressure

Peak pressure for Level B, C, and D Service Limits must be restricted to certain values in accordance with NC/ND-3611.2(c)(2), (3), and (4). In categorizing Service Loadings into appropriate Service Limits, the Design Specification should include the peak pressure.

ARTICLE B-7000 SPECIFIC CONTAINMENT REQUIREMENTS

B-7100 CERTIFIED DESIGN SPECIFICATION REQUIREMENTS

In addition to the Design Specification requirements indicated in B-2000, Generic Requirements, the Design Specification for containment should include the other requirements of B-7110 and B-7120.

B-7110 GENERAL REQUIREMENTS

Covered by B-2110.

B-7120 DESIGN

B-7121 Design Pressure

NE-3112.1 provides the requirements concerning specification of Design Pressure.

B-7122 Design Temperature

NE-3112.2 provides the requirements concerning specification of Design Temperature.

B-7123 Design Mechanical Loads

NE-3112.3 provides the requirements concerning specification of Design Mechanical Loads.

B-7124 Service Conditions

NE-3113 provides the requirements concerning specification of Level A, B, C, and D Service Conditions which satisfy the Generic Requirements for Service Limits in NCA-2142.

Page 269

ARTICLE B-8000 SPECIFIC COMPONENT SUPPORT REQUIREMENTS

B-8100 CERTIFIED DESIGN SPECIFICATION REQUIREMENTS

In addition to the Design Specification requirements indicated in B-2000, Generic Requirements, the Design Specification for component and piping supports should include the other requirements of B-8110, B-8120, and B-8130.

B-8110 GENERAL REQUIREMENTS

In addition to the general requirements of B-2110, the information required by NF-1111 for intervening elements in the component support load path should be included in the Design Specification for the supported component.

B-8120 DESIGN

B-8121 Standard Supports

NF-3134 provides the requirements for standard supports.

B-8130 MATERIALS

Requirements for items, such as gaskets, seals, springs, compression spring endplates, bearings, retaining rings, washers, wear shoes, hydraulic fluids, etc., should be stated in the Design Specification. Such items should be made of materials that are not injuriously affected by the fluid, temperature, or irradiation conditions to which the item will be subjected (NF-2121).

B-8300 REGULATORY REQUIREMENTS

Regulatory requirements are covered in B-2300 and a reference list is given in B-11000.

Page 270

ARTICLE B-9000 SPECIFIC CORE SUPPORT STRUCTURES REQUIREMENTS

B-9100 CERTIFIED DESIGN SPECIFICATION REQUIREMENTS

In addition to the Design Specification requirements indicated in B-2000, Generic Requirements, the Design Specification for core support structures should include the other requirements of B-9110, B-9120, B-9130, and B-9140.

B-9110 GENERAL REQUIREMENTS

(a) All information and requirements contained in the specifications which are beyond the jurisdiction of Subsection NG should be so identified.

(b) The Design Specifications should stipulate any specific additional core support structure requirements which the Owner intends to be incorporated in the specific structures covered by the Design Specifications or any additional requirements intended to be more specific or more restrictive than the minimum requirements of this Section.

(c) Where additional terms, definitions, or expressions are required, they should be clearly defined and explained and adequately referenced.

(d) Identification of the core support structure is required as determined by their function and operating requirements (Structures whose purpose is only to limit the motion of the core following the postulated occurrence of a failure in the structure normally supporting the core are not considered core support structures. They are normally designed to meet deformation limits for this postulated condition and are not intended to meet the stress limits of NG-3200.) (NG-1121).

(e) Delineation of those internal structures which are required to be analyzed in order to ensure the structural integrity of the mating core support structures (NG-1122).

(f) The boundaries of the core support structures and their relationship to the support and restraint of the core shall be clearly defined through the use of dimensions, descriptions, or drawings (NG-1120).

B-9120 DESIGN

B-9121 Loading Conditions

The following should be specified:

- (a) pressure differences due to coolant flow;
- (b) weight of the core support structure;
- (c) superimposed loads, such as those due to other structures, the reactor core, steam separating equipment, flow distributors and baffles, thermal shields, and safety equipment;
- (d) earthquake loads or other loads which result from motion of the reactor vessel;
- (e) reactions from the support or restraints, or both;
- (f) loads due to temperature effects, such as thermal gradients and differential expansion;
- (g) loads resulting from the impingement or flow of reactor coolant or other contained or surrounding fluids;
- (h) transient pressure difference loads, such as those which would result from rupture of the main coolant pipe;
- (i) vibratory loads;
- (j) reaction loads from control rods;
- (k) handling loads experienced in preparation for or during refueling or inservice inspection.

B-9122 Loading Combinations

The loadings to be simultaneously considered and the applicable Service Limits should be specified (NG-3112).

Page 271

B-9123 Deformation Limits

In addition to Service Limits given in Subsection NG, static and dynamic deformation limits should be specified to ensure the performance of all safety related functions of the core support structure. These limits are to be those that cause loss of function and are not intended to include a margin of safety (NG-3220).

B-9124 Reinforcement for Openings

The Design Specification should stipulate if the rules for reinforcing applicable to Class 1 vessels may be used for core support structures (NB-3132).

B-9130 MATERIALS

The Design Specifications should provide any special requirements for materials and testing specifically applicable to the core support structures. The Owner is responsible for selecting materials suitable for the conditions stated at the Design Specification with specific attention being given to the effects of service conditions upon the properties of the materials (NB-2160). The requirements for impact testing shall be specified [NG-2311(a)].

B-9140 FABRICATION

The extent or removal of additional material by mechanical means when P-No. 8 material is prepared by thermal cutting

ARTICLE B-10000 SPECIFIC PARTS AND MISCELLANEOUS ITEMS REQUIREMENTS

B-10100 CERTIFIED DESIGN SPECIFICATION REQUIREMENTS

In addition to the Design Specification requirements indicated in B-2000, Generic Requirements, the Design Specification for parts and miscellaneous items should include the other requirements of B-10110.

B-10110 GENERAL REQUIREMENTS

The following general requirements should be considered when preparing a Design Specification for parts and miscellaneous items.

B-10111 Parts

The Design Specification for components or component supports should apply to the parts of such components or component supports (NCA-2131).

B-10112 Appurtenances

NCA-1260 provides the requirements for appurtenances.

B-10113 Control Rod Drive Housings

NCA-1271 provides the requirements for control rod drive housings.

B-10114 Heater Elements

NCA-1272 provides the requirements for heater elements.

B-10115 Fluid Conditioner Devices

NCA-1273 provides the requirements for fluid conditioner devices.

ARTICLE B-11000 REFERENCE LIST OF REGULATORY REQUIREMENTS

B-11100 INTRODUCTION

This list is intended as a guide only and it should be recognized that new regulatory requirements may exist that are not listed or that some of those listed may be revised or voided.

B-11200 TITLE 10 OF CODE OF FEDERAL REGULATIONS

Title 10 of the Code of Federal Regulations (10 CFR) includes requirements on the use, construction, and operation of production and utilization facilities, such as nuclear power plants. Of particular importance to the construction of nuclear components and safety related structures are Part 50 of the regulations, "Licensing of Production and Utilization Facilities," and Part 100 of the regulations, "Reactor Site Criteria." The following portions of 10 CFR Parts 50 and 100 highlight requirements that should be considered in the preparation of Design Specifications.

(a) 10 CFR Part 50.55a constitutes one of the most important of the regulations relative to the Design Specifications. Among other requirements, it designates the Codes and Standards and their Editions and Addenda that must be used for pressure retaining components and within the reactor coolant pressure boundary.

(b) 10 CFR 50.59 - Changes, Tests, and Experiments;

- (c) 10 CFR 50.109 - Backfitting;
- (d) Appendix A to 10 CFR Part 50 - General Design Criteria;
- (e) Appendix B to 10 CFR Part 50 - Quality Assurance Criteria;
- (f) Appendix G to 10 CFR Part 50 - Fracture Toughness Requirements;
- (g) Appendix H to 10 CFR Part 50 - Reactor Vessel Material Surveillance Program;
- (h) Appendix J to 10 CFR Part 50 - Containment Leak Testing;
- (i) Appendix M to 10 CFR Part 50 - Standardization of Design;
- (j) Appendix N to 10 CFR Part 50 - Standardization of Nuclear Power Plant Design;
- (k) Appendix O to 10 CFR Part 50 - Standardization of Designs;
- (l) Appendix A to 10 CFR Part 100 - Seismic and Geological Siting.

B-11300 REGULATORY GUIDES

B-11310 DESIGN

- 1.1 Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal System Pumps (Safety Guide 1, 11/2/70)
- 1.2 Thermal Shock to Reactor Pressure Vessels (Safety Guide 2, 11/2/70)
- 1.11 Instrument Lines Penetrating Primary Reactor Containment (Safety Guide 11, 3/10/71)
- 1.13 Fuel Storage Facility Design Basis (Revision 1, 12/75)
- 1.14 Reactor Coolant Pump Flywheel Integrity (Revision 1, 8/75)
- 1.26 Quality Group Classifications and Standards for Water-, Steam-, and Radioactive- Waste-Containing Components of Nuclear Power Plants (Revision 3, 3/76)
- 1.27 Ultimate Heat Sink for Nuclear Power Plants (Revision 2, 1/76)

Page 274

- 1.29 Seismic Design Classification (Revision 3, 9/78)
- 1.46 Protection Against Pipe Whip Inside Containment (5/73)
- 1.48 Design Limits and Loading Combinations for Seismic Category I Fluid System Components (5/73)
- 1.52 Design, Testing, and Maintenance Criteria for Atmosphere Cleanup System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants (Revision 2, 3/78)
- 1.57 Design Limits and Loading Combinations for Metal Primary Reactor Containment System Components (6/73)
- 1.59 Design Basis Floods for Nuclear Power Plants (Revision 2, 8/77)
- 1.60 Design Response Spectra for Seismic Design of Nuclear Power Plants (Revision 1, 12/73)
- 1.61 Damping Values for Seismic Design of Nuclear Power Plants (10/73)
- 1.63 Electric Penetration Assemblies in Containment Structures for Water-Cooled Nuclear Power Plants (Revision 2, 7/78)
- 1.67 Installation of Overpressure Protection Devices (10/73)
- 1.76 Design Basis Tornado for Nuclear Power Plants (4/74)
- 1.84 Code Case Acceptability - ASME Section III Design and Fabrication (Revision 14, 11/78)

- 1.92 Combining Modal Responses and Spatial Components in Seismic Response Analysis (Revision 1, 2/76)
- 1.96 Design of Main Steam Isolation Valve Leakage Control Systems for Boiling Water Reactor Nuclear Power Plants (Revision 1, 6/76)
- 1.102 Flood Protection for Nuclear Power Plants (Revision 1, 9/76)
- 1.106 Thermal Overload Protection for Electric Motors on Motor Operated Valves (Revision 1, 3/77)
- 1.115 Protection Against Low-Trajectory Turbine Missiles (Revision 1, 7/77)
- 1.117 Tornado Design Classification (Revision 1, 4/78)
- 1.120 Fire Protection Guidelines for Nuclear Power Plants (Revision 1, 11/77)
- 1.122 Development of Floor Response Spectra for Seismic Design of Floor Supported Equipment or Components (Revision 1, 2/78)
- 1.124 Design Limits and Loading Combinations for Class 1 Linear Type Component Supports (Revision 1, 1/78)
- 1.130 Service Limits and Loading Combinations for Class 1 Plate and Shell Type Component Supports (11/78)

B-11320 MATERIALS

- 1.34 Control of Electroslag Weld Properties (12/28/72)
- 1.36 Nonmetallic Thermal Installation for Austenitic Stainless Steel (2/23/73)
- 1.43 Control of Stainless Steel Weld Cladding of Low-Alloy Steel Components (5/73)
- 1.44 Control of the Use of Sensitized Stainless Steel (5/73)
- 1.65 Materials and Inspections for Reactor Vessel Closure Studs (10/73)
- 1.85 Code Case Acceptability - ASME Section III Materials (Revision 14, 11/78)
- 1.99 Effects of Residual Elements on Predicted Radiation Damage to Reactor Vessel Materials (Revision 1, 4/77)

B-11330 EXAMINATION

- 1.58 Qualification of Nuclear Power Plant Inspection, Examination, and Testing Personnel (8/73)
- 1.65 Materials and Inspections for Reactor Vessel Closure Studs (10/73)
- 1.83 Inservice Inspection of Pressurized Water Reactor Steam Generator Tubes (Revision 1, 7/75)

Page 275

B-11340 FABRICATION

- 1.31 Control of Stainless Steel Welding (Revision 3, 4/78)
- 1.50 Control of Preheat Temperature for Welding of Low-Alloy Steel (5/73)
- 1.84 Code Case Acceptability - ASME Section III Design and Fabrication (Revision 14, 11/78)

B-11350 INSTALLATION

- 1.31 Control of Stainless Steel Welding (Revision 1, 6/73)
- 1.50 Control of Preheat Temperature for Welding of Low-Alloy Steel (5/73)
- 1.71 Welder Qualification for Areas of Limited Accessibility (12/73)

B-11360 TESTING

- 1.20 Comprehensive Vibration Assessment Program for Reactor Internals During Preoperational and Initial Startup Testing (Revision 2, 5/76)
- 1.52 Design, Testing, and Maintenance Criteria for Atmosphere Cleanup System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants (Revision 2, 3/78)
- 1.58 Qualification of Nuclear Power Plant Inspection, Examination, and Testing Personnel (8/73)

B-11370 QUALITY ASSURANCE

- 1.28 Quality Assurance Program Requirements (Design and Construction) (Safety Guide 28, Revision 2, 2/79)
- 1.37 Quality Assurance Requirements for Cleaning of Fluid Systems and Associated Components of Water-Cooled Nuclear Power Plants (3/16/73)
- 1.38 Quality Assurance Requirements for Packaging, Shipping, Receiving, Storage, and Handling of Items for Water-Cooled Nuclear Power Plants (Revision 2, 5/77)
- 1.54 Quality Assurance Requirements for Protective Coatings Applied to Water-Cooled Nuclear Power Plants (6/73)
- 1.58 Qualification of Nuclear Power Plant Inspection, Examination, and Testing Personnel (8/73)
- 1.64 Quality Assurance Requirements for the Design of Nuclear Power Plants (Revision 2, 6/76)
- 1.74 Quality Assurance Terms and Definitions (2/74)
- 1.88 Collection, Storage, Maintenance of Nuclear Power Plant Quality Assurance Records (Revision 2, 10/76)
- 1.116³ Quality Assurance Requirements for Installation, Inspection, and Testing of Mechanical Equipment and Systems (O-R, 5/77)
- 1.123⁴ Quality Assurance Requirements for Control of Procurement of Items and Services for Nuclear Power Plants (Revision 1, 7/77)

3 Excludes Code components.

4 Used in conjunction with Section III.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP C

APPENDIX C CERTIFICATE HOLDER'S DESIGN REPORT

Page 277

C-1100 INTRODUCTION

C-1110 OBJECTIVE

The objective of this Appendix is to provide a guide for use by Certificate Holders in the preparation of Design Reports required by NCA-3551.1. Desirably, such Design Reports should be uniform as to format for all of the nuclear industry. Such uniformity is helpful in making for easier review by the Owner (NCA-3260), Inspectors, regulatory agencies, or independent groups. For NF supports designed by load rating (NF-3280), the preparation of a load capacity data sheet in accordance with NCA-3551.2 fulfills the requirements for preparation of a Design Report. The contents of this Appendix constitute only suggestions and are nonmandatory.

C-1120 BASIS

In order to meet the requirements of NCA-3551, the Design Report should be based upon analysis or testing adequate to

demonstrate the validity of the structural design to sustain and meet in every respect the requirements and provisions of the relevant certified Design Specifications and the requirements of this Section; the Report should include, as a minimum, the results, conclusions, and other considerations which show that the structural design meets these requirements.

C-1130 FORMAT

C-1131 General Requirements

Since a major purpose of the Design Report is to facilitate an independent review of its content, it is important that it be simple to follow and free from ambiguity. Nomenclature, definitions, and symbols used should be in agreement with those established in Subsection NB for Class 1 components, in Subsection NE for Class MC vessels, in Subsection NF for supports, in Subsection NG for Class CS core support structures, and in Subsection NC for vessels designed in accordance with NC-3200. Where additional terms, definitions, or expressions are required, they should be clearly defined and explained and adequately referenced. It is not the intention to limit the choice of analytical methods or computational techniques used for obtaining the values and results required for the Design Report.

C-1132 Presentation of Analysis

The analysis in the Design Report should be in three sections: Thermal Analysis, Structural Analysis, and Fatigue Evaluation. The desiderata listed in (a) through (j) below should be adhered to:

- (a) pages and figures in each section of the Report should be consecutively numbered;
- (b) reference data taken from other parts of the calculations should have the proper page number and section of the Report listed;
- (c) a general description of the method of analysis should be given;
- (d) all reference sources should be listed;
- (e) all computer programs should be properly identified and described;
- (f) stresses should be tabulated for each area of investigation;
- (g) areas which have the most severe stress condition for design conditions or for any specified transient should be listed in the Report, along with the stress values in these areas;
- (h) results should be summarized and a general summary of all stresses should be made in each section of the Report;
- (i) drawings and sketches necessary for an understanding of the analysis should be part of the Report;
- (j) the Report should include copies of sufficient computer printouts to justify the governing stress values used in the Design Report and enable independent review. Copies of any manual calculations prepared which establish the final design should also be included.

Page 280

C-1140 BASIC INFORMATION

It should be noted that the references in this Appendix to basic information which is to be obtained from the certified Design Specifications (NCA-3250) are predicated on the requirement of NCA-3252 that such information be provided.

C-1150 DISTRIBUTION OF COPIES OF DESIGN REPORT

Copies of the completed certified Design Report (NCA-3355) should be made available for the Owner's review, certification, and distribution as required by NCA-3556, NCA-3260, and NCA-3270. The Certificate Holder shall also make a copy available to the Inspector (NCA-3557).

C-1200 THERMAL ANALYSIS

C-1210 DESCRIPTIONS OF OPERATING CYCLES

Data for the various transients and operating cycles should be obtained from the certified Design Specifications. Typical cycles which should be considered are referenced in Appendix B.

C-1220 STEADY STATE CONDITION

The steady state condition to provide a thermal equilibrium condition for normal operating transients should be obtained from the certified Design Specifications.

C-1230 GEOMETRY FROM TEMPERATURE DISTRIBUTION POINT OF VIEW

The geometrical structure of the component should be divided into suitable areas for thermal analysis. Sketches of the thermal model should be included in the Report. The areas listed in (a) through (m) below are typical of those that should be investigated:

- (a) nozzle junctions in the component wall;
- (b) stud bolts;
- (c) cylinder junction with cylinder flange;
- (d) point of support attachment;
- (e) cylinder junction with head;
- (f) junction of component wall and internal baffles, tubesheets, and attachments;
- (g) tube-to-tubesheet junction for heat exchangers;
- (h) heater penetrations to component junction for pressurizer;
- (i) junction area between component supports and building structure;
- (j) external attachments;
- (k) changes in thickness within a component (such as a reducer, branch connection, component support, etc.) or across a welded joint (such as a socket weld, butt weld of different thickness, etc.);
- (l) instrument penetrations to component junction (such as thermowells, flow devices, etc.);
- (m) core barrel and core support plate.

C-1240 GEOMETRIES FROM STRESS INVESTIGATION POINT OF VIEW

The final breakdown of the geometries, which will correspond to the method of stress calculation, should be indicated in the calculations. Typical areas listed in C-1230 which are applicable to the component under consideration should be included.

C-1250 TEMPERATURE-DEPENDENT DATA FOR EACH THERMAL GEOMETRY AND TRANSIENT

The Certificate Holder should specify values for all parameters, such as coefficients for water and air, which are required for thermal calculations. References to sources should be given for all such data used.

C-1260 TEMPERATURE DISTRIBUTION FOR EACH GEOMETRY

The temperature profile of the applicable areas listed under C-1230 should be calculated and the temperature values attached to the calculations. The temperature distributions should be based on two or three dimensional heat transfer calculations. For calculating through wall (radial) temperature distributions to obtain values of ΔT_1 and ΔT_2 (NB-3650), one-dimensional heat transfer calculations are acceptable.

C-1270 THERMAL GRADIENTS

Individual transients should be investigated separately for each area. The longitudinal, radial, and circumferential gradients should be plotted separately. The temperature gradients used in the stress calculations should be plotted.

Page 281

C-1300 STRUCTURAL ANALYSIS

C-1310 IMPORTANT THERMAL AND MECHANICAL LOADING ON COMPONENT STRUCTURE

C-1311 Mechanical Loading

The mechanical loads used in the Design Report to calculate primary stresses should be obtained directly from the Design Specification (such as Design Pressure and Temperature) or from information contained in the Design Specification (such as seismic spectra, valve opening and/or closing times, etc.).

C-1312 Thermal and Mechanical Loading

Specific reference should be made to the thermal transients and resulting gradients which are to be used for the Design Report. The internal pressure and external loads to be used should be in accordance with the time and thermal condition analyzed. Values for external nozzle loads should include sign convention of the loadings and be referenced specifically to the geometries.

C-1320 METHODS OF CALCULATIONS

The Certificate Holder should submit a short description of the calculation methods used in connection with the stress analysis. All computer programs used in making calculations should be verified by comparing the program with the results of an appropriate analytical or experimental solution. The basic theories on which the calculations are based and the assumptions should also be included.

C-1330 PRINCIPAL STRESSES FOR EACH GEOMETRY

In calculating stress components, the requirements of NB-3200, NC-3200, NE-3200, NF-3220, NF-3230, or NG-3200 should be followed. The following are typical of stress components that should be considered:

(a) Mechanical stresses generated by:

- (1) pressure load
- (2) deadweight load
- (3) piping load
- (4) externally applied load
- (5) seismic loads
- (6) dynamic loads

(b) Thermal stresses generated by:

- (1) radial gradient
 - (a) thermal stress
 - (b) thermal discontinuity stress
- (2) longitudinal gradient
 - (a) thermal stress
 - (b)

C-1340 ALLOWABLE LIMITS

Each individual stress component and combination of the stress components should satisfy the requirements of NB-3220, NC-3220, NE-3220, NF-3220, NF-3230, or NG-3220.

C-1400 FATIGUE EVALUATION

C-1410 SCOPE OF FATIGUE EVALUATION

Fatigue evaluation when required should include the considerations and investigations described in this Subarticle.

C-1420 LOCATIONS OF STRESS CONCENTRATIONS

Stress concentration should be investigated at any geometrical changes in the structure, such as difference in wall thickness, joints and corners, and junctions of dissimilar metals. A list of the locations subject to fatigue evaluation should be included in the Report. For piping, K indices are given for standard piping components in NB-3600 which represent elastic stress concentration factors.

C-1430 FATIGUE STRENGTH REDUCTION FACTORS AS FUNCTION OF LOCATIONS AND TYPES OF STRESS

Fatigue strength reduction factors should be numerically listed for the stresses where they are to be applied. The references and methods of finding the fatigue strength reduction factors should be included in the Report.

Page 282

C-1440 PROPER STRESS CONCENTRATION OR FATIGUE STRENGTH REDUCTION FACTOR APPLICATION TO STRESSES

The numerical value of the individual stress components should be listed with and without the stress concentration or fatigue strength reduction factor applied. Factors should be applied to each individual stress component and not applied to the total stress at a point or to the stress intensity.

C-1450 COMBINED STRESSES AND ALLOWABLE NUMBER OF CYCLES

Where the rules do not specifically control this, as they do in NB-3500 and NB-3600, methods of combining stresses, determining principal stresses, determining alternating stress intensity, and determining cumulative damage effects and allowable number of cycles should be shown in the Report. These results should be reconciled with the required values.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP D

APPENDIX D NONMANDATORY PREHEAT PROCEDURES

Page 283

ARTICLE D-1000 NONMANDATORY PREHEAT PROCEDURES

D-1100 INTRODUCTION

D-1110 SCOPE

The preheat temperatures given herein are a general guide for the materials listed in P-Numbers of Section IX. Specific rules for preheating are not given since the need for preheat and the minimum preheat temperatures vary and are dependent on a number of factors, such as chemical analysis, degree of restraint, physical properties, and thickness. Preheat

requirements for different materials of the same P-Number may be more or less restrictive depending upon the specific circumstances associated with making a particular weld. The welding procedure specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX (NB-4611).

D-1120 TEMPERATURE MAINTENANCE

(a) Difficulty may be experienced with certain materials if the temperature is allowed to fall below the preheat temperature between passes. It may be desirable to maintain the preheat temperature or to heat the joint to the postweld heat treatment temperature before allowing it to cool to ambient temperature.

(b) The preheat temperature may be checked by suitable methods, such as temperature-indicating crayons or thermocouple pyrometers, to ensure that the required preheat temperature is maintained during the welding operation. The Certificate Holder should be cautious in the use of temperature-indicating crayons and pellets because some metals may be severely attacked by the chemicals in crayons or pellets at elevated temperatures.

D-1200 FERROUS MATERIALS

D-1210 PREHEAT TEMPERATURES

Suggested minimum preheat temperatures are given in the following subparagraphs.

D-1210.1 P-No. 1, Group 1.

200°F (93°C) is suggested for material that has a maximum carbon content of 0.30% or less and a thickness in excess of $1\frac{1}{2}$ in. (38 mm). 250°F (121°C) is suggested for material that has both a maximum carbon content in excess of 0.30% and a thickness in excess of 1 in. (25 mm). This does not apply to fillet welds $\frac{1}{2}$ in. (13 mm) and less in size that are used to attach insulation clips and other parts not carrying loadings due to internal pressure. 50°F (10°C) is suggested for all other materials in this group.

D-1210.2 P-No. 1, Group 2.

200°F (93°C) is suggested for material that has a maximum carbon content of 0.30% or less and a thickness in excess of 1 in. (25 mm). 250°F (121°C) is suggested for material that has a maximum carbon content in excess of 0.30% and a thickness in excess of 1 in. (25 mm).

D-1210.3 P-No. 1, Group 3 and P-No. 3 and P-No. 11A.

250°F (121°C) is suggested for material that has either a specified maximum tensile strength in excess of 70.0 ksi (480 MPa) or a thickness at the joint in excess of $\frac{5}{8}$ in. (16 mm). 50°F (10°C) is suggested for all other materials in this group.

D-1210.4 P-No. 4.

300°F (149°C) is suggested for material that has either a specified minimum tensile strength in excess of 60.0 ksi (410 MPa) or a thickness at the joint in excess of $\frac{1}{2}$ in. (13 mm). 50°F (10°C) is suggested for all other materials in this group.

D-1210.5 P-No. 5.

400°F (204°C) is suggested for material that has either a specified minimum tensile strength in excess of 60.0 ksi (410 MPa) or has both a specified minimum chromium content above 6.0% and a thickness at the joint in excess of $\frac{1}{2}$ in. (13 mm).

Page 286

300°F (149°C) is suggested for all other materials in this group.

D-1210.6 P-No. 6.

400°F (204°C) is suggested for all materials.

D-1210.7 P-No. 7 and P-No. 8.

None is suggested.

D-1210.8 P-No. 9.

300°F (149°C) is suggested for all materials.

D-1210.9 P-No. 10

(a) 175°F (79°C) is suggested for P-No.10A.

(b) 250°F (121°C) is suggested for P-No.10B.

(c) Preheat and interpass temperatures should be controlled for various thicknesses to avoid detrimental effects on the mechanical properties of heat treated material.

(d) 300°F (149°C) is suggested for P-No. 10D and P-No. 10E with interpass at 300 - 450°F (149 - 232°C).

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP E

APPENDIX E MINIMUM BOLT CROSS-SECTIONAL AREA

Page 287

E-1100 INTRODUCTION

[98]

E-1110 SCOPE

This Article implements NB-3230 by providing specific methods for the determination of the minimum bolt cross-sectional area. Stresses in the bolts during service must also satisfy the requirements of NB-3232.2 and NB-3232.3. Evaluation of service bolt stresses requires analysis in addition to that described by this Article, generally involving the performance of a discontinuity analysis in accordance with the principles described in A-6000.

[98]

E-1120 NOMENCLATURE

The nomenclature defined below is used in the equations of this Article.

A_b	= actual total cross-sectional area of bolts at root of thread or section of least diameter under stress, sq in.
A_m	= total design cross-sectional area of bolts, taken as the greater of A_{m1} and A_{m2} sq in.
A_{m1}	= total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for the Design Conditions, sq in. $= W_{m1}/S_b$
A_{m2}	= total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for gasket seating, sq in.

	<i>m2 a</i>
b	= effective gasket or joint contact surface seating width, in. (E-1210, footnote ¹)
b_o	= basic gasket seating width, in. (Table E-1210-2)
G	= diameter at location of gasket load reaction. G is defined as follows (Table E-1210-2): when $b_o \leq \frac{1}{4}$ in., G is the mean diameter of gasket contact face, in.; when $b_o > \frac{1}{4}$ in., G is the outside diameter, in., of gasket contact face less $2b$.
H	= total hydrostatic end force, lb = $0.785G^2P$
m	= gasket factor obtained from Table E-1210-1 [footnote ¹ to E-1210(a)(1)]
N	= width, in., used to determine the basic gasket seating width, b_o , based upon the contact width of the gasket (Table E-1210-2)
P	= Design Pressure, psi
S_a	= allowable bolt stress at atmospheric temperature, psi (Section II, Part D, Subpart 1, Table 4)
S_b	= allowable bolt stress at Design Temperature, psi (Section II, Part D, Subpart 1, Table 4)
T	= thickness, in., used to determine the basic gasket seating width, b_o (Table E-1210-2)
W_{m1}	= minimum required bolt load for the Design Pressure, lb (E-1210)
W_{m2}	= minimum required bolt load for gasket seating, lb (E-1210)
w	= width, in., used to determine the basic gasket seating width b_o based upon the contact width between the flange facing and the gasket (Table E-1210-2)
y	= minimum design seating stress, psi

E-1200 DESIGN CROSS-SECTIONAL AREA

[98]

E-1210 BOLT LOADS

(a) *Design Bolt Loads.* The flange bolt loads used in calculating the design cross-sectional area of bolts shall be determined as stipulated in (1) and (2) below.

(1) The design bolt load for the Design Pressure W_{m1} shall be sufficient to resist the hydrostatic end force H , exerted by the Design Pressure on the area bounded by the diameter of gasket reaction, and, in addition, to maintain on the gasket or joint contact surface a compression load H_p , which experience has shown to be sufficient to ensure a tight joint. This compression load is expressed as a multiple m of the internal pressure. Its value is a function of the gasket

Page 290

material and construction.¹ The design bolt load for the Design Pressure W_{m1} is determined in accordance with Eq. (1).

$$W_{m1} = H + H_p$$

$$= 0.785G^2P + (2b \times 3.14GmP) \quad (1)$$

(1)

Tables E-1210-1 and E-1210-2 give a list of many commonly used gasket materials and contact facings with suggested values of m , b , and y that have proved satisfactory in actual service. These values are suggested only and are not mandatory. Values that are too low may result in leakage at the joint, without affecting the safety of the design. The primary proof that the values are adequate is the hydrostatic test.

(2) Before a tight joint can be obtained it is necessary to seat the gasket or joint contact surface properly by applying a minimum initial load, under atmospheric temperature conditions without the presence of internal pressure, which is a function of the gasket material and the effective gasket area to be seated. The minimum initial bolt load W_{m2} required for this purpose, shall be determined in accordance with Eq. (2).

$$(2) W_{m2} = 3.14bGy$$

The need for providing sufficient bolt load to seat the gasket or joint contact surfaces in accordance with Eq. (2) will prevail on many low pressure designs and with facings and materials that require a high seating load, and where the bolt load, computed by Eq. (1) for the Design Pressure, is insufficient to seat the joint. Accordingly, it is necessary to furnish bolting and to pretighten the bolts sufficiently to satisfy both of these requirements, each one being individually investigated. When Eq. (2) governs, flange proportions will be a function of the bolting instead of internal pressure.

(b) *Minimum Required and Actual Bolt Areas A_m and A_b* The minimum cross-sectional area of bolts A_m required for both the Design Pressure and gasket seating is the greater of the values for A_{m1} and A_{m2} , where $A_{m1} = W_{m1}/S_b$ and $A_{m2} = W_{m2}/S_a$. A selection of bolts to be used shall be made such that the actual total cross-sectional area of bolts A_b will not be less than A_m (NB-3230).

(c) Bolt Loads for Flanges Using Gaskets of the Self-Energizing Type

(1) The design bolt load for the Design Pressure W_{m1} shall be sufficient to resist the hydrostatic end force H , exerted by the maximum allowable working pressure on the area bounded by the outside diameter of the gasket. H_p is to be considered as 0 for all self-energizing gaskets, except certain seal configurations that generate axial gasket loads which shall be considered.

$$(2) W_{m2} = 0.$$

Self-energizing gaskets are considered to be those that require only an inconsequential amount of bolt force to produce an initial seal. The bolting, however, may have to be sufficiently pretightened to prevent extrusion of the gasket, to prevent cyclic fatigue of the bolts, or to resist any external loads or moments that may be imposed on the joint.

[98]

Page 291

Page 293

Pages 292-292

TABLE E-1210-1
GASKET MATERIALS AND CONTACT FACINGS¹
Gasket Factors m for Operating Conditions and Minimum Design Seating Stress y

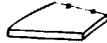
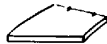
Gasket Material	Gasket Factor m	Min. Design Seating Stress y , psi	Sketches	Facing Sketch and Column in Table E-1210-1
Self-energizing types (O rings, metallic, elastomer, other gasket types considered as self-sealing)	0	0	...	...
Elastomers without fabric or high percent of asbestos fiber:				
Below 75A Shore Durometer	0.50	0		(1a),(1b),(1c),(1d), (4),(5); Column II
75A or higher Shore Durometer	1.00	200		
Asbestos with suitable binder for operating conditions:	2.00	1,600		(1a),(1b),(1c),(1d), (4),(5); Column II
1/8 in. thick	2.75	3,700		
1/16 in. thick	3.50	6,500		
1/32 in. thick				
Elastomers with cotton fabric insertion	1.25	400		(1a),(1b),(1c),(1d), (4),(5); Column II
Elastomers with asbestos fabric insertion (with or without wire reinforcement):	2.25	2,200		
3-ply				
2-ply	2.50	2,900		(1a),(1b),(1c),(1d), (4),(5); Column II
1-ply	2.75	3,700		
Vegetable fiber	1.75	1,100		(1a),(1b),(1c),(1d), (4),(5); Column II
Spiral-wound metal, asbestos filled:	2.50	10,000		(1a),(1b); Column II
Carbon	3.00	10,000		
Stainless or Monel				
Corrugated metal, asbestos inserted, or corrugated metal, jacketed asbestos filled:	2.50	2,900		(1a),(1b); Column II
Soft aluminum	2.75	3,700		
Soft copper or brass	3.00	4,500		
Iron or soft steel	3.25	5,500		
Monel or 4-6% chrome	3.50	6,500		
Stainless steels				

TABLE E-1210-1 GASKET MATERIALS AND CONTACT FACINGS¹

TABLE E-1210-1 (CONT'D)
GASKET MATERIALS AND CONTACT FACINGS¹
Gasket Factors m for Operating Conditions and Minimum Design Seating Stress y

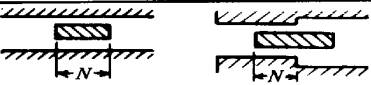
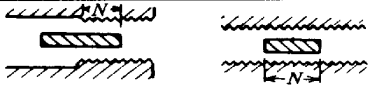
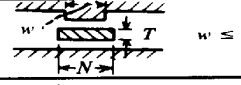
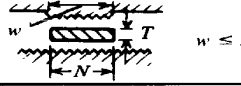
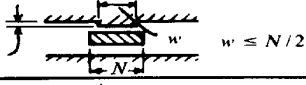
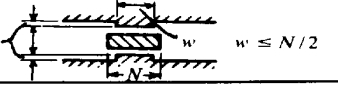
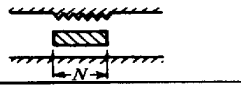
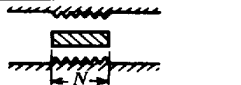
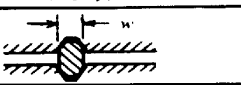
Gasket Material	Gasket Factor m	Min. Design Seating Stress y , psi	Sketches	Facing Sketch and Column in Table E-1210-1
Corrugated metal:				
Soft aluminum	2.75	3,700		(1a),(1b),(1c),(1d), Column II
Soft copper or brass	3.00	4,500		
Iron or soft steel	3.25	5,500		
Monel or 4-6% chrome	3.50	6,500		
Stainless steels	3.75	7,600		
Flat metal, jacketed asbestos filled:				
Soft aluminum	3.25	5,500		(1a),(1b),(1c), ² (1d), ² (2) ² ; Column II
Soft copper or brass	3.50	6,500		
Iron or soft steel	3.75	7,600		
Monel	3.50	8,000		
4-6% chrome	3.75	9,000		
Stainless steels	3.75	9,000		
Grooved metal:				
Soft aluminum	3.25	5,500		(1a),(1b),(1c),(1d), (2),(3); Column II
Soft copper or brass	3.50	6,500		
Iron or soft steel	3.75	7,600		
Monel or 4-6% chrome	3.75	9,000		
Stainless steels	4.25	10,100		
Solid flat metal:				
Soft aluminum	4.00	8,800		(1a),(1b),(1c),(1d), (2),(3),(4),(5); Column I
Soft copper or brass	4.75	13,000		
Iron or soft steel	5.50	18,000		
Monel or 4-6% chrome	6.00	21,800		
Stainless steels	6.50	26,000		
Ring joint:				
Iron or soft steel	5.50	18,000		(6), Column I
Monel or 4-6% chrome	6.00	21,800		
Stainless steels	6.50	26,000		

NOTES:

- (1) This Table gives a list of many commonly used gasket materials and contact facings with suggested design values of m and y that have generally proved satisfactory in actual service when using effective gasket seating width b given in Table E-1210-2. The design values and other details given in this Table are suggested only and are not mandatory.
- (2) The surface of a gasket having a lap should not be against the nubbin.

TABLE E-1210-1 (CONT'D) GASKET MATERIALS AND CONTACT FACINGS¹

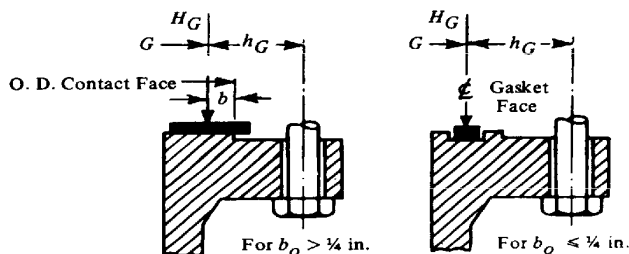
**TABLE E-1210-2
EFFECTIVE GASKET WIDTH**

Facing Sketch (Exaggerated)		Basic Gasket Seating Width, b_o	
		Column I	Column II
(1a)		$\frac{N}{2}$	$\frac{N}{2}$
(1b)			
See Note (1)			
(1c)		$\frac{w' + T}{2}; \left(\frac{w + N}{4} \text{ max.} \right)$	$\frac{w' + T}{2}; \left(\frac{w + N}{4} \text{ max.} \right)$
(1d)			
See Note (1)			
(2)		$\frac{w' + N}{4}$	$\frac{w' + 3N}{8}$
(3)		$\frac{N}{4} \text{ min.}$	$\frac{3N}{8} \text{ min.}$
(4)		$\frac{3N}{8}$	$\frac{7N}{16}$
See Note (1)			
(5)		$\frac{N}{4}$	$\frac{3N}{8}$
See Note (1)			
(6)		$\frac{w'}{8}$	

Effective Gasket Seating Width, b

$$b = b_o, \text{ when } b_o \leq \frac{1}{4} \text{ in.}; \quad b = 0.5 \sqrt{b_o}, \text{ when } b_o > \frac{1}{4} \text{ in.}$$

Location of Gasket Load Reaction



NOTES:

- (1) Where serrations do not exceed $\frac{1}{64}$ in. depth and $\frac{1}{32}$ in. width spacing, sketches (1b) and (1d) shall be used.
- (2) The gasket factors listed only apply to flanged joints in which the gasket is contained entirely within the inner edges of the bolt holes.

TABLE E-1210-2 EFFECTIVE GASKET WIDTH

July 1, 1998
American Society Of Mechanical Engineers

SEC III D1 NMA APP F

APPENDIX F RULES FOR EVALUATION OF SERVICE LOADINGS WITH LEVEL D SERVICE LIMITS

Page 295

ARTICLE F-1000 RULES FOR EVALUATION OF SERVICE LOADINGS WITH LEVEL D SERVICE LIMITS

F-1100 INTRODUCTION

F-1110 SCOPE

This Appendix provides rules and service limits which may be used by Owners and N-Type Certificate Holders for evaluating components and supports subjected to loads for which Level D Service Limits are specified by the Design Specification (NCA-3250).

F-1200 INTENT OF LEVEL D SERVICE LIMITS

(a) The Level D Service Limits and design rules contained in F-1300 are provided for limiting the consequences of the specified event. They are intended (NCA-2142) to assure that violation of the pressure retaining boundary will not occur, but are not intended to assure operability of components either during or following the specified event.

(b) The limits and rules specified for core support structures are intended to assure maintenance of structural integrity but not to prevent leakage.

(c) The limits and rules of this Appendix need not be applied to that portion of a component or support in which a failure has been postulated.

F-1300 LEVEL D SERVICE LIMITS AND DESIGN RULES

F-1310 GENERAL

(a) These limits and design rules are provided to limit the consequences of loads for which Level D Service Limits are specified in the Design Specification.

(b) The contents of F-1320 provide general procedures which are applicable to all components and supports. Specific procedures, which may be used as alternatives to the procedures of F-1320, are provided as follows:

F-1400 Vessels

F-1410 Pumps

F-1420 Valves

F-1430 Piping

F-1440 Core Support Structures

(c) Only limits on primary stresses are prescribed. Unless specifically required by this Appendix, self-relieving stresses resulting from loads for which Level D Service Limits are specified need not be considered.

(d) When compressive stresses are present the stability of the component or component support shall be considered.

(e) Potential for unstable crack growth shall also be considered.

F-1320 DESIGN BY ANALYSIS

F-1321 Terms Related to Analysis

Terms used in this paragraph relating to analysis are defined in the following subparagraphs. Additional definitions are given in NB-3213.

F-1321.1 System Analysis.

System analysis is performed to determine loads on components and supports. A system is an assemblage of components, supports, and other interconnected structures. The system analysis is generally dynamic due to the nature of the loads.

F-1321.2 Component and Support Analysis.

Component analysis is the calculation of stresses and displacements in a component or support to determine compliance with the service limits listed herein. Loads applied in the component analysis and support analysis shall include those determined in a system analysis plus additional loads as applicable.

Page 298

F-1321.3 Elastic Analysis.

Elastic analysis is based on the assumption of a linear relationship between stress and strain. Consideration of gaps between parts of the structure may cause the relationship between loads and deformations to be nonlinear.

F-1321.4 Inelastic Analysis.

Inelastic analysis is a class of methods which computes structural behavior considering nonlinearities in the relationship between stresses and strains. Inelastic analysis as applied in this Appendix shall not be considered to include the time dependent effects of creep.

(a) *Limit Analysis.* Limit analysis is that method which computes the maximum load or combination of loads a structure made of ideally plastic (nonstrain-hardening) material can carry. Limit analysis for components is described in NB-3213.21 and NB-3213.22 and for linear supports in NF-3340.

(b) *Plastic Analysis.* Plastic analysis is defined in NB-3213.24.

F-1321.5 Interaction Method.

Interaction method (formerly Stress Ratio Method) is a method used to evaluate the adequacy of structures under combined loads. Procedures for the method are described in A-9000.

F-1321.6 Collapse.

Collapse of a structure occurs upon formation of an unstable mechanism of plastic hinges under a given combination of loads. The collapse load is defined as follows:

(a) *limit analysis collapse load* is defined in NB-3213.28;

(b) *test collapse load* is defined as that load determined by test according to the criteria given in II-1430;

(c) *plastic analysis collapse load* is defined as that load determined by plastic analysis according to the criteria given in II-1430.

F-1321.7 Plastic Instability Load.

Plastic instability load is defined in NB-3213.26.

F-1321.8 Experimental Stress Analysis.

Experimental stress analysis is a method for evaluation of structural behavior, based on direct measurement of response of test specimens, where the configuration of the model and the applied loads are representative of the component or support under consideration. Response parameters measured are selected to provide data appropriate to

the acceptance criteria applied. Experimental methods are provided for in Appendix II.

F-1321.9 Primary Stress Intensities.

The definitions of general primary membrane stress intensity, designated as P_m ; local primary membrane stress intensity, designated as P_L ; and primary bending stress intensity, designated as P_b , are provided in NB-3221.

F-1322 Methods and Requirements for Analysis

The following requirements shall be satisfied in the evaluation of components or supports under the loads or load combinations for which Level D Service Limits are specified.

F-1322.1 Analysis Combinations

(a) System analysis may be performed by elastic analysis methods as defined in F-1321.3 or by plastic analysis methods as defined in F-1321.4(b). If elastic system analysis is used, the components and supports shall be designed to meet the acceptance criteria in F-1330. If plastic system analysis is used, the components and supports may be designed based on the acceptance criteria in F-1340.

(b) If elastic system analysis is used, the components and supports may be designed based alternatively on the acceptance criteria of F-1340 provided a reevaluation of the system analysis is performed to determine that it has not been significantly invalidated due to load and stress redistribution and changes in geometry. Some of the conditions under which this analysis combination may be acceptable are:

- (1) the plastic deformation is highly localized; or
- (2) the changes in geometry are not significant.

This combination may also be considered valid if bounding solutions are established which conservatively account for redistribution of loads and stresses due to plasticity.

(c) If all loads on a component or support are determined independently from system behavior (e.g., specified pressures), then the component or support may be designed based on acceptance criteria in either F-1330 or F-1340.

(d) The Design Specification for the components and supports shall indicate what type of system analysis (if any) has been used to derive the specified loads.

F-1322.2 Dynamic Effects.

Postulated events for which Level D Service Limits are specified are generally dynamic in nature. The determination of loads for components and supports shall account for dynamic amplification of structural response, both in the component and in the system.

F-1322.3 Material Behavior

(a) The mechanical and physical properties shall be taken from Section II, Part D, Subpart 2 at the actual temperature of the material. The allowable stresses shall

Page 299

be based on material properties given in Section II, Part D, Subpart 2 at temperature. If S_u values at temperature are not tabulated in Section II, Part D, Subpart 2, Table U,¹ the value used shall be included and justified in the Design Report.

(b) The stress and strain allowables given in this Appendix are based on an engineering stress-strain curve. If another type of stress-strain curve (e.g., true stress-strain or Kirchoff stress-strain) is used, the results from the analysis or the allowables given in this Appendix shall be appropriately transformed.

(c) When performing plastic analysis, the stress-strain curve used shall be included and justified in the Design Report. It is permissible to adjust the stress-strain curve to include strain rate effects resulting from dynamic behavior. However, the allowables shall be selected in accordance with (a) above.

(d) The yield criteria and associated flow rule used in the inelastic analysis may be either those associated with the maximum shear stress theory (Tresca) or the strain energy distortion theory (Von Mises).

F-1322.4 Geometric Nonlinearities.

Geometric nonlinearities may be produced by relatively large deformations and/or rotations and by gaps between parts of the structure. Analyses performed for derivation of loads and for evaluation of acceptability of components and supports shall consider geometric nonlinearities if appropriate.

F-1322.5 Strain and/or Deformation Limits.

In addition to the limits given in this Appendix, the strain or deformation limits (if any) provided in the Design Specification shall be satisfied.

F-1330 ACCEPTANCE CRITERIA USING ELASTIC SYSTEM ANALYSIS

The acceptance criteria in this Section shall be applied when elastic system analysis is used to determine loads on components and supports. These criteria are subject to the restrictions on methods of evaluation stated in F-1322.

1 In addition to Section II, Part D, Subpart 2, Table U, S_u values are also available in Code Cases covering new or additional materials for components and their supports.

F-1331 Criteria for Components

F-1331.1 Elastic Analysis

(a) The general primary membrane stress intensity P_m shall not exceed the lesser of $2.4S_m$ and $0.7S_u$ for materials included in Section II, Part D, Subpart 1, Tables 2A and 2B for austenitic and high alloy steels, or $0.7S_u$ for ferritic materials included in Table 2A.

(b) The local primary membrane stress intensity P_L shall not exceed 150% of the limit for general primary membrane stress intensity P_m .

(c) The primary membrane (general or local) plus primary bending stress intensity $P_L + P_b$ shall be limited in accordance with one of the following provisions:

(1) stress intensity $P_L + P_b$ shall not exceed 150% of the limit for general primary membrane stress intensity P_m ;

(2) static or equivalent static loads shall not exceed 90% of the limit analysis collapse load using a yield stress which is the lesser of $2.3S_m$ and $0.7S_u$ or 100% of the plastic analysis collapse load or test collapse load (F-1321.6).

(d) The average primary shear stress across a section loaded in pure shear shall not exceed $0.42S_u$.

F-1331.2 Interaction Method.

As an alternative to the requirements of F-1331.1 above, acceptability of individual members of components may be demonstrated using the interaction method. Procedures for interaction method analysis are given in A-9000. The allowable stress S_{al} shall not exceed the lesser of $2.4S_m$ and $0.7S_u$.

F-1331.3 Bearing Stresses.

Except for pinned and bolted joints, bearing stresses need not be evaluated for loads for which Level D Service Limits are specified.

F-1331.4 Stress Limits for Bolts.

Bolts shall be evaluated in accordance with the rules of F-1335.

F-1331.5 Requirements for Compressive Loads.

Components subjected to compressive loads shall be evaluated against buckling limits. Maximum compressive load (or stress) shall be limited to a value established by (a), (b), or (c) below.

(a) Two-thirds of the value of buckling load (or stress) determined by one of the methods given below:

(1) comprehensive analysis which considers effects such as geometric imperfections, deformations due to existing loading conditions, nonlinearities, large deformations, residual stresses, and inertial forces; or

(2) tests of physical models under conditions of restraint and loading the same as those to which the configuration is expected to be subjected;

(b) a value equal to 150% of the limit established by the rules of NB-3133, except that the pressure is permitted to be 250% of the given value when the ovality is limited to 1% or less; or

(c) a value determined in accordance with the procedures contained in a Code Case for metal containment

Page 300

shell buckling design methods using a factor of safety of 1.34.

F-1332 Criteria for Plate and Shell Type Supports

The criteria presented in this paragraph pertain to primary stresses only. Stresses resulting from constraint of free end displacement and anchor point motion (NF-3121.12 and NF-3121.13) shall be considered primary stresses in the evaluation. Neither peak stresses nor stresses resulting from thermal expansion within the support need be evaluated.

F-1332.1 Primary Membrane Stress Intensity.

The general primary membrane stress intensity P_m is limited to the greater of $1.2S_y$ and $1.5S_m$ but may not exceed $0.7S_u$.

F-1332.2 Primary Membrane Plus Bending Stress Intensity.

The general primary membrane plus primary bending stress intensity, $P_m + P_b$, shall be limited in accordance with one of the following provisions:

(a) 150% of the limit for general primary stress intensity P_m ; or

(b) static or equivalent static loads shall not exceed 90% of the limit analysis collapse load (F-1321.6) using a yield strength which is the lesser of $1.2S_y$ and $0.7S_u$, or 100% of the plastic analysis collapse load or test collapse load (F-1321.6).

F-1332.3 Bearing Stress.

Except for pinned and bolted joints, bearing stresses need not be evaluated for loads for which Level D Service Limits are specified.

F-1332.4 Pure Shear.

The average primary shear across a section loaded in pure shear shall not exceed $0.42S_u$.

F-1332.5 Requirements for Compressive Stresses.

Plate and shell type supports subject to compressive stresses shall be evaluated in accordance with the rules of F-1331.5(a).

F-1332.6 Stress Limits for Bolts.

Bolts shall be evaluated in accordance with the rules of F-1335.

F-1332.7 Load Rating.

As an alternative to the requirements of F-1332.1 through F-1332.6 above, plate and shell type supports may be qualified to Service Level D Limits using the procedure for load rating (NF-3282). The load rating for Level D Service Loadings shall be determined by the following equation:

$$\text{load rating} = \text{TL} \times 0.7 \frac{S_u}{S_u^*}$$

where

TL

= support test load equal to or less than the load under which the support fails to perform its specified support function, lb

S_u

= tensile strength of the support material at temperature, ksi

S_u^*

= tensile strength of the support material at test temperature, ksi

but

$$\frac{S_u}{S_u^*} \leq 1$$

F-1333 Criteria for Standard Supports

Criteria in F-1332 or F-1334 shall be applied according to whether standard supports are plate and shell or linear type

supports.

F-1334 Criteria for Linear Type Supports

The criteria presented in this paragraph pertain to primary stresses only. Stresses resulting from constraint of free end displacement and anchor point motion (NF-3121.12 or NF-3121.13) shall be considered primary stresses in the evaluation.

Neither peak stresses nor stresses resulting from thermal expansion within the support need be evaluated.

Unless otherwise specified, the allowable stresses presented (NF-3320) for Level A Service Condition may be increased using the following factors: the smaller of 2 or $1.167S_u/S_y$, if $S_u > 1.2S_y$, or 1.4 if $S_u \leq 1.2S_y$, where S_y is the yield strength, ksi, and S_u is the ultimate tensile strength, ksi, both at temperature. In addition, members must be checked for local and general instability.

F-1334.1 Stresses in Tension.

The tensile stress on the net section, except at pin holes and in the through-plate thickness direction, shall not exceed the lesser of $1.2S_y$ and $0.7S_u$.

F-1334.2 Stresses in Shear.

The shear stress on the gross section shall not exceed the lesser of $0.72S_y$ and $0.42S_u$. Gross section shall be determined in accordance with NB-3322.1(b).

F-1334.3 Axial Compression.

Maximum load in axially loaded compression members shall be limited in accordance with either (a) or (b) below.

Page 301

(a) Two-thirds of the buckling load, as determined by one of the following methods:

(1) comprehensive stability analysis which considers effects such as large deformations, deformations due to existing loading conditions, material nonlinearities, local buckling, out-of-straightness and other tolerances, load eccentricity, end conditions, residual stresses and inertia loads (for dynamic loading); or

(2) testing of a full-scale prototype under conditions of support and loading the same as those to which the actual compression member is expected to be subjected;

(b) the maximum allowable load for ferritic steels shall be determined in accordance with the following provided that the initial out-of-straightness does not exceed 1/1000 of the unsupported length. Effects of deformations due to existing loads shall also be considered.

(1) Except as noted in (2) below, the following rules shall be applied:

For $0 \leq \lambda \leq 1$

$$\frac{P}{P_y} = \frac{1 - \lambda^2 / 4}{1.11 + 0.50\lambda + 0.17\lambda^2 - 0.28\lambda^3}$$

For $1 \leq \lambda \leq \sqrt{2}$

$$\frac{P}{P_y} = \frac{2}{3} (1 - \lambda^2 / 4)$$

For $\lambda > \sqrt{2}$

$$\frac{P}{P_y} = \frac{2}{3\lambda^2}$$

where

P

= maximum allowable load, lb

P_y

= $S_y A_g$, lb

A_g

= area of gross section, in.²

$$\lambda = \left(\frac{KL}{r} \right) \frac{1}{\pi} \sqrt{\frac{S_y}{E}}$$

E

= modulus of elasticity, psi

K

= effective length factor

L

= unbraced length, in.

r

= radius of gyration, in.

(2) For nonstress-relieved heavy structural shapes (web or flange thickness greater than 1 in.) or for nonstress-relieved built-up members using universal mill plate, the following rules shall be applied:

For $0 < \lambda < 1$

$$\frac{P}{P_y} = \frac{1 - \lambda^2 / 4}{1.11 + 0.75\lambda + 0.83\lambda^2 - 0.81\lambda^3}$$

For $1 < \lambda < \sqrt{2}$

$$\frac{P}{P_y} = \frac{1 - \lambda^2 / 4}{1.88}$$

For $\lambda > \sqrt{2}$

$$\frac{P}{P_y} = \frac{1}{1.88\lambda^2}$$

F-1334.4 Combined Axial Tension and Bending

(a) For members subject to both axial tension and bending stresses, the following equation shall be satisfied:

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1$$

where

$$F_a = \text{smaller of } 1.2S_y \text{ or } 0.7S_u \text{ ksi}$$

(b) For members qualifying as compact sections under criteria of NF-3322.1(d)(1), the maximum bending stress shall be given by:

$$F_b = fS_y$$

where

$$f = \text{plastic shape factor for the cross section}$$

(c) If members do not meet the compact section requirements, they shall be designed using one of two methods below to determine F_b for use in the equation above.

(1) Allowable values for F_b given in NF-3322.1(d)(2) may be increased by a factor of 1.11 (to maintain a nominal factor of safety of 1.5 against instability).

(2) Rigorous analysis of member stability may be used to determine critical bending stress. A factor of safety of 1.5 shall be used in determining allowable design bending stress.

F-1334.5 Combined Axial Compression and Bending.

Members subject to combined axial compression and bending shall satisfy Eqs. (20), (21), and (22) of NF-3322.1 (e)(1) with allowable stresses defined as follows.

(a) $F_a = P/A_g$ where P shall be determined in accordance with F-1334.3.

(b) The value of F'_e shall be taken as:

$$F'_e = \frac{\pi^2 E}{1.30(Kl_b / r_b)^2}$$

with terms as defined in NF-3313.1.

(c) F_b shall be determined using F-1334.4(b) or (c) as appropriate.

F-1334.6 Collapse Load Analysis.

As an alternative to the requirements in F-1334.4 above, acceptability of linear type supports may be established using one of the methods given below:

- (a) using lower bound limit analysis given in NF-3340, static or equivalent static loads shall not exceed 90% of the limit analysis collapse load using a yield stress which is the greater of $1.2S_y$ and $1.5S_m$, but not larger than $0.7S_u$;
- (b) 100% of the plastic analysis collapse load; or
- (c) 100% of the test collapse load (F-1321.6).

F-1334.7 Interaction Method.

As an alternative to the requirements of F-1334.1 through F-1334.5 above, acceptability for individual structural members of linear type supports may be demonstrated using the interaction method. Procedures for interaction method analysis are given in A-9000. The allowable stress S_{at} shall not exceed the greater of $1.2S_y$ and $1.5S_m$, but not larger than $0.7S_u$.

F-1334.8 Load Rating.

As an alternative to the requirements of F-1334.1 through F-1334.5 above, linear type supports may be qualified to Service Level D Limits using load rating criteria given in F-1332.7.

F-1334.9 Stress Limits for Bolts.

Bolts shall be evaluated in accordance with the rules of F-1335.

F-1334.10 Bearing Stresses.

Except for pinned and bolted joints, bearing stresses need not be evaluated for loads for which Level D Service Limits are specified.

F-1335 Requirements for Bolted Joints

(a) The requirements provided in this Section shall be applied to components and supports. Threaded structural fasteners used in core support structures shall be evaluated using the rules of F-1440.

(b) Allowable stresses for bolts are given in the paragraphs below. These allowable stresses are only applicable if the bolt stresses are calculated using elastic methods.

F-1335.1 Allowable Tensile Stress.

The average tensile stress computed on the basis of the available tensile stress area shall not exceed the smaller of 0.7 S_u and S_y . When high strength bolts or threaded parts having an ultimate tensile strength greater than 100 ksi at operating temperature are used in component applications, the maximum value of the stress at the periphery of the bolt cross section resulting from direct tension plus bending and excluding stress concentrations shall not exceed S_u . The bolt load shall be the sum of the external load and any bolt tension resulting from prying action produced by deformation of the connected parts.

F-1335.2 Allowable Shear Stress

(a) For bearing type joints, the average bolt shear stress expressed in terms of available shear stress area shall not exceed the smaller of $0.42S_u$ and $0.6S_y$.

(b) Friction type joints shall be evaluated using the rules of NF-3324.6(a)(3)(b).

F-1335.3 Combined Tensile and Shear Stress

(a) Bolts subjected to combined shear and tension in bearing type joints shall be so proportioned that the shear and the tensile stresses satisfy the following equation:

$$\frac{f_t^2}{F_{tb}^2} + \frac{f_v^2}{F_{vb}^2} \leq 1$$

where

f_t

= computed tensile stress, ksi

f_v

= computed shear stress, ksi

F_{tb}

= allowable tensile stress at temperature per F-1335.1, ksi

F_{vb} = allowable shear stress at temperature per F-1335.2(a), ksi

(b) In friction type joints, the joint clamping force will be reduced by any direct tension load on the joint. Therefore, the bolt clamping force used to calculate the allowable shear load in NF-3324.6(a)(3)(b) shall be reduced by an equivalent amount.

F-1335.4 Minimum Edge Distance in Line of Load.

In both bearing and friction type joints, the minimum distance from the center of the end bolt to that edge of the connected part toward which the load is directed shall satisfy (a) and (b) below:

$$(a) L/d \geq [0.5 + 1.2 (f_p/S_u)]$$

$$(b) f_p/S_u \leq 2.1$$

where

L = distance from center of bolt hole to edge of connected part, in.

d = nominal diameter of bolt, in.

f_p = nominal bearing stress, ksi
= P/dt

P = bearing load transmitted by the fastener, lb

t = thickness of the connected part, in.

Page 303

S_u = tensile strength of the connected parts at temperature, ksi

F-1336 Requirements for Pinned Joints

Except for bearing, pinned joints shall be evaluated in accordance with the acceptance criteria of F-1331. The allowable bearing stress shall be $2.1S_u$.

F-1340 ACCEPTANCE CRITERIA USING PLASTIC SYSTEM ANALYSIS

The acceptance criteria in this section may be applied provided the system analysis considers effects of material nonlinear behavior. The criteria are subject to the restrictions on methods of evaluation stated in F-1322.

F-1341 Criteria for Components

Acceptability of components may be demonstrated using any one of the following methods:

- (a) elastic analysis
- (b) plastic analysis
- (c) collapse load analysis
- (d) plastic instability analysis
- (e) interaction method

The primary stress limits for these alternative methods are given in F-1341.1 through F-1341.5. The other limits given in F-1341.6 and F-1341.7 shall also be satisfied as applicable.

F-1341.1 Elastic Analysis.

Where the component is evaluated on an elastic basis, the following primary stress limits shall be applied.

(a) The general primary membrane stress intensity P_m shall not exceed the lesser of $2.4S_m$ and $0.7S_u$ for materials included in Section II, Part D, Subpart 1, Tables 2A and 2B, or $0.7S_u$ for materials included in Section II, Part D, Subpart 1, Table 2A.

(b) The local primary membrane stress intensity P_L shall not exceed 150% of the limit for general primary membrane stress intensity P_m .

(c) The primary membrane (general or local) plus primary bending stress intensity, $P_L + P_B$ shall not exceed 150% of the limit for general primary membrane stress intensity P_m .

(d) The average primary shear across a section loaded in pure shear shall not exceed $0.42S_u$.

[98]

F-1341.2 Plastic Analysis.

Where the component is evaluated on a plastic basis the following primary stress limits shall be applied.

(a) The general primary membrane stress intensity P_m shall not exceed $0.7S_u$ for ferritic steel materials included in Section II, Part D, Subpart 1, Table 2A and the greater of $0.7S_u$ and $S_y + \frac{1}{3}(S_u - S_y)$ for austenitic steel, high-nickel alloy, and copper-nickel alloy materials included in Section II, Part D, Subpart 1, Table 2A.

(b) The maximum primary stress intensity at any location shall not exceed $0.90S_u$.

(c) The average primary shear across a section loaded in pure shear shall not exceed $0.42S_u$.

[98]

F-1341.3 Collapse Load.

Static or equivalent static loads shall not exceed 90% of the limit analysis collapse load using a yield stress which is the lesser of $2.3S_m$ and $0.7S_u$ or 100% of the plastic analysis collapse load or test collapse load (F-1321.6).

F-1341.4 Plastic Instability Load.

The plastic instability load (F-1321.7) is designated P_I and may be determined by one of the following methods:

(a) plastic analysis (NB-3213.24);

(b) experimental analysis (F-1321.8).

The applied load shall not exceed $0.7P_I$.

F-1341.5 Interaction Method.

Acceptability for individual members of components may be demonstrated using the interaction method. Procedures for interaction method analysis are given in A-9000. The allowable stress S_{al} shall not exceed $0.7S_u$.

F-1341.6 Bearing Stresses.

Except for pinned and bolted joints, bearing stresses need not be evaluated for loads for which Level D Service Limits are specified.

F-1341.7 Stress Limits for Bolts.

Bolts shall be evaluated in accordance with the rules of F-1335.

F-1341.8 Requirements for Compressive Loads.

Components subjected to compressive loads shall be evaluated in accordance with the rules of F-1331.5.

F-1342 Criteria for Plate and Shell Type Supports

(a) The criteria presented in this paragraph pertain to primary stresses only. Stresses resulting from constraint of free end and anchor point motion (NF-3121.12 and NF-3121.13) shall be considered as primary stresses in the evaluation. Neither peak stresses nor stresses resulting from thermal expansion within the support need be evaluated.

(b) The allowable stresses for plate and shell type supports shall be per F-1341, with material properties

Page 304

provided by the applicable table of Appendix I per Table NF-2121(a)-1.

(c) As an alternative to the requirements of (b) above, plate and shell type supports may be qualified to Service Level D Limits using the procedure for load rating (NF-3282). The load rating for Level D Service Loadings shall be determined by the following equation:

$$\text{load rating} = \text{TL} \times 0.7 \frac{S_u}{S_u^*}$$

where

TL

= support test load equal to or less than the load under which the support fails to perform its specified support function, lb

S_u

= tensile strength of the support material at temperature, ksi

S_u^*

= tensile strength of the support material at test temperature, ksi

but

$$\frac{S_u}{S_u^*} \leq 1$$

F-1343 Criteria for Standard Supports

The rules of F-1342 or F-1344 shall be applied according to whether standard supports are plate and shell or linear type supports.

F-1344 Criteria for Linear Type Supports

The criteria presented in this paragraph pertain to primary stresses only. Stresses resulting from constraint of free end displacement and anchor point motion (NF-3121.12 and NF-3121.13) shall be considered primary stresses in the evaluation. Neither peak stresses nor stresses resulting from thermal expansion within the support need be evaluated.

Acceptability of linear type supports may be demonstrated using any one of the following methods:

- (a) elastic analysis
- (b) plastic analysis
- (c) collapse load analysis
- (d) plastic instability analysis
- (e) interaction method

The primary stress limits for these alternative methods are given in F-1344.1 through F-1344.5. The other limits given in F-1344.6 and F-1344.7 shall also be satisfied as applicable.

F-1344.1 Elastic Analysis.

The criteria provided in F-1334 through F-1334.5 shall be applied.

F-1344.2 Plastic Analysis.

The criteria provided in F-1341.2 shall be applied. In addition, members shall be checked for local and general instability following the requirements given in F-1334.3.

F-1344.3 Collapse Load Analysis.

The criteria provided in F-1334.6 shall be applied.

F-1344.4 Plastic Instability Analysis.

The plastic instability load (F-1321.7) is designated P_I and may be determined by one of the following methods:

(a) plastic analysis [F-1321.4(b)];

(b) experimental analysis (F-1321.8).

The applied load shall not exceed $0.7P_I$.

F-1344.5 Interaction Method.

Acceptability for individual structural members of linear type supports may be demonstrated using interaction method analysis. Procedures for interaction method analysis are given in A-9000. The allowable stress S_{al} shall not exceed $0.7S_{ut}$.

F-1344.6 Stress Limits for Bolts.

Bolts shall be evaluated in accordance with the rules of F-1335.

F-1344.7 Bearing Stresses.

Except for pinned and bolted joints, bearing stresses need not be evaluated for loads for which Level D Service Limits are specified.

F-1400 VESSELS

The design rules given in F-1330 and F-1340 shall be used for evaluation of vessels for loads for which Service Level D Limits are specified.

F-1410 PUMPS

The design rules given in F-1330 and F-1340 shall be used for evaluation of pumps for loads for which Service Level D Limits are specified.

F-1420 VALVES

As an alternative to the procedures of F-1300, the criteria of both (a) and (b) below may used.

(a) The maximum internal pressure shall not exceed the lesser of 2.0 times the Design Pressure and the rated pressure at the temperature for which Service Level D Limits are specified.

(b) Calculate the valve crotch (Fig. NB-3545.2-1, Section A-A) stress intensity S_n due to all applicable loads:

Page 305

$$S_n = 0.5Q_p + P_{es}$$

or

$$S_n = 0.5Q_p + nP_{eb}$$

where

Q_p

= as defined in NB-3545.2

P_{es}

= primary stress in crotch region of valve body caused by piping loads for which Level D Service Limits are specified; includes combined axial, bending, and torsion, ksi

n

= 1.3 for ferritic pipe materials in Section II, Part D, Subpart

1, Table 2A

= 1.5 for Austenitic and high alloy pipe materials in Section II, Part D, Subpart 1, Tables 2A and 2B

P_{eb}

= as defined in NB-3545.2(b)

The allowable value of this stress intensity is the lesser of $3.6S_m$ and $1.05S_u$ for materials in Section II, Part D, Subpart 1, Tables 2A and 2B, or $1.05S_u$ for materials in Section II, Part D, Subpart 1, Table 2A.

F-1430 PIPING

For piping, as an alternative to the procedures of F-1331, the criteria of (a) and (b) below may be used.

(a) The internal pressure shall not exceed 200% of the Design Pressure calculated in accordance with Eq. (2) of NB-3641.1.

(b) When applying the procedures of NB-3652, Eq. (9) of NB-3652 shall be satisfied using a stress limit of $3.0S_m$ or $2S_y$, whichever is less.

F-1440 CORE SUPPORT STRUCTURES

The procedures of F-1300 may be used except as stipulated in (a) through (d) below.

(a) The specified dynamic or equivalent static loads shall not exceed 80% of the ultimate collapse load as obtained from test P_r where P_r is defined as the load at which the horizontal tangent to the load deformation curve occurs, or 80% of a load combination used in the test of a prototype or model. In using this method, account shall be taken of the size effect and dimensional tolerances as well as differences which may exist in the ultimate strength or other governing material properties of the actual part and the tested parts to assure that the loads obtained from the test are a conservative representation of the load carrying capability of the actual component under postulated loading conditions for which Level D Service Limits apply.

(b) For core support structures, component inelastic analysis may be combined with elastic system analysis (F-1331). For this analysis, the maximum stress limit shall be $0.67S_u$ for primary membrane stress intensity, and shall be equal to the greater of $0.67S_{ut}$ and $S_y + 1/3 (S_{ut} - S_y)$, but not to exceed $0.9S_u$ for maximum primary stress intensity, where S_{ut} is defined as the value of ultimate stress obtained from the true stress-strain curve. In this case, the elastic system analysis shall be checked, accounting for component plastic deformation.

(c) The stress limits for high strength threaded structural fasteners having ultimate strength greater than 100 ksi at operating temperatures for core support structure applications are as given in (1) through (3) below. S_m is as tabulated in Section II, Part D, Subpart 1, Tables 2A and 2B.

(1) For component elastic analysis, combined with either elastic or inelastic system analysis, P_m shall not exceed $2S_m$ and $P_m + P_b$ shall not exceed $3S_m$.

(2) For component plastic analysis, combined with either elastic or inelastic system analysis, P_m shall not exceed $2S_m$ and maximum primary stress intensity shall not exceed the larger of $0.67S_{ut}$ and $S_y + 1/3 (S_{ut} - S_y)$, but not to exceed $0.9S_u$ where S_{ut} is defined as the value of ultimate stress obtained from the true stress-strain curve.

(3) For component limit analysis, combined with either elastic or inelastic system analysis, P_m shall not exceed $1.33L_L$ and $P_m + P_b$ shall not exceed $1.33L_L$, where the shape factor is less than or equal to 1.5, with S_y equal to $1.5S_m$ where L_L is defined in Fig. NG-3224-1, Note (6).

(d) The stress limits for threaded structural fasteners having ultimate strength less than or equal to 100 ksi at operating temperatures shall be determined in accordance with F-1331 or F-1341, as appropriate.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP G

APPENDIX G PROTECTION AGAINST NONDUCTILE FAILURE

Page 307

ARTICLE G-1000 INTRODUCTION

This Appendix presents a procedure for obtaining the allowable loadings for ferritic pressure retaining materials in components. This procedure is based on the principles of linear elastic fracture mechanics. At each location being investigated a maximum postulated flaw is assumed. At the same location the *mode I stress intensity factor*¹ K_I is produced by each of the specified loadings as calculated and the summation of the K_I values is compared to a reference value K_{IR} which is the highest critical value of K_I that can be ensured for the material and temperature involved. Different procedures are recommended for different components and operating conditions.

¹ The stress intensity factor as used in fracture mechanics has no relation to and must not be confused with the stress intensity used in Articles of this Section. Furthermore, stresses referred to in this Appendix are calculated normal tensile stresses not stress intensities in a defect free stress model at the surface nearest the location of the assumed defect.

Page 310

ARTICLE G-2000 VESSELS

G-2100 GENERAL REQUIREMENTS

[98]

G-2110 REFERENCE CRITICAL STRESS INTENSITY FACTOR

(a) Figure G-2210-1 is a curve showing the relationship that can be conservatively expected between the critical, or reference, stress intensity factor K_{IR} , $\text{ksi}\sqrt{\text{in.}}$, and a temperature which is related to the reference nil ductility temperature RT_{NDT} determined in NB-2331. This curve is based on the lower bound of static, dynamic, and crack arrest critical K_I values measured as a function of temperature on specimens of SA-533 Type B Class 1, and SA-508 Grade 1, SA-508 Grade 2 Class 1, and SA-508 Grade 3 Class 1 steels. No available data points for static, dynamic, or arrest tests fall below the curve. An analytical approximation to the curve is:

$$K_{IR} = 26.78 + 1.223\exp[0.0145(T - RT_{NDT} + 160)]$$

Unless higher K_{IR} values can be justified for the particular material and circumstances being considered, Fig. G-2210-1 may be used for ferritic steels which meet the requirements of NB-2331 and which have a specified minimum yield strength at room temperature of 50.0 ksi or less.

(b) For materials which have specified minimum yield strengths at room temperature greater than 50.0 ksi (345 MPa) but not exceeding 90.0 ksi (620 MPa), Fig. G-2210-1 may be used provided fracture mechanics data (similar to the K_{ID} data referenced in WRCB 175) are obtained on at least three heats of the material on a sufficient number of specimens to cover the temperature range of interest, including the weld metal and heat-affected zone, and provided that the data are equal to or above the curve of Fig. G-2210-1. These data shall be included in the Design Specification. Where these materials of higher yield strengths [specified minimum yield strength greater than 50.0 ksi (345 MPa) but not exceeding 90.0 ksi (620 MPa)] are to be used in conditions where radiation may affect the material properties, the effect of radiation on the K_{IR} curve shall be determined for the material prior to its use in manufacture. This information shall be included in the Design Specification.

[98]

[98]

G-2120 MAXIMUM POSTULATED DEFECT

The postulated defect used in this recommended procedure is a sharp, surface defect normal to the direction of maximum stress. For section thicknesses of 4 in. to 12 in. (102 mm to 305 mm), it has a depth of one-fourth of the section thickness and a length of $1\frac{1}{2}$ times the section thickness. For sections greater than 12 in. (305 mm) thick, the postulated defect for the 12 in. (305 mm) section is used. For sections less than 4 in. (102 mm) thick, the 1 in. (25 mm) deep defect is conservatively postulated. These postulated defects were used in developing the curves of Fig. G-2214-1. Smaller defect

sizes² may be used on an individual case basis if a smaller size of maximum postulated defect can be ensured. Due to the safety factors recommended here, the prevention of nonductile fracture is ensured for some of the most important situations even if the defects were to be about twice as large in linear dimensions as this postulated maximum defect. [98]

G-2200 LEVEL A AND LEVEL B SERVICE LIMITS

G-2210 SHELLS AND HEADS REMOTE FROM DISCONTINUITIES

G-2211 Recommendations

The assumptions of this Subarticle are recommended for shell and head regions during Level A and B Service Limits.

2 WRCB 175 (Welding Research Council Bulletin 175) "PVRC Recommendations on Toughness Requirements for Ferritic Materials" provides procedures in Paragraph 5c(2) for considering maximum postulated defects smaller than those described.

Page 311

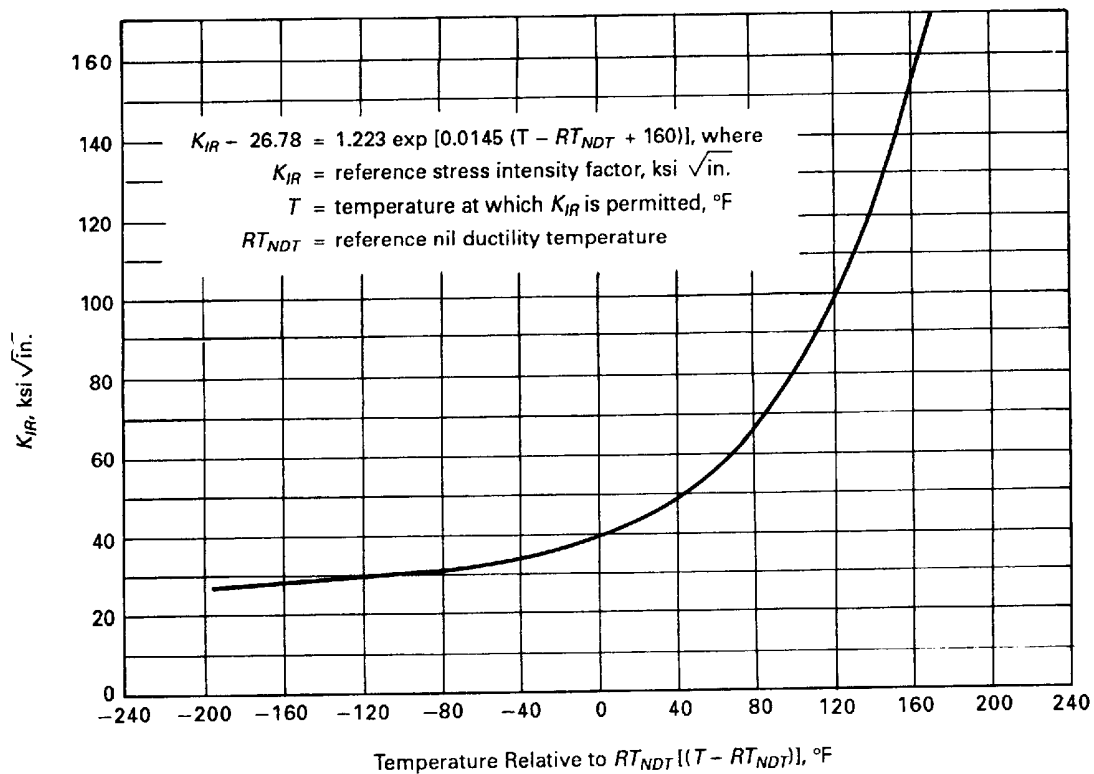


FIG. G-2210-1

FIG. G-2210-1

G-2212 Reference Critical Stress Intensity Factor for Material

The K_{IR} values of Fig. G-2210-1 are recommended.

G-2213 Maximum Postulated Defect

The recommended maximum postulated defect is that described in G-2120.

G-2214 Calculated Stress Intensity Factors

G-2214.1 Membrane Tension.

The K_I corresponding to membrane tension for the postulated defect of G-2120 is $K_{Im} = M_m \times$ membrane stress, where M_m is as shown in Fig. G-2214-1.

G-2214.2 Bending Stress.

The K_I corresponding to bending stress for the postulated defect of G-2120 is $K_{Ib} = M_b \times$ maximum bending stress, where M_b is two-thirds of the M_m shown in Fig. G-2214-1.

[98]

G-2214.3 Radial Thermal Gradient.

The K_I produced by a radial thermal gradient across a wall thickness for the postulated defect of G-2120 is $K_{It} = M_t \times$ temperature difference through the wall, °F, where M_t is as shown in Fig. G-2214-2.

(a) The M_t values in Fig. G-2214-2 are applicable only for the conditions given in (1) and (2).

(1) An assumed shape of the temperature gradient is approximately as shown in Fig. G-2214-3.

(2) The temperature change starts from a steady state condition and has a rate, associated with startup and shutdown, less than about 100°F/hr (56°C/hr). The results would be overly conservative if applied to rapid temperature changes.

(b) If the conditions of (a) above are not met, other means must be used for calculating the K_I produced by thermal stress. For example, the moment produced by the radial thermal gradient may be calculated and the equivalent linear stress [NB-3213.13(a)(3)] considered by the provisions of G-2214.2.

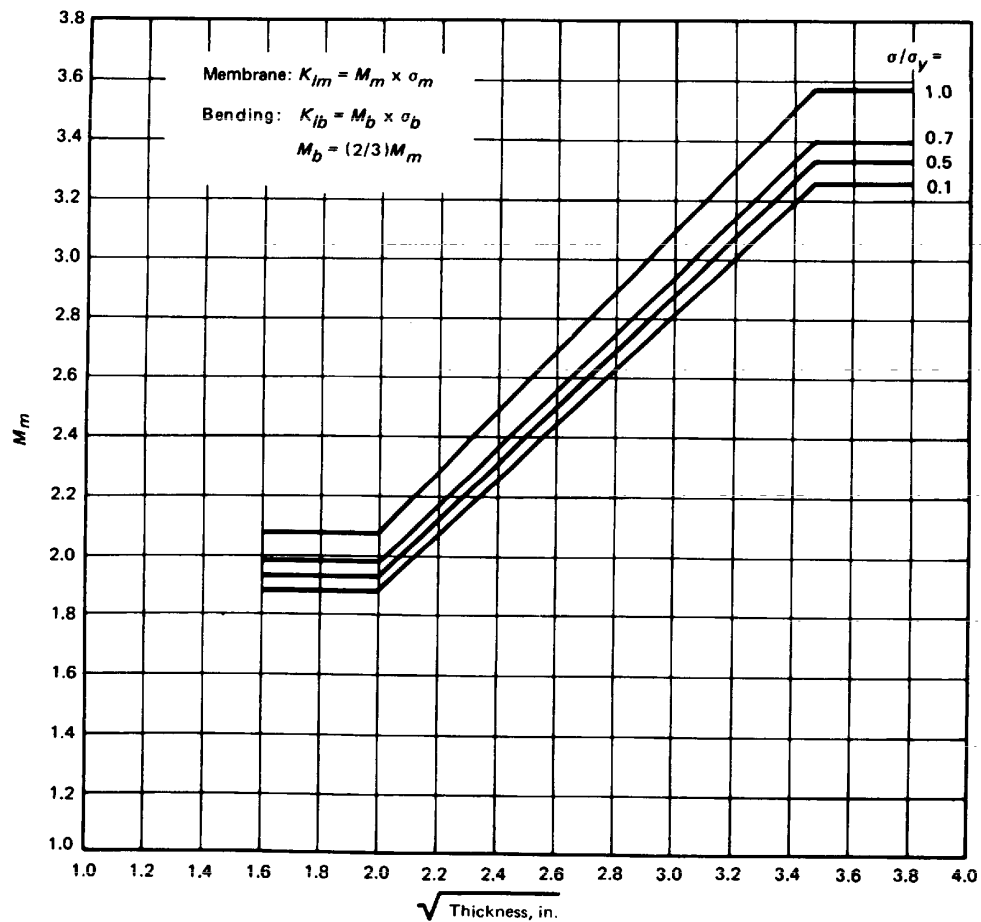
[98]

G-2214.4 Stresses Exceeding Material Yield Strength.

WRCB 175 provides procedures in Paragraph 5C(3) for considering elastically calculated stresses which exceed the yield strength of the material. This

Page 312

method may be used in lieu of using Figs. G-2214-1 through G-2214-3, which are not applicable for combined stresses above the material yield strength.



98

FIG. G-2214-1

[98]

FIG. G-2214-1

[98]

G-2215 Allowable Pressure

The equations given in this Subarticle provide the basis for determination of the allowable pressure at any temperature at the depth of the postulated defect during Service Conditions for which Level A and Level B Service Limits are specified. In addition to the conservatism of these assumptions, it is recommended that a factor of 2 be applied to the calculated K_f values produced by primary stresses. In shell and head regions remote from discontinuities, the only significant loadings are: (1) general primary membrane stress due to pressure; and (2) thermal stress due to thermal gradient through the thickness during startup and shutdown. Therefore, the requirement to be satisfied and from which the allowable pressure for any assumed rate of temperature change can be determined is:

$$(1) 2K_{Im} + K_{It} < K_{IR}$$

throughout the life of the component at each temperature

with K_{Im} from G-2214.1, K_{It} from G-2214.3, and K_{IR} from Fig. G-2210-1.
[98]

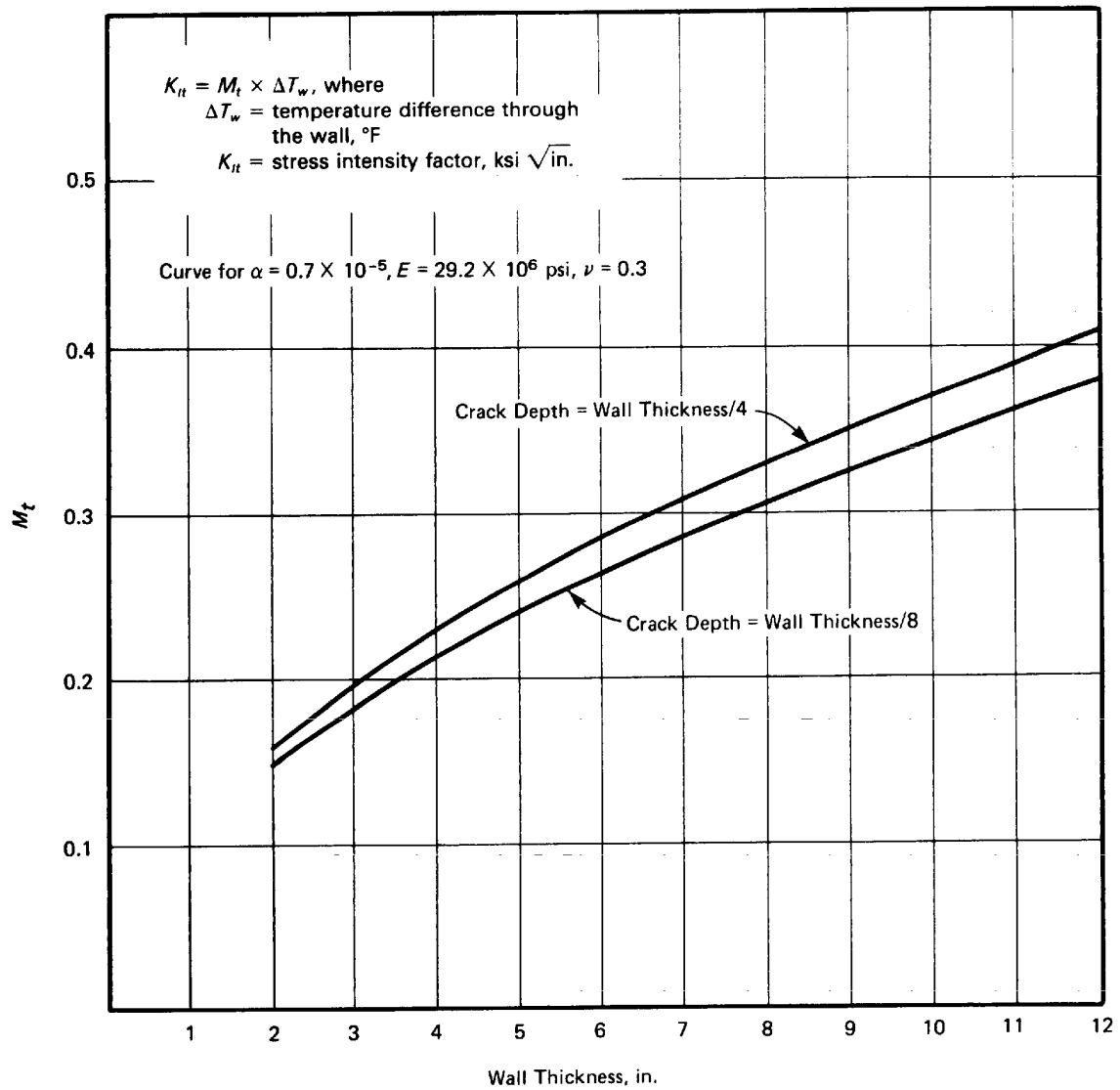


FIG. G-2214-2

FIG. G-2214-2

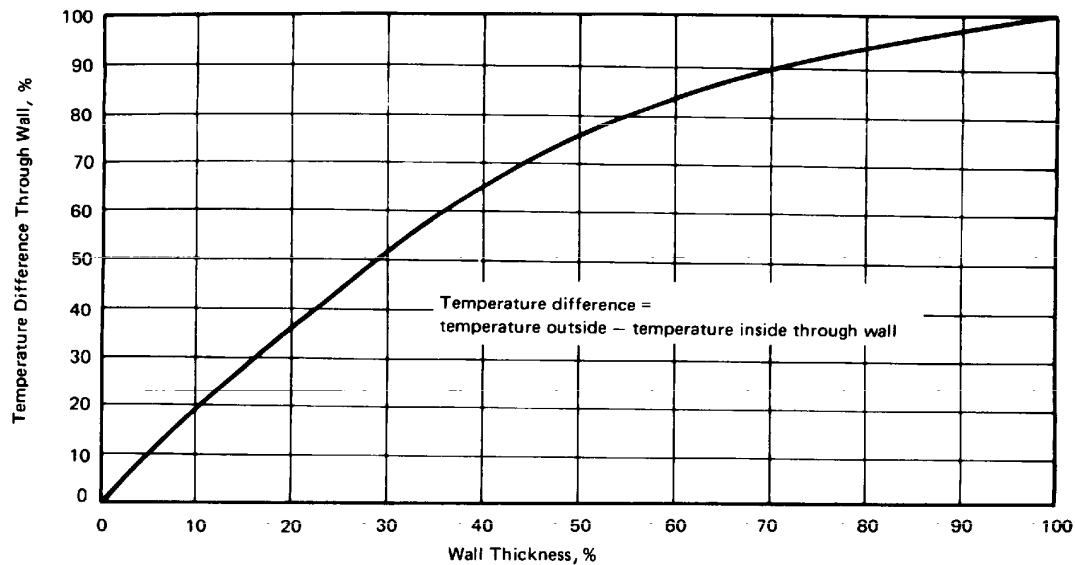


FIG. G-2214-3

FIG. G-2214-3

G-2220 NOZZLES, FLANGES, AND SHELL REGIONS NEAR GEOMETRIC DISCONTINUITIES

G-2221 General Requirements

The same general procedure as was used for the shell and head regions in G-2210 may be used for areas where more complicated stress distributions occur, but certain modifications of the procedures for determining allowable applied loads shall be followed in order to meet special situations, as stipulated in G-2222 and G-2223.

[98]

G-2222 Consideration of Membrane and Bending Stresses

(a) Equation (1) of G-2215 requires modification to include the bending stresses which may be important contributors to the calculated K_I value at a point near a flange or nozzle. The terms whose sum must be $< K_{IR}$ for Level A and Level B Service Limits are:

- (1) $2K_{Im}$ from G-2214.1 for primary membrane stress;
- (2) $2K_{Ib}$ from G-2214.2 for primary bending stress;
- (3) K_{Im} from G-2214.1 for secondary membrane stress;
- (4) K_{Ib} from G-2214.2 for secondary bending stress.

(b) For purposes of this evaluation, stresses which result from bolt preloading shall be considered as primary.

(c) It is recommended that when the flange and adjacent shell region are stressed by the full intended bolt preload and by pressure not exceeding 20% of the preoperational system hydrostatic test pressure, minimum metal temperature in the stressed region should be at least the initial RT_{NDT} temperature for the material in the stressed regions plus any effects of irradiation at the stressed regions.

irradiation at the stressed regions.

(d) Thermal stresses shall be considered as secondary except as provided in NB-3213.13(b). The K_I of Fig. G-2214-2 is not recommended for the evaluation of thermal stress because more complicated stress distributions are not adequately represented by the simplified approach of Fig. G-2214-2.

[98]

G-2223 Toughness Requirements for Nozzles

(a) A quantitative evaluation of the fracture toughness requirements for nozzles is not feasible at this time,

Page 315

but preliminary data indicate that the design defect size for nozzles, considering the combined effects of internal pressure, external loading and thermal stresses, may be a fraction of that postulated for the vessel shell. Nondestructive examination methods shall be sufficiently reliable and sensitive to detect these smaller defects.

(b) WRCB 175 provides an approximate method in Paragraph 5C(2) for analyzing the inside corner of a nozzle and cylindrical shell for elastic stresses due to internal pressure stress.

(c) Fracture toughness analysis to demonstrate protection against nonductile failure is not required for portions of nozzles and appurtenances having a thickness of 2.5 in. or less, provided the lowest service temperature is not lower than RT_{NDT} plus 60°F.

G-2300 LEVEL C AND LEVEL D SERVICE LIMITS

G-2310 RECOMMENDATIONS

The possible combinations of loadings, defect sizes, and material properties which may be encountered during Level C and Level D Service Limits are too diverse to allow the application of definitive rules, and it is recommended that each situation be studied on an individual case basis. The principles given in this Appendix may be applied, where applicable, with any postulated loadings, defect sizes, and material toughness which can be justified for the situation involved.

G-2400 HYDROSTATIC TEST TEMPERATURE

(a) For system and component hydrostatic tests performed prior to loading fuel in the reactor vessel, it is recommended that hydrostatic tests be performed at a temperature not lower than RT_{NDT} plus 60°F. The 60°F margin is intended to provide protection against nonductile failure at the test pressure.

(b) For system and component hydrostatic tests performed subsequent to loading fuel in the reactor vessel, the minimum test temperature should be determined by evaluating K_I . The terms given in (1) through (4) below should be summed in determining K_I :

(1) $1.5K_{Im}$ from G-2214.1 for primary membrane stress;

(2) $1.5K_{Ib}$ from G-2214.2 for primary bending stress;

(3) K_{Im} from G-2214.1 for secondary membrane stress;

(4) K_{Ib} from G-2214.2 for secondary bending stress.

K_I calculated by summing the four values given in (1) through (4) above, shall not exceed the applicable K_{IR} value.

(c) The system hydrostatic test to satisfy (a) or (b) above should be performed at a temperature not lower than the highest required temperature for any component in the system.

Page 316

ARTICLE G-3000 PIPING, PUMPS, AND VALVES

[98]

G-3100 GENERAL REQUIREMENTS

In the case of the materials other than bolting used for piping, pumps, and valves for which impact tests are required (NB-2311), the tests and acceptance standards of this Section are considered to be adequate to prevent nonductile failure under the loadings and with the defect sizes encountered under Level A and Level B Service Limits and testing conditions. Level C and Level D Service Limits should be evaluated on an individual case basis (G-2300).

[98]

Page 317

ARTICLE G-4000 BOLTING

[98]

G-4100 GENERAL REQUIREMENTS

In the case of bolting materials for which impact tests are required, the tests and acceptance standards of this Section are considered to be adequate to prevent nonductile failure under the loadings and with the defect sizes encountered under Level A and Level B Service Limits and testing conditions. Level C and Level D Service Limits should be evaluated on an individual case basis (G-2300). Welding Research Council Bulletin 175 (WRCB 175) "PVRC Recommendations on Toughness Requirements for Ferritic Materials," provides procedures in Paragraph 7 for evaluating various defect sizes and associated toughness levels in bolting materials.

[98]

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP J

APPENDIX J OWNER'S DESIGN SPECIFICATIONS FOR CORE SUPPORT STRUCTURES

Page 319

ARTICLE J-1000 OWNER'S DESIGN SPECIFICATIONS FOR CORE SUPPORT STRUCTURES

J-1100 INTRODUCTION

J-1110 OBJECTIVE

The objective of this Appendix is to provide a guide for Owners (NCA-3210) or their agents in the preparation of Design Specifications for core support structures. Desirably, such Design Specifications should be as uniform throughout the nuclear industry as is reasonably attainable. Such uniformity is helpful in promoting adequacy of coverage and clarity of intent.

J-1120 SCOPE OF DESIGN SPECIFICATIONS

The Design Specifications shall contain sufficient detail to provide a complete basis for the construction of the core support structure.

J-1130 FORMAT AND TERMINOLOGY USED IN DESIGN SPECIFICATIONS

J-1131 Format

The Design Specifications shall be organized in a logical manner and be free from ambiguity. All information and requirements contained in the specifications which are beyond the jurisdiction of Subsection NG should be so identified.

J-1132 Outline of Design Specifications

A suggested core support structures Design Specifications outline is:

- (a) Plant Designation and Owner
- (b) Definition of Terms
- (c) General Information
- (d) Specific Information:
 - (1) Boundaries of jurisdiction
 - (2) Materials
 - (3) Loading criteria (NG-3110)
 - (4) Maximum deformation limits, where applicable
- (e) Requirements Beyond the Jurisdiction of this Section
- (f) Design Specifications Certification

J-1133 Terminology

Nomenclature, definitions, and symbols used shall be in agreement with Subsection NG. Where additional terms, definitions, or expressions are required, they should be clearly defined, explained, and adequately referenced.

J-1140 DISTRIBUTION OF COPIES OF DESIGN SPECIFICATIONS

Copies of the Design Specifications shall be filed in accordance with NCA-3256.

J-1200 INFORMATION TO BE INCLUDED

J-1210 GENERAL INFORMATION

The Design Specifications shall include the information designated in (a) through (h) below:

(a) identification of the core support structures, as determined by their function and operating conditions [Structures whose purpose is only to limit the motion of the core following the postulated occurrence of a failure in the structure normally supporting the core are not considered core support structures. They are normally designed to meet deformation limits (J-1224) for this postulated condition and are not intended to meet the stress limits of NG-3200.];

Page 322

(b) delineation of those internal structures which are required to be analyzed in order to ensure the structural integrity of the mating core support structures;

(c) nominal environmental conditions, such as temperature, pressure, and fluid chemistry;

(d) stipulation of handling, storage, shipping, and delivery technical requirements (identified as non-Code requirements);

(e) procedure for review and certification of the Design Report by those responsible for the Design Specifications;

(f) identification of the location of core support structure installation;

(g) procedure for handling various data reports, particularly with respect to transmittal to enforcement authorities;

(h) certification of the Design Specifications.

J-1220 SPECIFIC INFORMATION

J-1221 Boundaries of Jurisdiction

The boundaries of the core support structures and their relationship to the support and restraint of the core shall be clearly defined through the use of dimensions, description, or drawings.

J-1222 Materials

The Design Specifications should provide the information relative to materials designated in (a) through (g) below:

- (a) applicable temperature limits;
- (b) any reductions to design stress intensity values, allowable stresses, or fatigue curves necessitated by environmental conditions (NCA-1130);
- (c) any restrictions on cladding materials;
- (d) materials which are acceptable from the standpoints of environment and location when cladding is required;
- (e) any restrictions on heat treating furnace atmospheres;
- (f) any requirements with respect to cleanliness;
- (g) special requirements, such as materials and testing.

J-1223 Design

J-1223.1 Design Conditions.

The Owner shall stipulate in the Design Specifications data for the following categories of operating conditions:

- (a) Level A Service Limits
- (b) Level B Service Limits
- (c) Level C Service Limits
- (d) Level D Service Limits

J-1223.2 Loading Conditions

(a) The Design Specifications need not include specific values of forces and moments at the boundaries and interfaces that result from each of the operating conditions. However, sufficient information shall be provided that will allow the designer to adequately assess the significant resultant loads. Forces and moments used in the stress analysis shall be included in the Design Report.

(b) The Design Specifications shall include information that will allow the designer to account for the loading of NG-3111, identified as to the applicable operating condition category. The information shall include a description of operating cycles and the number of occurrences of each.

J-1223.3 Loading Combinations.

For each operating condition category, the loadings of NG-3111 to be simultaneously considered shall be specified.

J-1223.4 Deformation Limits.

In addition to the stress limits given in Subsection NG, static and dynamic deformation limits shall be specified to ensure the performance of all safety related functions of the core support structure. These limits are to be those that cause loss of function and are not intended to include a margin of safety.

J-1224 Requirements Beyond the Jurisdiction of This Section

The Design Specifications shall stipulate any additional requirements which the Owner intends to be incorporated in the specific system covered by the Design Specifications or any additional requirements intended to be more specific or more restrictive than the minimum requirements of this Section.

J-1230 DESIGN SPECIFICATION CERTIFICATION

The Design Specifications shall be certified in accordance with NCA-3255.

July 1, 1998

American Society Of Mechanical Engineers SEC III D1 NMA APP K APPENDIX K TOLERANCES

Page 323

ARTICLE K-1000 TOLERANCES

[98]

K-1100 INTRODUCTION

It is recognized that design of supports is based on the use of nominal dimensions. This is not different from the design of piping or equipment which also is based on nominal dimensions. Good design practice dictates that the designer consider the degree of deviation from nominal design which can be tolerated when supports are manufactured as well as when they are installed. It is the intent of this Appendix to provide guidance to the designer as to the need for establishing such tolerances. The tolerances shown in Table K-1330-1 are for guidance and need not be measured.

[98]

[98]

K-1200 OBJECTIVE

(a) Tolerances referred to in this Appendix apply only to such values that may affect Code compliance of a support and are not already addressed in the body of the Code. Any other dimensions and tolerances associated with a support are not addressed.

(b) Since specific tolerance values are a function of the interrelationship between design, manufacturing and installation, it is impossible to provide specific values in this Appendix, with the exception of Table K-1330-1. In addition, it is recognized that there can be cost/benefit considerations associated with the establishment of tolerances.

[98]

K-1300 GENERAL REQUIREMENTS

[98]

K-1310 Material

Material supplied to an SA, SB, SFA Specification, or Table NF-3132-1 Dimensional Standards, need not have material dimensional tolerances specified by the support designer. Material provided to those specifications and standards have their own tolerances and the use of nominal dimension design is adequate. However, tolerance(s) on any manufacturing operation(s) affecting the support load capacity needs to be considered.

[98]

[98]

K-1320 Supports and Support Parts

(a) It is the responsibility of the designer to specify any tolerances associated with the support or support part. Such tolerances shall be cited in the Design Specification, Design Report, Design Drawing, Load Capacity Data Sheet or Design Report Summary.

(b) For a support or support part procured from an N-type Certificate Holder or a QSC supplier of standard supports who also provided the related Design Report or Design Report Summary, or Load Capacity Data Sheet, it is the responsibility of the Certificate Holder to assure that tolerances associated with the support or support part have been considered.

[98]

[98]

K-1330Installation

(a) Installation tolerances of supports need to be established. There are two categories of installation tolerances associated with a support. The first is a local installation tolerance affecting only the load capacity of the support itself. The second being a global installation tolerance which may affect the conclusions of the component or piping qualification.

(b) The support Design Specification, Design Report, Design Report Summary, or Load Capacity Data Sheet shall specify local installation tolerances. Table K-1330-1 provides acceptable local installation tolerances for piping supports. When piping support installation meets these tolerances, any change in the established piping support load capacity is considered minor to the point that existing load capacity calculations are adequate. Global installation tolerances should be addressed in the piping or component Design Specification or Design Report.

(c) It is the responsibility of the Construction Specification or Design Report Summary preparer to incorporate any component and piping support installation tolerances into the Construction Specification.

[98]

TABLE K-1330-1
LOCAL INSTALLATION TOLERANCES FOR PIPING SUPPORTS

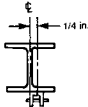
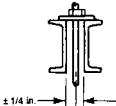
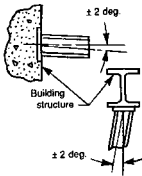
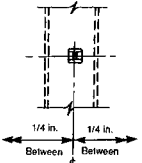
Item	Total Tolerance	Configuration
<i>I. Tolerance for General Measurement/Installation</i>		
A) Deviations in the location of the centerline of any attachment to the flange centerline of building steel member(s) or piping support steel member(s); if the support drawing specifies an offset, the attachment may be relocated to any distance towards the centerline of the member to facilitate installation.	$\pm 1/4$ in.	
B) Deviation of back-to-back distance for channels with rod type component support.	$\pm 1/4$ in.	
C) Deviation in the centerline angular orientation of piping support steel members in the horizontal or vertical planes.	$\pm 2^\circ$	
D) Deviation in the centerline location of attachments between flanges of building steel members.	$\pm 1/4$ in.	

TABLE K-1330-1
LOCAL INSTALLATION TOLERANCES FOR PIPING SUPPORTS (CONT'D)

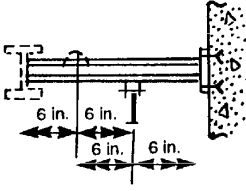
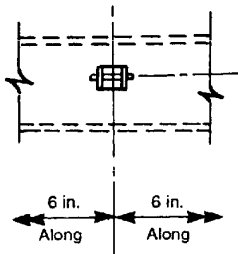
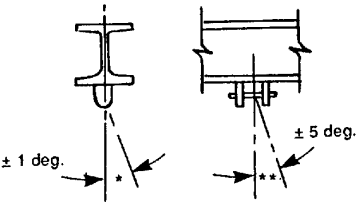
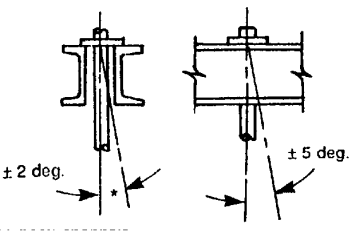
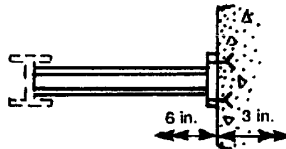
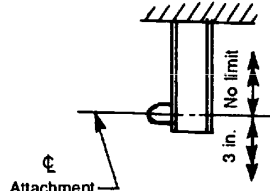
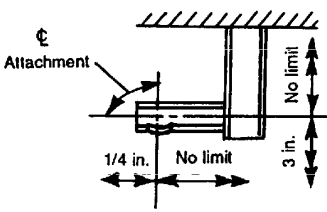
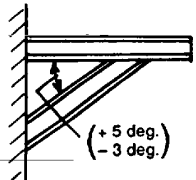
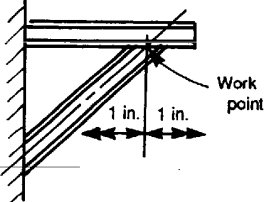
Item	Total Tolerance	Configuration
<i>II. Tolerances for Attachment Installation</i>		
A) Deviations in the location of attachments to piping support steel member with two ends attached to the building structure (ends may be pinned or fixed).	± 6 in.	
B) Deviations in the centerline location of attachments along building steel member length.	± 6 in.	
C) Deviation in conical angularity of snubber or strut attachments to piping support steel member or building steel member * $\pm 1^\circ$ need not be justified $\pm 5^\circ$ is more reasonable and should be considered in the designer's calculations to allow $\pm 5^\circ$ in practice. ** Subject to limitations defined by hardware manufacturer.	$\pm 5^\circ$	
D) Deviation in angularity of rod type component attachments to back-to-back channels. * $\pm 2^\circ$ need not be justified $\pm 5^\circ$ is more reasonable and should be considered in the designer's calculations to allow $\pm 5^\circ$ in practice.	$\pm 5^\circ$	

TABLE K-1330-1 LOCAL INSTALLATION TOLERANCES FOR PIPING SUPPORTS (CONT'D)

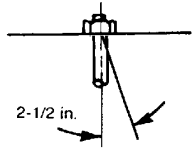
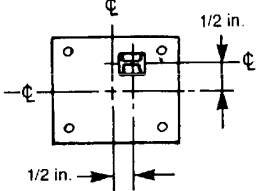
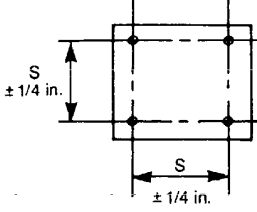
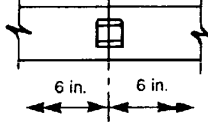
**TABLE K-1330-1
LOCAL INSTALLATION TOLERANCES FOR PIPING SUPPORTS (CONT'D)**

Item	Total Tolerance	Configuration
<i>III. Tolerance for Piping Support Steel Member Installation</i>		
A) Deviation in the length of steel member with two ends attached to the building structure (ends may be pinned or fixed).	+3 in. -6 in.	
B) Deviation of component attachment centerline for a single steel cantilever member attached to the building structure. Note: A cantilever with a kneebrace connection has the same installation tolerances as a single cantilever. See items (D) and (E) for kneebrace tolerances.	+3 in.	
C) Deviation of connection centerline for double (or more) cantilevers. See figure. Note: Any cantilever member (single, both members of a double, etc.) can be shortened any distance required to complete installation.	+1/4 in.	
D) Deviation in kneebrace angle with respect to cantilever.	+5°, -3°	
E) Deviation in brace work point with respect to cantilever.	±1 in.	

[98]

TABLE K-1330-1 LOCAL INSTALLATION TOLERANCES FOR PIPING SUPPORTS (CONT'D)

**TABLE K-1330-1
LOCAL INSTALLATION TOLERANCES FOR PIPING SUPPORTS (CONT'D)**

Item	Total Tolerance	Configuration
<i>IV. Tolerances for Concrete Expansion Anchor (CEA)/Plate Installation</i>		
A) Deviation in conical angularity of CEA	$\pm 2 \frac{1}{2}$ in.	
B) Deviation of centerline of attachment with respect to specified attachment point.	$\pm 1/2$ in.	
C) Deviation of CEA location with respect to design location.* * Minimum edge distance must be maintained.	$\pm 1/4$ in.	
<i>V. Tolerances for Embedment Plate Attachment Installation</i>		
Deviation in attachment centerline with respect to embedment plate design location.		
A) Individual embedment plate	$\pm 1/4$ in. (See Note)	
B) Strip embedment plate 1) perpendicular to longitudinal axis 2) along longitudinal axis	$\pm 1/4$ in. (See Note) ± 6 in.	

Note: The designer shall determine the appropriate distances to be maintained between centerline or edge of attachments and edge of embedment plates.

TABLE K-1330-1 LOCAL INSTALLATION TOLERANCES FOR PIPING SUPPORTS (CONT'D)

**TABLE K-1330-1
LOCAL INSTALLATION TOLERANCES FOR PIPING SUPPORTS (CONT'D)**

Item	Total Tolerance	Configuration
<i>VI. Tolerances for Standard Support Component Setting</i>		
A) Deviation in variable spring load settings.		±10% of specified loads
B) Deviation in constant spring settings.		±1/4 in. of specified position
C) Deviation in cold setting of snubber.		±1/4 in. of specified setting
<i>VII. Miscellaneous Tolerances</i>		
A) Deviation in gap between pipe and supporting steel member (in nonsupport direction)	Gap (G) Size	
	G < 1/8 in.	± 0 in.
	1/8 in. < G < 1/2 in.	+ 1/2 in., -0
	G > 1/2 in.	+ 1/2 in., -1/8 in.
B) Deviation in dimensions of piping support lugs		± applicable measurement tolerance
C) Deviation in weld size		specified size minimum
Deviation in weld length		
For welds <3 in. long		-1/8 in., no max.
For welds ≥3 in. long		-1/4 in., no max.

TABLE K-1330-1 LOCAL INSTALLATION TOLERANCES FOR PIPING SUPPORTS (CONT'D)

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP L

APPENDIX L CLASS FF FLANGE DESIGN FOR CLASS 2 AND 3 COMPONENTS AND CLASS MC VESSELS

Page 331

ARTICLE L-1000 CLASS FF FLANGES - INTRODUCTION

L-1100 GENERAL REQUIREMENTS

L-1110 ACCEPTABILITY

The requirements for acceptability of Class FF flange design are that the general design requirements of Subsections NC, ND, or NE and the specific requirements of this Appendix are met.

L-1120 DEFINITION OF CLASS FF FLANGES

Class FF flanges are circular flanges having flat faces which are either bolted directly together or are separated by a metal spacer such that there is metal to metal contact between the flange faces and the metal spacer initially or after the flanges have been bolted up.

ARTICLE L-2000 CLASS FF FLANGES - MATERIALS

L-2100 MATERIAL REQUIREMENTS

The rules of Article XI-2000 apply.

ARTICLE L-3000 CLASS FF FLANGES - DESIGN

L-3100 GENERAL REQUIREMENTS

L-3110 SCOPE

The rules in this Appendix apply to circular, bolted flanged connections where the assemblage is comprised of identical or nonidentical flange pairs, and where the flanges are flat faced and are in uniform metal-to-metal contact across their entire face during assembly before the bolts are tightened or after a small amount of preload is applied to compress a gasket. The rules also apply when a pair of identical flat faced flanges are separated by a metal spacer. The rules are not intended for cases where the faces are intentionally made nonparallel to each other such that initial contact is at the bore.

Construction details for attachment and configuration of the flange are not covered in this Appendix. Minimum weld sizes and geometric limitations given in Fig. XI-3120-1 and Fig. NC-4243-2, Fig. ND-4243-1, or Fig. NE-4243-1, as applicable, apply to Appendix L flanges. Similarly, when applying the rules of this Appendix, use of the graphs in Appendix XI for obtaining applicable design parameters is necessary; namely, Figs. XI-3240-1 through XI-3240-6.

L-3120 ASSUMPTIONS AND LIMITATIONS OF RULES

It is assumed that a self-sealing gasket is used approximately in-line with the wall of attached pipe or vessel. The rules provide for hydrostatic end loads only and assume that the gasket seating loads are small and may in most cases be neglected. It is also assumed that the seal generates a negligible axial load under operating conditions. If such is not the case, allowance shall be made for a gasket load H_G dependent on the size and configuration of the seal and design pressure. Proper allowance shall be made if connections are subject to external forces other than external pressure.

L-3130 FATIGUE CONSIDERATIONS

As with flanges with ring type gaskets, the stress in the bolts may vary appreciably with pressure. There is an additional bolt stress generated due to a prying effect resulting from the flanges interacting beyond the bolt circle. As a result, fatigue of the bolts and other parts comprising the flanged connection may require consideration and adequate pretensioning of the bolts may be necessary. It is important to note that the operating bolt stress is relatively insensitive to changes in prestress up to a certain point and that thereafter the two stresses are essentially the same. This is a desirable characteristic of Appendix L flanges; it means that if the assembly stress (prestress) in the bolts is close to the operating design stress σ_b , then subsequent applications of pressure loadings ranging from zero to full load will have no significant effect on the actual operating stress in the bolts.

Unlike Appendix XI flanges and their bolts which are stressed during assembly (although some readjustment in the stresses may occur during pressurization), Appendix L flanges become stressed during pressurization; however, the effect of pressurization on the operating stress in the bolts depends upon the extent to which the bolts are stressed during assembly.

L-3140 ANALYTICAL APPROACHES

In the case of identical flange pairs, the analytical procedure described in this Appendix considers the flanges to be continuous, annular plates whose flexural characteristics can be approximated by beam theory by considering the flanges to be comprised of a series of discrete, radial beams. For nonidentical flange pairs, beam theory is supplemented by the theory of rigid body rotation so as to preserve equilibrium of moments and forces. Moments associated with beam theory are designated as *balanced moments*, whereas moments used when the theory of rigid body rotations is applied are designated as *unbalanced moments*. Balanced and

unbalanced moments are designated M_b and M_u respectively. When no subscript appears, a balanced moment is intended, i.e., in the equations for the analysis of identical flange pairs (L-3242).

L-3150 REDUCTION IN CONTACT FORCES

A reduction in flange-to-flange contact forces beyond the bolt circle occurs when the flanges are stiff with respect to the bolting and, in the extreme, flange separation occurs. The rules in this Appendix provide little insight into the problem except when the reduction in the contact force is due to the flange-hub interaction moment. The problem is considered to be of little practical significance when the nuts are tightened during assembly using ordinary wrenching techniques.

L-3160 TANGENTIAL CONTACT BETWEEN FLANGES OUTSIDE THE BOLT CIRCLE

The design procedure is based on the assumption that the flanges are in tangential contact at their outside diameter or at some lesser distance h_C from the bolt circle. [See L-3221(b) and L-3260 when

$$h_C < h_{Cmax}$$

for additional requirements.] The diameter of the circle where the flanges are in tangential contact is a design variable; the smaller the diameter of the contact circle

$$C + 2h_C$$

the greater the required prestress in the bolts, the higher the ratio of prestress to operating bolt stress, S_f/σ_b , and the smaller the flange separation at the gasket. The requirement of tangential contact, even when it is assumed to occur at the outside diameter

$$(C + 2h_{Cmax})$$

of the flanges, automatically yields a high ratio of S_f/σ_b which means that the possibility of flange separation or an appreciable decrease in the flange-to-flange contact forces is no longer a problem even when the flanges are stiff with respect to the bolts.

L-3170 RELATIVE STIFFNESS OF FLANGES AND BOLTS

The equation for the calculated strain length l of the bolts is generally applicable. However, variations in the thickness of material actually clamped by each bolt, such as sleeves, collars, or multiple washers placed between a flange and the bolt heads or nuts, or by counterboring, must be considered in establishing a value of l for use in the design equations. A large increase in l may cause the flanges to become abnormally stiff with respect to such bolts and the provision of tangential contact may not yield a sufficiently high value of the ratio S_f/σ_b unless h_C is reduced to cause an increase in the ratio.

L-3180 COMBINED STRESSES

Most of the calculated stresses are bending only, so that tensile and compressive stresses of the same magnitude occur on opposite surfaces at the point under consideration. However, when a membrane stress occurs in conjunction with a bending stress, the combined stress represents the maximum absolute value at the point and may be tension or compression (denoted by a - sign).

L-3190 NOTATION

L-3191 Symbols

The symbols described below are used in the formulas for the design of flanges.

A	= outside diameter of flange, in.
A_b	= cross-sectional area of the bolts using the root diameter of the thread or least diameter of unthreaded portion, if less, sq in.
A_m	= total required cross-sectional area of bolts, taken as the greater of A_{m1} and A_{m2} , sq in.

A_{m1}

= total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for the opening conditions, sq in.

$$= W_{m1}/S_b$$

A_{m2}

= total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for gasket seating, sq in.

$$= W_{m2}/S_a$$

Page 338

$\overline{AR}$

= bolt hole aspect ratio used in calculating bolt hole flexibility factor r_B

$$= \frac{nD}{\pi C}$$

a

= shape factor

$$= (A + C)/2B_1$$

B

= inside diameter of flange, in. When B is less than $20g_1$, it will be optional for the designer to substitute B_1 for B in the formula for longitudinal stress S_H

B_1

= $B + g_1$ for loose type flanges and for integral type flanges that have calculated values h/h_0 and g_1/g_0 which would indicate an f value of less than 1.0, although the minimum value of f permitted is 1.0

= $B + g_0$ for integral type flanges when f is equal to or greater than one

= B for Category 3 (loose type) flanges

b

= effective gasket or joint-contact-surface seating width, in. [see Note 1, XI-3221.1]

b_0

= basic gasket seating width, in. (from Table XI-3221.1-2)

C

= bolt circle diameter, in.

C_1

= factor

$$= - \left(0.748 - 1.567 J_S \log \frac{A}{B_1} \right) \div (1 + 1.3 J_S) \quad (1)$$

$$C_2 = \text{factor} \quad (1)$$

$$= \left[\frac{\pi}{32} (P B_1^3) - 1.3 J_P M_P \right] \div (1 + 1.3 J_S) \quad (2)$$

$$C_3 = \text{factor} \quad (2)$$

$$= - \left(0.575 - 1.206 J_S \log \frac{A}{B_1} \right) \div (J_S + t_1^3 / F_1') \quad (3)^1$$

$$C_4 = \text{factor} \quad (3)^1$$

$$= - (J_P M_P) \div (J_S + t_1^3 / F_1') \quad (4)^1$$

$$c = \text{basic dimension used for the minimum sizing of welds, in., equal to } t_n \text{ or } t_p \text{ whichever is less} \quad (4)^1$$

$$D = \text{diameter of bolt hole, in.}$$

$$d = \text{factor}$$

¹ $C_3 = C_4 = 0$ when $F_1' = 0$.

$$d = \frac{U}{V} h_0 g_0^2 \text{ for integral type flanges}$$

$$d = \frac{U}{V_L} h_0 g_0^2 \text{ for loose type flanges}$$

E = modulus of elasticity of flange material, corrected for operating temperature (see Section II, Part D, Subpart 2, Tables TM)

E_I^* = factor
 $= E_I t_I^3$

E_{II}^* = factor
 $= E_{II} t_{II}^3$

e = factor

$$= \frac{F}{h_0} \text{ for integral type flanges}$$

$$= \frac{F_L}{h_0} \text{ for loose type flanges}$$

F = factor for integral type flanges (from Fig. XI-3240-2)

F_L = factor for loose type flanges (from Fig. XI-3240-4)

$$F' = g_0^2 (h_0 + Ft) / V \text{ for Category 1,} \\ \text{Group 1 assembly} \quad (5a)$$

$$F' = g_0^2 (h_0 + F_L t) / V_L \text{ for Category 2,} \\ \text{Group 1 assembly} \quad (5b)$$

$$F' = 0 \text{ for Category 3, Group 1 assembly} \quad (5c)$$

$$F'_1 = g_0^2 (h_0 + Ft_1) / V \text{ for Category 1,} \\ \text{Group 3 assembly} \quad (6a)$$

$$F'_1 = g_0^2 (h_0 + F_L t_1) / V_L \text{ for Category 2,} \\ \text{Group 3 assembly} \quad (6b)$$

$$F'_1 = 0 \text{ for Category 3, Group 3 assembly} \quad (6c)$$

f	= hub stress correction factor for integral flanges from Fig. XI-3240-6. (When greater than 1, this is the ratio of the stress in the small end of hub to the stress in the large end.) (For values below limit of the Figure, use $f=1$.)
G	= diameter at location of gasket load reaction, in. = mean diameter of gasket, in.
g_0	= thickness of hub at small end, in.
g_1	= thickness of hub at back of flange, in.
H	= total hydrostatic end force, lb = $0.785 G^2 P$
H_C	= contact force between mating flanges, lb
H	

	$= 0.785 B^2 P$
H_G	= gasket load due to seating pressure, plus axial force generated by self-sealing of gasket, lb
H_p	= total joint-contact-surface compression load, lb $= 2b \times 3.14 GmP$
H_T	= difference between total hydrostatic end force and the hydrostatic end force on area inside of flange, lb $= H - H_D$
h	= hub length, in.
h_C	= radial distance from bolt circle to flange-spacer or flange-flange bearing circle where tangential contact occurs. Tangential contact exists from the selected value of h_C to h_{Cmax} , in.
h_{Cmax}	= radial distance from bolt circle to outer edge of flange or spacer, whichever is less, in.
h_D	= radial distance from the bolt circle, to the circle on which H_D acts, as prescribed in Table XI-3230-1, in.
h_G	= radial distance from gasket load reaction to the bolt circle, in.

$$= \frac{C - G}{2}$$

h_0	= factor, in. $= \sqrt{Bg_0}$
h_T	= radial distance from the bolt circle to the circle on which H_T acts as prescribed in Table XI-3230-1, in.

$$J_P = \frac{1}{B_1} \left[\frac{h_D}{\beta} + \frac{h_C}{a} \right] + \pi r_B$$

$$J_S = \frac{1}{B_1} \left[\frac{2h_D}{\beta} + \frac{h_C}{a} \right] + \pi r_B$$

K = ratio of outside diameter of flange to inside diameter of flange

$$= A/B$$

L = factor

$$= \frac{te + 1}{T} + \frac{t^3}{d}$$

l = calculated strain length of bolt

$$= 2t + t_s + (1/2)d \text{ for each threaded end for a Group 1 assembly}$$

$$= t_1 + t_{11} + (1/2)d \text{ for each threaded end for a Group 3 assembly}$$

M_b = balanced moment acting at diameter B_1 of flange, in.-lb

M_D = component of moment due to H_D , in.-lb

$$= H_D h_D$$

M_G = component of moment due to H_G , in.-lb

$$= H_G h_G$$

M_H = moment acting on end of hub, pipe, or shell, at its junction with back face of flange ring, in.-lb

M_P = moment due to $H_D H_P H_G$, in.-lb

=

$$H_D h_D + H_T h_T + H_G h_G$$

M_S = total moment on flange ring due to continuity with hub, pipe, or shell, in.-lb

	$= M_H + Ql/2$ where
t	= thickness of the flange under consideration (t , t_p , or t_{fl} , as applicable)
M_T	= component of moment due to H_T , in.-lb $= H_T h_T$
M_u	= unbalanced moment acting at diameter B_1 of flange, in.-lb
m	= gasket factor; obtain from Table XI-3221.1-1 [see Note 1, XI-3221.1]
N	= width, in., used to determine the basic gasket seating with b_0 based upon the possible contact width of the gasket (see Table XI-3221.1-2)
n	= number of bolts
P	= design pressure, psi
Q	= shear force between flange ring and end of hub, pipe, or shell, positive as indicated in Fig. L-3191-2 sketch (b), lb
R	= radial distance from bolt circle to point of intersection of hub and back of flange, in. For integral and hub flanges,

$$R = \frac{C - B}{2} - g_1$$

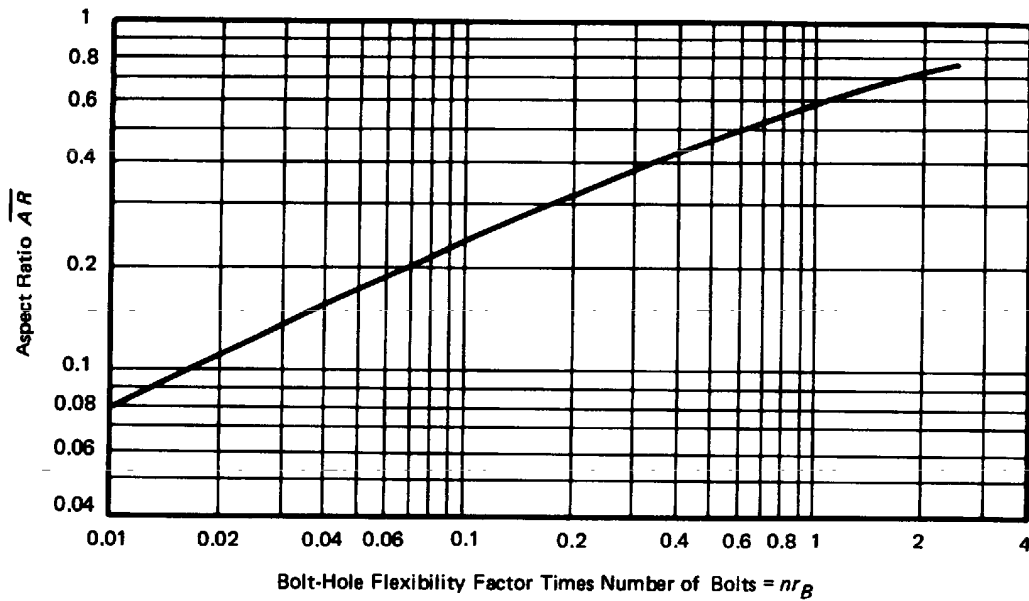


FIG. L-3191-1 BOLT HOLE FLEXIBILITY FACTOR

FIG. L-3191-1 BOLT HOLE FLEXIBILITY FACTOR

$$r_B = \frac{1}{n} \left(\frac{4}{\sqrt{1 - \overline{AR}^2}} \tan^{-1} \sqrt{\frac{1 + \overline{AR}}{1 - \overline{AR}}} - \pi - 2\overline{AR} \right)$$

(See Fig. L-3191-1 for a curve of nr_B vs $\overline{AR}$. In the above equation for r_B $\tan^{-1}$ must be expressed in radians.)

r_E

= elasticity factor

	= modulus of elasticity of flange material divided by modulus of elasticity of bolting material, corrected for operating temperature (see Section II, Part D, Subpart 2, Tables TM)
r_S	= initial bolt stress factor
	= $1 - S_f/\sigma_b$
S_a	= allowable bolt stress at atmospheric temperature, psi (given in Section II, Part D, Subpart 1, Table 3)
S_b	= allowable bolt stress at design temperature, psi (given in Section II, Part D, Subpart 1, Table 3)
S_f	= allowable design stress for material of flange at design temperature (operating condition) or atmospheric temperature (gasket seating), as may apply, psi (given in Section II, Part D, Subpart 1, Tables 1A and 1B)
S_n	= allowable design stress for material of nozzle neck, vessel or pipe wall, at design temperature (operating condition) or atmospheric temperature (gasket seating), as may apply, psi (given in Section II, Part D, Subpart 1, Tables 1A and 1B)
S_H	= calculated longitudinal stress in hub, psi
S_i	= initial bolt stress (always less than S_b), psi
S_R	= calculated radial stress in flange, psi
S_T	= calculated tangential stress in flange, psi
T	= factor involving K (from Fig. XI-3240-1)
t	= flange thickness of an identical flange pair in a Group 1 assembly, in.
t_1	= thickness of the nonreducing flange in a Group 3 assembly (see L-3231), in.
t_{II}	= thickness of the reducer or flat circular head in a Group 3 assembly (see L-3231), in.
t_i	= two times the thickness g_o , when the design is calculated as an integral flange, in., or two times the thickness, in., of shell or nozzle wall required for internal pressure, when the design is calculated as a loose flange, but not less than $\frac{1}{4}$ in.
t_n	= nominal thickness of shell or nozzle wall to which flange or lap is attached, in.

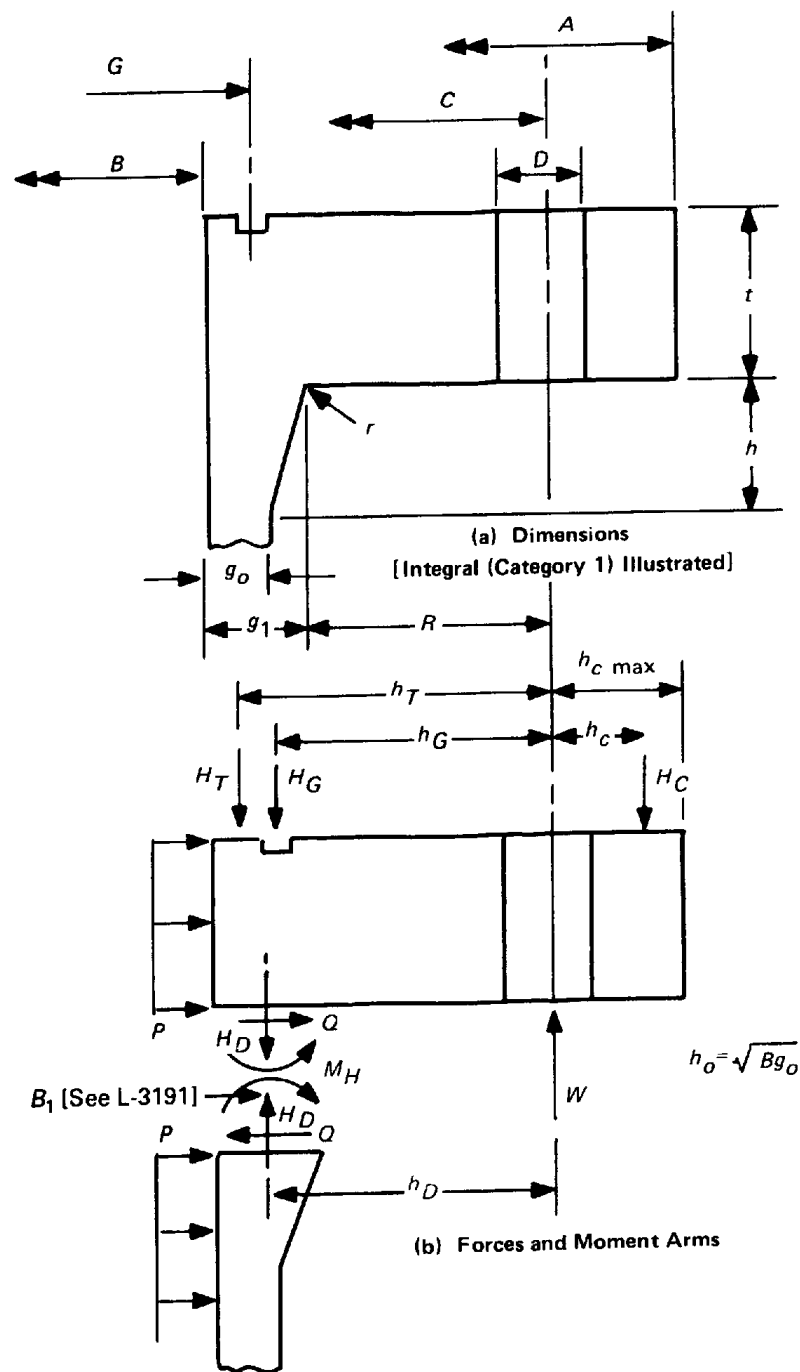


FIG. L-3191-2 FLANGE DIMENSIONS AND FORCES

FIG. L-3191-2 FLANGE DIMENSIONS AND FORCES

t_s	= thickness of spacer, in.
U	= factor involving K (from Fig. XI-3240-1)
V	= factor for integral type flanges (from Fig. XI-3240-3)
V_L	= factor for loose type flanges (from Fig. XI-3240-5)
W	= flange design bolt load, for the operating conditions or gasket seating, as may apply, lb (see L-3220)
W_{ml}	= minimum required bolt load for the operating conditions, lb (see L-3220)
w	= width, in., used to determine the basic gasket seating width b_g based upon the contact width between the flange facing and the gasket (see Table XI-3221.1-2)
X	= factor = $E_I^*/(E_I^* + E_{II}^*)$
Y	= factor involving K (from Fig. XI-3240-1)
y	= gasket or joint-contact-surface unit seating load, psi (see footnote 1, XI-3221.1)
Z	= factor involving K (from Fig. XI-3240-1)
β	= shape factor for full face metal-to-metal contact flanges = $(C + B_1)/2B_1$
θ_A	= slope of flange face at outside diameter, rad
θ_B	= slope of flange face at inside diameter, rad
θ_{rb}	= change in slope which flange pair undergoes due to an unbalanced moment, rad

L-3192 Subscripts

Subscripts I and II where noted are used to distinguish between the flanges in a nonidentical flange pair (Group 2 or 3 assemblies). B_1 without a subscript always refers to Flange I (the nonreducing flange) in a Group 2 or 3 assembly.

L-3193 Based on Nonreducing Flange

Unless otherwise noted, B_1, J_S, J_P , and F_1' [Eqs. (6a), (6b), and (6c) of L-3191] and M_P are based on the dimensions of the nonreducing flange (Flange I) in a Group 2 or 3 assembly.

L-3194 Logarithms

All logarithms are to base 10.

L-3200 DESIGN OF FLANGES AND BOLTING

L-3210 ESTIMATING FLANGE THICKNESSES AND BOLTING

L-3211 Equations for Trial Flange Thickness and Bolting

The following simple equations are offered for calculating approximate values of t , t_p , t_{II} , and A_b before applying the rules in L-3220 through L-3260. The equations are not intended to replace the rules; however, they should significantly reduce the amount of work required to achieve a suitable design. Since the flanges are in metal-to-metal contact and interact, the stresses in one flange are influenced by the stiffness of the mating flange and theoretically an unlimited number of designs can be found which satisfy the rules. In practice, however, economics, engineering judgment, and dimensional constraints will show which is the "best" design. It should be noted that the equations in Table L-3212-1 assume that both flanges comprising an assembly have essentially the same modulus of elasticity and allowable stress.

$$t_a = 2.45 \sqrt{\frac{M_p}{(\pi C - nD) S_f}} \quad (7)$$

$$t_b = 0.56 B_1 \sqrt{P / S_f} \quad (8)$$

$$t_c = \text{greater of } t_a \text{ or } t_b$$

$$t_d = t_a + \frac{(B_1 - B_{II})}{(B_1 - 0.5C)} (t_b - t_a) \quad (9)$$

$$t_e = t_a \text{ when } t_b < t_a$$

$$t_e = t_d \text{ when } t_b > t_a$$

$$A_b' = [H + 2M_p / (A - C)] \div S_b \quad (10)$$

$$t_f = 2.45 \sqrt{\frac{H_1 l_1 + H_2 l_2}{(\pi C - nD) S_f}} \quad (11)$$

$$A_b^* = 0.95 \left[\frac{2(H_1 l_1 + H_2 l_2)}{(A - C)} + 0.785 G^2 P \right] \div S_b \quad (12)$$

(7-12)

where

$$H_1 = 0.785 B_{II}^2 P$$

Page 343

$$H_2 = 0.785 (G^2 - B_{II}^2) P$$

$$l_1 = (C - B_{II})/2$$

$$l_2 = (C - G)/2 + (G - B_{II})/4$$

$$t_g = \text{smaller of } t_c \text{ or } t_f$$

TABLE L-3212-1
TRIAL FLANGE THICKNESS AND AREA OF BOLTING FOR VARIOUS GROUPS OF
ASSEMBLIES AND FLANGE CATEGORIES

Group (Assembly)	Category of Flanges		Suggested Trial Values		
	Nonreducing	Reducing	t or t_I	t_{II}	A_b
1	1 or 2	...	$0.9t_a$	...	$0.9A_b'$
	3	...	t_a	...	A_b'
2	1 or 2	1 or 2	t_a	t_e	A_b'
	3	3	$1.1t_a$	$1.1t_c$	$1.1A_b'$
	3	1 or 2	t_a	t_c	A_b'
	1 or 2	3	$1.1t_g$	$1.1t_g$	$A_b'^*$
3	1, 2, or 3	...	$1.1t_a$	$1.1t_c$	$1.05A_b'$

TABLE L-3212-1 TRIAL FLANGE THICKNESS AND AREA OF BOLTING FOR VARIOUS GROUPS OF ASSEMBLIES AND FLANGE CATEGORIES

L-3212 Trial Values of t , t_I , t_{II} , and A_b

The simple equations given in Table L-3212-1 should yield relatively good trial values of t , t_I , t_{II} , and A_b but they do not assure that the "first trial design" will meet the requirements of L-3240 through L-3250. As a result, it becomes necessary to select new trial values and reanalyze. In order to assist the designer in selecting the second trial values, the following comments concerning the behavior of different groups of Class FF flanges are offered.

(a) The hub of a Category 1 or 2 flange of a Group 1 assembly reduces the radial stress at the bolt circle (due to a negative hub-flange interaction moment) and the longitudinal hub stress. As a result, a pair of Category 1 or Category 2 flanges will be thinner than a pair of identical Category 3 flanges.

(b)

(b) Increasing the thickness of the reducing flange of a Group 3 assembly, when the nonreducing flange is Category 1 and 2, generally reduces the significant stresses in both flanges comprising the assembly. When the stress in Flange I (nonreducing) is excessive, increasing t_I will generally be more effective in reducing the stresses; however, a nominal increase of the stresses in Flange II will occur due to the additional restraint provided by increasing t_I . When the stress in Flange I is excessive and only marginally acceptable in Flange II, both t_I and t_{II} should be increased with the emphasis placed on t_I .

(c) A Category 3 reducing flange bolted to a Category 1 or 2 nonreducing flange produces a large overturning moment which tends to rotate Flange I in a negative direction. As a result, the radial stress at the bolt circle in Flange I will often be excessive due to a large, positive hub-flange interaction moment. As a result, it is usually necessary to increase t_I so that $t_I = t_{II}$. The same problem does not occur when Flange I is Category 3 since there exists no hub-flange interaction moment. When Flange I is an optional type treated as a loose type (Category 3), a hub-flange interaction moment actually exists but is disregarded in the analysis by assigning the flange to Category 3.

(d) When the longitudinal hub stress of a Category 1 or 2 flange is excessive, it can be reduced by increasing the size of the hub, or g_0 when $g_1 = g_0$; however, this will cause an increase in the radial stress at the flange-hub junction. When S_H is excessive and S_R is marginally acceptable, an increase in the thickness of the flange is indicated in which case it may or may not be necessary to alter the size of the hub.

(e) When the longitudinal stress in the hub of the nonreducing flange of a Group 2 or Group 3 assembly is low compared to the allowable stress and the radial stress at the bolt circle is excessive, increasing S_H by making the hub smaller (more flexible) will often reduce the radial stress at the bolt circle to S_r . If it does not, an increase in t_I is indicated.

Page 344

L-3220 BOLT LOADS

L-3221 Required Bolt Load

The flange bolt load used in calculating the required cross-sectional area of bolts shall be determined as follows.

(a) The required bolt load for the operating condition W_{m1} shall be sufficient to resist the sum of the hydrostatic end force H exerted by the maximum allowable working pressure on the area bounded by the diameter of the gasket reaction, and the contact force H_C exerted by the mating flange on the annular area where the flange faces are in contact. To this shall be added the gasket load H_G for those designs where gasket seating requirements are significant.

(b) Before the contact force H_C can be determined, it is necessary to obtain a value for its moment arm h_C . Due to the interaction between bolt elongation and flange deflection, h_C involves the flange thickness t , operating bolt stress σ_b , initial bolt prestress factor r_s , and calculated strain length l , elasticity factor r_E , and total moment loading on the flange. This Article is based on starting a design by assuming a value for h_C and then calculating the value of the initial bolt stress S_i which satisfies the assumption.

Although the distance h_C from the bolt circle to the flange-to-flange contact circle is a design variable, for the purpose of this Article the use of

$$h_C < h_{Cmax}$$

to optimize stresses is considered to be a special situation requiring controlled bolt tightening and verification (see L-3260). Except in special instances, setting h_C equal to h_{Cmax} should be satisfactory. It is inherent in the computational process that the flanges will be in tangential contact between the selected bearing circle

$$C + 2h_C$$

and the outside diameter of the flanges

$$C + 2h_{Cmax}$$

(c) The hub-flange interaction moment M_S , which acts on the flange, is expressed by Formulas (13), (25), and (26); for Category 3 flanges

$$M_S = 0$$

The contact force H_C is determined by Formulas (15) or (33).

(d)

(d) The required bolt load for operating conditions is determined in accordance with the following formula:

$$W_{ml} = H + H_C + H_G$$

L-3222 Total Required and Actual Bolt Areas, and Flange Design Bolt Load

The total required cross-sectional area of bolts A_M equals W_{ml}/S_b . A selection of bolts to be used shall be made such that the actual total cross-sectional area of bolts A_b will not be less than A_m . The flange design bolt load W shall be taken equal to W_{ml} .

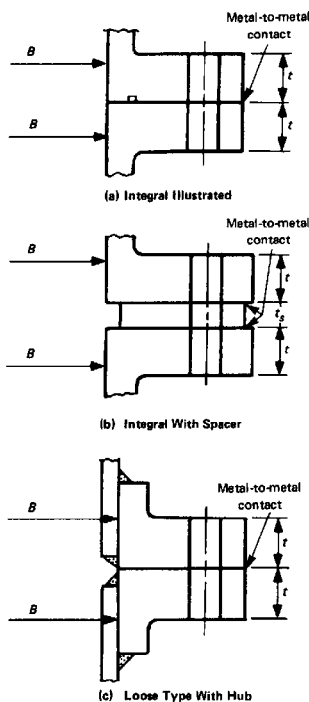
L-3230 CLASSIFICATION OF ASSEMBLIES AND CATEGORIZATION OF INDIVIDUAL FLANGES

It is necessary to classify the different types of flanged assemblies and to further categorize each flange which comprises the assembly under consideration.

L-3231 Classification of a Class FF Flange Assembly

Since the flanges comprising an assembly are in contact outside the bolt circle, the behavior of one flange is influenced by the stiffness of the other. For the purpose of computation it is helpful to classify an assembly consisting of different types of flanges according to the way the flanges influence the deformation of the assembly.

Page 345

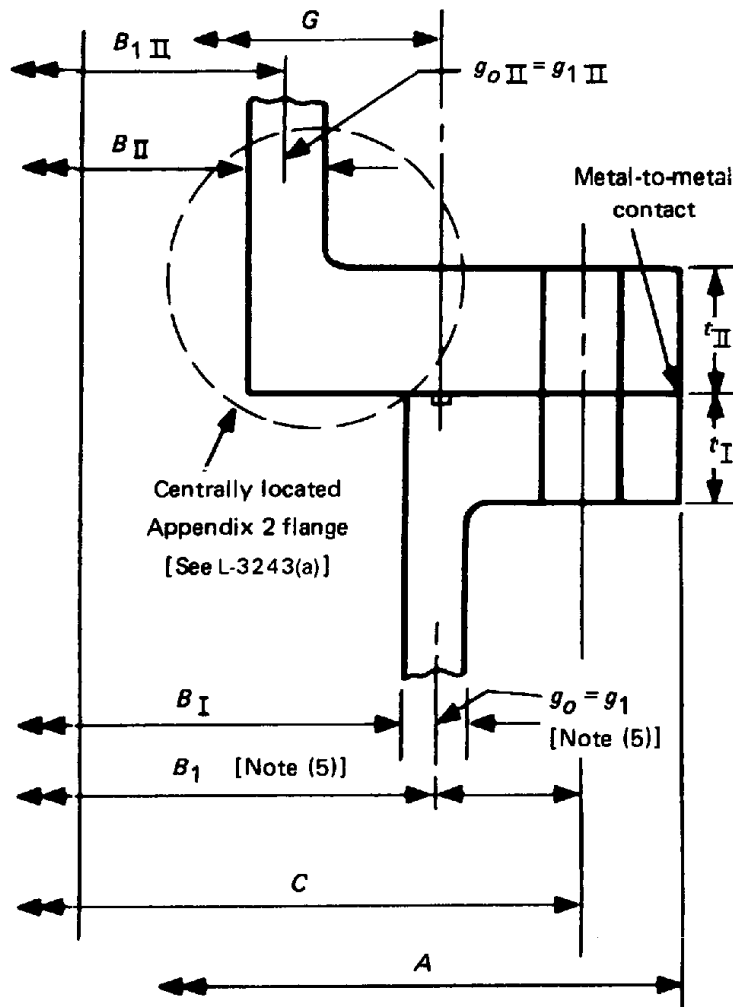


NOTES:

(1) Category 1 flanges illustrated in sketch (a) and (b); Category 2 flanges illustrated in sketch (c).

(2) Permitted weld details are in accordance with Figs. XI-3120-1 and NC-4243-2, ND-4243-1 or NE-4243-1, as applicable.

**FIG. L-3230-1 GROUP 1 FLANGE ASSEMBLY
(IDENTICAL FLANGE PAIRS)**



NOTES:

- (1) Category 1 flanges illustrated. Categories II and III permitted.
- (2) For purposes of analysis of Flange II by method in L-3243(a), assume $A_{II} = G_{II} = C_{II} = B_1$
- (3) $B_{II} > C/2$
- (4) Permitted weld details are in accordance with Figs. XI-3120-1 and NC-4243-2, ND-4243-1 or NE-4243-2, as applicable.
- (5) See L-3192 and L-3193.

FIG. L-3230-2 GROUP 2 FLANGE ASSEMBLY

FIG. L-3230-2 GROUP 2 FLANGE ASSEMBLY

L-3231.1 Group 1 Assembly.²

A pair of flanges which are bolted together and which are nominally identical with respect to shape, dimensions, physical properties, and allowable stresses³ except that one flange of the pair may contain a gasket groove. (A Group I assembly is also referred to as an identical flange pair.) Figure L-3230-1 illustrates configuration of a Group I assembly.

L-3231.2 Group 2 Assembly.

Any assemblage which does not fit the description of Group 1 where, in the case of reducers, the inside diameter of the reducing flange exceeds one-half of the bolt circle diameter. Figure L-3230-2 illustrates configuration of a Group 2 assembly.

L-3231.3 Group 3 Assembly.

Any assemblage consisting of a reducer or a flat circular head without an opening or with a central, reinforced opening provided the diameter of the opening in the reducing flange or flat cover is less than one-half of the bolt circle diameter. In the analysis the reducing flange is considered to be the equivalent of a flat circular head without an opening. Figure L-3230-3 illustrates configuration of a Group 3 assembly.

L-3232 Categorization of a Class FF Flange

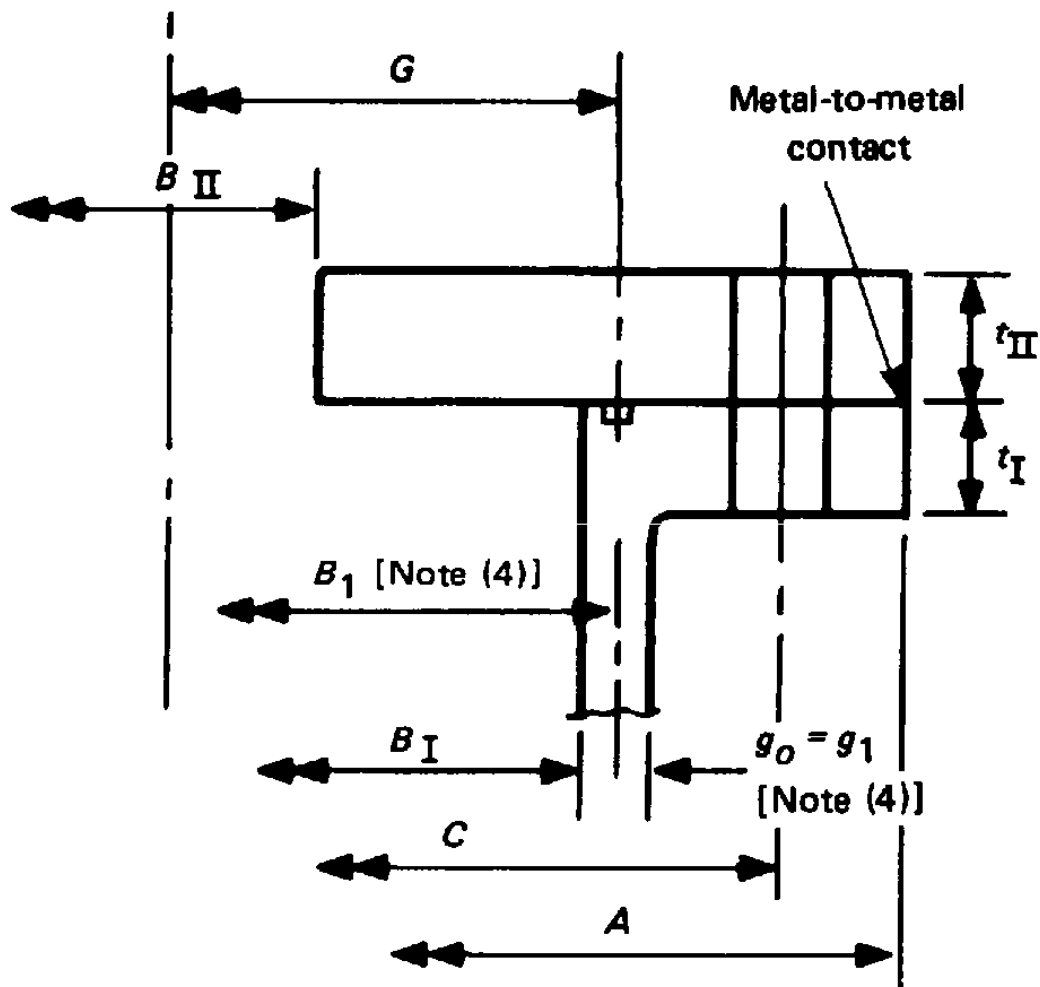
In addition to classifying an assembly, the individual flanges (except the reducing flange or flat circular head) must be categorized for the purpose of computation as loose type, integral type, or optional type. This can be done using XI-3120; Fig. XI-3120-1 is suitable by considering the flanges as flat faced (as a result of removing the raised gasket surface by machining and recessing the gasket in a groove) and by adding a flange-to-flange contact force H_C at some distance h_c outside the bolt circle. Since certain design options exist depending upon the category of the flange, the following categories include both the type of flange and the various design options.

(a) *Category 1 Flange.* An integral flange or an optional flange calculated as an integral flange.

(b) *Category 2 Flange.* A loose type flange with a hub where credit is taken for the strengthening effect of the hub.

² A Class FF flange bolted to a rigid foundation may be analyzed as a Group 1 assembly by substituting 2 for 1 in Eq. (18) of L-3242.

³ Where the flanges are identical dimensionally and have the same elastic modulus E , but have different allowable stresses S_f , the assembly may be analyzed as a Group I assembly provided the calculated stresses are evaluated against the lower allowable stress.



NOTES:

- (1) Category I flange illustrated. Categories II and III permitted.
- (2) $B_{II} \leq C/2$
- (3) Permitted weld details are in accordance with Figs. XI-3120 and NC-3225-3.
- (4) See L-3192 and L-3193.

FIG. L-3230-3 GROUP 3 FLANGE ASSEMBLY

FIG. L-3230-3 GROUP 3 FLANGE ASSEMBLY

(c) *Category 3 Flange*. A loose type flange with a hub where no credit is taken for the strengthening effect of the hub, a loose type flange without a hub, or an optional-type flange calculated as a loose type without a hub. Substitute B for B_1 in the applicable equation for this category of flange.

L-3240 FLANGE ANALYSIS

L-3241 General Method

(a) In order to calculate the stresses in the flanges and bolts of a flanged assembly, classify the assemblage in accordance with L-3231 and then categorize each flange per L-3232.

(b) The method of analyzing various groups and categories of flanges is basically the same. Although many equations appear to be identical, subtle differences do exist and care must be exercised in the analysis. To minimize the need for numerous footnotes and repetitive statements throughout the text, the formulas to be used in analyzing the various groups of assemblies and categories of flanges are given in Table L-3240-1.

Page 347

TABLE L-3240-1
SUMMARY OF APPLICABLE FORMULAS FOR
DIFFERENT GROUPS OF ASSEMBLIES AND
DIFFERENT CATEGORIES OF FLANGES

Group	Category [Note (1)]	Applicable Formulas
1	1	(5a), (13)–(19), (20a), (21a), (22a)
1	2	(5b), (13)–(19), (20b), (21b), (22b)
1	3	(5c), (13)–(19), (20c), (21c), (22c)
2	All	See L-3243
3	1	(1)–(4), (6a), (23)–(37), (38a), (39a), (40a), (41)–(44)
3	2	(1)–(4), (6a), (23)–(37), (38b), (39b), (40b), (41)–(44)
3	3	(1)–(4), (6a), (23)–(37), (38c), (39c), (40c), (41)–(44)

NOTE:

(1) Of the nonreducing flange in a Group 2 or Group 3 assembly.

TABLE L-3240-1 SUMMARY OF APPLICABLE FORMULAS FOR DIFFERENT GROUPS OF ASSEMBLIES AND DIFFERENT CATEGORIES OF FLANGES

In general, the terms should be calculated in the same order as they are listed in the table. It is important to refer to the table before starting an analysis since only a limited number of the equations contained in this Article are used in the design of a particular pair of flanges. Some of the numbered equations appear in L-3191 along with general purpose, unnumbered expressions.

(c) Subscripts I and II refer to the nonreducing flange and the reducer (or flat circular head), respectively, of a Group 3 assembly and of a Group 2 assembly designed using the method of L-3243(a).

L-3242 Analysis of a Group 1 Assembly

The following equations are used for the analysis of Category 1, 2, and 3 flanges of a Group 1 assembly in accordance with Table L-3240-1.

Flange Moment Due to Flange-Hub Interaction

$$M_S = - \frac{J_P F' M_P}{t^3 + J_S F'} \quad (13)$$

(13)

Slope of Flange at Inside Diameter Times E

$$E\theta_B = \frac{5.46}{\pi t^3} (J_S M_S + J_P M_P) \quad (14)$$

(14)

Contact Force Between Flanges at h_C

$$(15) H_c = (M_p + M_s)/h_C$$

Bolt Load at Operating Conditions

$$(16) W_{ml} = H + H_G + H_C$$

Operating Bolt Stress

$$(17) \sigma_b = W_{ml}/A_b$$

Design Prestress in Bolts

$$S_i = \sigma_b - \frac{1.159h_C^2 (M_P + M_S)}{at^3 lr_E B_1} \quad (18)$$

(18)

Radial Flange Stress at Bolt Circle

$$S_R = \frac{6(M_P + M_S)}{t^2 (\pi C - nD)} \quad (19)$$

(19)

Radial Flange Stress at Inside Diameter

$$S_R = - \left(\frac{2Ft}{h_0 + Ft} + 6 \right) \frac{M_S}{\pi B_1 t^2} \quad (20a)$$

$$S_R = - \left(\frac{2F_L t}{h_0 + F_L t} + 6 \right) \frac{M_S}{\pi B_1 t^2} \quad (20b)$$

$$S_R = 0 \quad (20c)$$

(20a-20c)

Tangential Flange Stress at Inside Diameter

$$S_T = \frac{tE\theta_B}{B_1} + \left(\frac{2FtZ}{h_0 + Ft} - 1.8 \right) \frac{M_S}{\pi B_1 t^2} \quad (21a)$$

$$S_T = \frac{tE\theta_B}{B_1} + \left(\frac{2F_L tZ}{h_0 + F_L t} - 1.8 \right) \frac{M_S}{\pi B_1 t^2} \quad (21b)$$

(21a-21b)

Page 348

$$S_T = \frac{tE\theta_B}{B_1} \quad (21c)$$

(21c)

Longitudinal Hub Stress

$$S_H = \frac{h_0 E \theta_B f}{0.91 (g_1 / g_0)^2 B_1 V} \quad (22a)$$

$$S_H = \frac{h_0 E \theta_B}{0.91 (g_1 / g_0)^2 B_1 V_L} \quad (22b)$$

$$S_H = 0 \quad (22c)$$

(22a-22c)

L-3243 Analysis of a Group 2 Assembly

(a) The assembly may be analyzed using a variation of the analysis for a Group 3 assembly (L-3244) that accounts for the interaction of nonidentical flanges and the stiffening effect of an integral nozzle or hub centrally located in the reducing flange.

(1) The central nozzle of Flange II with diameter B_{II} shall be assumed for analysis purposes as an Appendix XI flange with outside diameter A , bolt circle C , and gasket circle G all equal to B_1 of Flange I. See Fig. L-3230-2.

(2) In addition it is necessary to categorize the centrally located Appendix XI flange (nozzle plus the associated over plate to diameter B_1) as a Category 1, 2, or 3 flange in accordance with L-3232.

(3) The moment due to pressure shall be designated M_p' where

$$M_p' = H_D' h_D' + H_T' h_T'$$

$$H_D' = 0.785 B_{II}^2 P$$

$$H_T' = 0.785 P (B_I^2 - B_{II}^2)$$

For Category 1, 2, or 3 flanges [see (a)(2) above],

$$h_T' = \frac{B_I - B_{II}}{4}$$

For Category 1 or 2 flanges [see (a)(2) above],

$$h_D' = \frac{B_I - B_{II} - g_{I II}}{2}$$

For Category 3 flanges [see (a)(2) above],

$$h_D' = \frac{B_I - B_{II}}{2}$$

(4) The rules in L-3244 and the summary of Table L-3240-1 for the analysis of a Group 3 assembly apply to the analysis of a Group 2 assembly with the following additions and substitutions:

C_5 and C_6 and all the symbols in equations in (a) and (b) below pertain only to the centrally located Appendix XI flange [nozzle plus the associated cover of thickness t_{II} to diameter B_I defined in (1) above]. All terms in equations in (c) and (d) below, except C_5 and C_6 , refer to the nonreducing flange (Flange I). C_1 and C_2 of equations in (c) and (d) below replace C_1 and C_2 of Eqs. (1) and (2) in L-3191.

(a) Let

$$C_5 = M_P', \text{ in.-lb}$$

(b) Let

$$C_6 = \frac{0.829}{\log (B_I / B_{II})}$$

for Category 3 flanges.⁴ Let

$$C_6 = \frac{0.91 t_{II}^3 V}{L h_0 g_0^2}$$

for Category 1 or 2 flanges.⁴

(c) Let

$$C_1 = [1 - 2.095 J_S \log (A/B_1)] \div [-C_6 - 1.738 J_S]$$

(d) Let

⁴ See L-3243(a)(2).

Page 349

$$C_2 = (1.738 J_P M_P - C_5 C_6) \div (-C_6 - 1.738 J_S)$$

(e) Replace Eq. (32) with:

$$E_{II} \theta_{BII} = \frac{5.46}{\pi t_{II}^3} (J_S M_{bII} + J_P M_P) + (E_{II}^* \theta_{rbII}) / t_{II}^3$$

(f) Delete Eq. (44). Subparagraphs L-3243(a)(1), (a)(2), and (a)(3) above apply only for calculating $C_5(M_P')$ and C_6 and subsequently when using (a)(5) below for calculating the stresses in and adjacent to the nozzle in Flange II.

(5) Stresses in the centrally located nozzle of Flange II shall be calculated in accordance with the following equations after M_{SI} has been found using (a)(4) above. All terms, such as e , Y , and Z , apply to the centrally located Appendix XI flange as defined in (a)(1) and (a)(2) above.

For Category 1 or 2 flanges [(a)(2) above]:

Longitudinal Hub Stress

$$S_{H\Pi} = \frac{f(M_p' - M_{S\Pi})}{Lg_{1\Pi}^2 B_{\Pi}}$$

Radial Flange Stress Adjacent to Central Nozzle

$$S_{R\Pi} = \frac{(1.33t_{\Pi}e + 1)(M_p' - M_{S\Pi})}{Lt_{\Pi}^2 B_{\Pi}}$$

Tangential Flange Stress Adjacent to Central Nozzle

$$S_{T\Pi} = \frac{Y(M_p' - M_{S\Pi})}{t_{\Pi}^2 B_{\Pi}} - ZS_{R\Pi}$$

For Category 3 Flanges [(a)(2) above]:

Tangential Flange Stress Adjacent to Central Nozzle

$$S_{TII} = \frac{Y(M_p' - M_{SII})}{t_{II}^2 B_{II}}$$

Radial and Longitudinal Hub Stress

$$S_{RII} = 0$$

$$S_{HII} = 0$$

(6) The stresses in Flange I and the remaining stresses in Flange II shall be calculated in accordance with L-3244 except as modified by L-3243(a)(4).

(b) As an alternative to the method in (a) above and at the option of the designer, the assembly may be analyzed as if it is one flange of an identical pair in a Group 1 assembly using the procedure in L-3242. All stresses shall satisfy L-3250. The same value of h_C shall be used in both calculations and the strain length l of the bolts shall be based on the thickness of the flange under consideration. This method is more conservative and more bolting may be required than the method in (a) above.

(c) The central nozzle or opening in Flange II of a Group 2 assembly determined by the rules in (a) or (b) above meets the general requirements of this Division and of this Article. The rules for determining thickness and reinforcing requirements of NC-3225, NC-3325, ND-3325, and NE-3325, and NC-3233, NC-3333, ND-3333, and NE-3333, respectively, are not applicable.

L-3244 Analysis of a Group 3 Assembly

(a) The following equations are used for the analysis of Category 1, 2, and 3 nonreducing flanges and the reducer (or flat circular head) of a Group 3 assembly:

Rigid Body Rotation of Flanges Times E^*

$$E_I^* \theta_{rbI} = \frac{X(C_4 - C_2)}{1.206 \log (A/B_1) - XC_3 - (1 - X)C_1} \quad (23)$$

$$E_{II}^* \theta_{rbII} = - E_I^* \theta_{rbI} (E_{II}^* / E_I^*) \quad (24)$$

(23-24)

Total Flange Moment at Diameter B_1

$$(25) M_{SI} = C_3(E_I^* \theta_{rbI}) + C_4$$

$$(26) M_{SII} = C_1(E_{II}^* \theta_{rbII}) + C_2$$

Unbalanced Flange Moment at Diameter B_1

$$(27) M_{Id} = 1.206 E_I^* \theta_{rbI} \log (A/B_1)$$

$$(28) M_{IdII} = 1.206 E_{II}^* \theta_{rbII} \log (A/B_1)$$

Balanced Flange Moment at Diameter B_1

$$(29) M_{bI} = M_{SI} - M_{Id}$$

$$(30) M_{bII} = M_{SII} - M_{IdII}$$

Slope of Flange at Diameter B_1 Times E

$$E_I \theta_{BI} = \frac{5.46}{\pi t_I^3} (J_S M_{bI} + J_P M_P) + E_I^* \theta_{rbI} / t_I^3 \quad (31)$$

$$E_{II} \theta_{BII} = \frac{-1.337(M_{SII} - \pi P B_1^3 / 32)}{t_{II}^3} \quad (32)$$

(31-32)

Contact Force Between Flanges at h_C

$$(33) H_C = (M_P + M_{bI}) / h_C$$

Bolt Load at Operating Conditions

$$(34) W_{mI} = H + H_G + H_C$$

Operating Bolt Stress

$$(35) \sigma_b = W_{mI} / A_b$$

Design Prestress in Bolts

$$S_i = \sigma_b - \frac{1.159 h_C^2 (M_P + M_{bI})}{2(1 - X) a t_I^3 l r_{EI} B_I} \quad (36)$$

(36)

Radial Stress in Flange I at Bolt Circle

$$S_{RI} = \frac{6(M_P + M_{SI})}{t_I^2(\pi C - nD)} \quad (37)$$

(37)

Radial Stress in Flange I at Inside Diameter

$$S_{RI} = - \left(\frac{2Ft_I}{h_0 + Ft_I} + 6 \right) \frac{M_{SI}}{\pi B_1 t_I^2} \quad (38a)$$

$$S_{RI} = - \left(\frac{2F_L t_I}{h_0 + F_L t_I} + 6 \right) \frac{M_{SI}}{\pi B_1 t_I^2} \quad (38b)$$

$$S_{RI} = 0 \quad (38c)$$

(38a-38c)

Tangential Stress in Flange I at Inside Diameter

$$S_{TI} = \frac{t_I E_I \theta_{BI}}{B_I} + \left(\frac{2F t_I Z}{h_0 + F t_I} - 1.8 \right) \frac{M_{SI}}{\pi B_I t_I^2} \quad (39a)$$

$$S_{TI} = \frac{t_I E_I \theta_{BI}}{B_I} + \left(\frac{2F_L t_I Z}{h_0 + F_L t_I} - 1.8 \right) \frac{M_{SI}}{\pi B_I t_I^2} \quad (39b)$$

(39a-39b)

$$S_{TI} = \frac{t_I E_I \theta_{BI}}{B_I} \quad (39c)$$

(39c)

Longitudinal Hub Stress in Flange I

$$S_{HI} = \frac{h_0 E_I \theta_{BI} f}{0.91 (g_1 / g_0)^2 B_1 V} \quad (40a)$$

$$S_{HI} = \frac{h_0 E_I \theta_{BI}}{0.91 (g_1 / g_0)^2 B_1 V_L} \quad (40b)$$

$$S_{HI} = 0 \quad (40c)$$

(40a-40c)

Radial Stress in Flange II at Bolt Circle

$$S_{R\Pi} = \frac{6(M_P + M_{S\Pi})}{t_{II}^2 (\pi C - nD)} \quad (41)$$

(41)

Radial Stress in Flange II at Diameter B_1

$$S_{R\Pi} = \frac{6M_{S\Pi}}{\pi B_I t_{\Pi}^2} \quad (42)$$

(42)

Tangential Stress in Flange II at Diameter B_I

$$S_{T\Pi} = \frac{t_{\Pi} E_{\Pi} \theta_{B\Pi}}{B_I} - \frac{1.8M_{S\Pi}}{\pi B_I t_{\Pi}^2} \quad (43)$$

(43)

Radial and Tangential Stress at Center of Flange II

$$S_{R\Pi} = S_{T\Pi} = \frac{0.3094PB_I^2}{t_{\Pi}^2} - \frac{6M_{S\Pi}}{\pi B_I t_{\Pi}^2} \quad (44)$$

(44)

(b) The thickness of Flange II of a Group 3 assembly determined by the above rules shall be used in lieu of the thickness that is determined by NC-3225, NC-3325, ND-3325, and NE-3325. However, any centrally located opening in Flange II shall be reinforced to meet the rules of Appendix XIX.

⁵ The symbols for the various stresses in the case of a Group 3 assembly also carry the subscript I or II. For example, S_{II} represents the longitudinal hub stress in Flange I of the Group 3 assembly.

L-3250 ALLOWABLE FLANGE DESIGN STRESSES

The stresses calculated by the above equations, whether tensile or compressive (-), shall not exceed the following values

- (a) operating bolt stress σ_b not greater than S_b for the design value of S_j ;
- (b) longitudinal hub stress S_H not greater than S_f for Category 1 and 2 cast iron flanges except as otherwise limited by (1) and (2) below and not greater than $1.5 S_f$ for materials other than cast iron:
 - (1) longitudinal hub stress S_H not greater than the smaller of $1.5 S_f$ or $1.5 S_n$ for Category 1 flanges where the pipe or shell constitutes the hub;
 - (2) longitudinal hub stress S_H not greater than the smaller of $1.5 S_f$ or $2.5 S_n$ for integral flanges (Category 1) similar to the Appendix XI flanges shown as Fig. XI-3120-1, sketches (6), (6a), and (6b).
- (c) radial stress S_R not greater than S_j ;
- (d) tangential stress S_T not greater than S_j ;
- (e) also,

$$(S_H + S_R)/2$$

not greater than S_f and

$$(S_H + S_T)/2$$

not greater than S_j ;

- (f) S_R and S_T at the center of the reducing flange in a Group 3 assembly [see Eq. (44)] shall not exceed S_f

L-3260 PRESTRESSING THE BOLTS

The design rules of this Article provide for tangential contact between the flanges at h_{Cmax} or some lesser value h_C beyond the bolt circle. As in the case of Appendix XI flanges, a Class FF flange must be designed so that the calculated value of the operating bolt stress σ_b does not exceed S_b . Also, as in the case of Appendix XI flanges, ordinary wrenching techniques without verification of the actual initial bolt stress (assembly stress) is considered to meet all practical needs with control and verification reserved for special applications. For the purposes of this Article, the use of

$$h_C < h_{Cmax}$$

to optimize stresses is considered to be a special application unless it is also shown that all of the requirements of this Article are also satisfied when

$$h_C = h_{Cmax}$$

L-3270 REFERENCES

Additional guidance on the design of flat faced metal-to-metal contact flanges can be found in the following references:

- (a) Schneider, R. W., and Waters, E. O., The Background of ASME Code Case 1828: A Simplified Model of Analyzing Part B Flanges, *Journal of Pressure Vessel Technology*, ASME, Vol. 100, No. 2, May 1978, pp. 215-219;
- (b) Schneider, R. W., and Waters, E. O., The Application of ASME Code Case 1828, *Journal of Pressure Vessel Technology*, ASME, Vol. 101, No. 1, February 1979, pp. 87-94.

It should be noted that the rules in Appendix L were formerly contained in Code Case 1828, A Simplified Method for Analyzing Flat Face Flanges with Metal-to-Metal Contact Outside the Bolt Circle/ Section VIII, Division 1.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP M

APPENDIX M RECOMMENDATIONS FOR CONTROL OF

WELDING, POSTWELD HEAT TREATMENT, AND NONDESTRUCTIVE EXAMINATION OF WELDS

Page 353

ARTICLE M-1000 RECOMMENDATIONS FOR CONTROL OF WELDING, POSTWELD HEAT TREATMENT, AND NONDESTRUCTIVE EXAMINATION OF WELDS

M-1100 INTRODUCTION

M-1110 SCOPE

This Appendix provides recommendations for control of welding, postweld heat treatment, and nondestructive examination of welds. The purpose of this Appendix is to identify the areas that should be controlled. It should not be construed that this Appendix describes the only controls that are necessary. Other controls may be necessary depending on the specific application.

M-1120 APPLICABILITY

The recommendations contained in this Appendix may be included in procedures, instructions, specifications, process sheets, shop travelers, checklists, drawings, or other documents that are part of the Quality Assurance or Control Program.

M-1200 WELDING PROCEDURE SPECIFICATIONS

M-1210 RESPONSIBILITY FOR PREPARATION

The responsibility for preparing and approving the Welding Procedure Specification, and the method of handling revisions should be defined in the Quality Assurance or Control Program.

M-1211 Content Requirements

Section IX identifies the essential and also the nonessential variables required to be included in a Welding Procedure Specification. Supplementary information that should be provided, as applicable, is listed in (a) through (k) below. This information may be provided in other specifications, drawings, or documents that are referenced in or used in conjunction with the Welding Procedure Specification, as described in M-1213:

- (a) weld joint design, including fit-up;
- (b) method of weld joint preparation;
- (c) cleaning requirements prior to welding;
- (d) purge requirements in addition to QW-408.5 of Section IX, such as oxygen content, volume changes, or time of purging prior to welding, and minimum thickness of deposited metal prior to removal or purge;
- (e) cleaning and examination requirements between weld passes;
- (f) instructions for measuring preheat and interpass temperatures;
- (g) preheat temperature control;
- (h) interpass temperature control;
- (i) temperature maintenance and control after welding;
- (j) welding current and voltage control including method and frequency of measurement;
- (k) welding technique including, as applicable, method of starts and stops, method of arc initiation, and weave or stringer bead.

M-1212 Format of Welding Procedure Specification

Welding Procedure Specifications may consist of a single document. Alternatively, there may be a general Welding Procedure Specification that applies to and is referenced by a number of detailed Welding Procedure Specifications. The general Welding Procedure Specification may also reference other specifications to define other requirements such as welding filler materials, purging, and postweld heat treatment.

Page 356

M-1213 Application of Welding Procedures

Selection of qualified welding procedures should be based on the essential variables applicable for the production weld. Any additional requirements of the Design Specification, such as component classification, applicable Code edition and addenda, fracture toughness requirements, and manufacturing considerations, should be evaluated in the selection of welding procedures for specific weld joints.

M-1300 WELDING PERFORMANCE QUALIFICATION AND ASSIGNMENT

It is necessary that a system be established to ensure that properly qualified welders and welding operators are used for specific weld joints. The system should include confirmation that the welder and welding operator qualifications are up to date and valid for the application.

M-1400 CONTROL OF WELDING

A system should be established and maintained that is capable of:

- (a) maintaining the identification of acceptable electrodes, filler metal, consumable inserts, and fluxes until consumed; and
- (b) minimizing moisture absorption of coated electrodes and of fluxes.

The system should include requirements for receiving inspection, storage, handling, use of holding ovens, control of exposure time at ambient temperature, and reconditioning.

M-1500 NONDESTRUCTIVE EXAMINATION OF WELDS

M-1510 RESPONSIBILITY FOR PREPARATION

Nondestructive examination procedures should be prepared in accordance with the requirements of the particular Article of this Section used in fabrication, including acceptance standards. The responsibility for preparation and approval of procedures and the method of handling revisions should be defined in the Quality Assurance or Control Program.

M-1520 VERIFICATION OF APPLICABILITY

Prior to assignment of nondestructive examination procedures to specific weld joints, a review should be made of the Code classification of the component and the Code edition and addenda to ensure that the type of examination, procedure and acceptance standards, frequency, and time of examination are all correct for the application.

M-1600 POSTWELD HEAT TREATMENT

A system should be established and maintained that is capable of meeting PWHT requirements for heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control. The location of thermocouples, furnace loading to prevent direct impingement of flame on parts or components, and the furnace atmosphere should be considered in establishing procedures.

M-1700 EXAMINATION AND DIMENSIONAL INSPECTION

Examinations and dimensional inspections should be made to provide assurance that the requirements of this Section are met and that welding conforms with the procedures, specifications, and drawings. As applicable, consideration should be given to (a) and (b) below.

- (a) Before welding:
 - (1) material identification
 - (2) weld preparation surfaces
 - (3) cleanliness
 - (4) root opening
 - (5) offset
 - (6) alignment
 - (7) socket engagement on socket welds
- (b) After welding:
 - (1) cracks or linear indications
 - (2) rounded indications
 - (3) overlap
 - (4) undercut
 - (5) lack of required penetration
 - (6) surface finish
 - (7) weld profile

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP N

APPENDIX N DYNAMIC ANALYSIS METHODS

Page 357

ARTICLE N-1000 DYNAMIC ANALYSIS METHODS

N-1100 INTRODUCTION AND SCOPE

Section III does not require dynamic analysis. However, the design of nuclear components requires consideration of the seismic and other dynamic inputs which are defined in the Design Specifications for the component. Component design may be based on the use of static forces resulting from equivalent earthquake acceleration acting at the centers of gravity of the extended masses, or a dynamic system analysis may be used to show how seismic loading is transmitted from the defined ground motions to all parts of the buildings, structures, equipment, and components. N-1100 through N-1200 of this Appendix are presented to illustrate one or more acceptable steps for seismic dynamic analysis. It is not intended that these steps are the only acceptable ones, since the seismic dynamic analysis involves a series of steps, and some of these steps have acceptable alternative methods. Dynamic analysis in general uses techniques which are illustrated in seismic analysis. Those technical areas of dynamic analysis used in nuclear component design which are not specifically illustrated by seismic analysis are included in N-1300 through N-1700.

N-1110 DEFINITIONS AND NOTATIONS

(a) The *magnitude* of an earthquake is a measure of the size of an earthquake and is related to the energy released in the form of seismic waves. Magnitude means the numerical value on a Richter scale. The intensity of an earthquake is a measure of its effects on man, on man-built structures, and on the earth's surface at a particular location. Intensity is measured by the numerical value of the modified Mercalli scale.

(b) The *Safe Shutdown Earthquake* (SSE) is that earthquake which is based upon an evaluation of the maximum earthquake potential considering the regional and local geology and seismology and specific characteristics of local subsurface material. It is that earthquake which produces the maximum vibratory ground motion for which those structures, systems, and components important to safety are designed to remain functional.

(c) The *Operating Basis Earthquake* (OBE) is that earthquake which, considering the regional and local geology and seismology and specific characteristics of local subsurface material, could reasonably be expected to affect the plant site during the operating life of the plant.

(d) The *response spectrum* is defined as a plot of the maximum response (acceleration, velocity, or displacement) of a family of idealized linear single-degree-of-freedom damped oscillators as a function of natural frequencies (or periods) of the oscillators to a specified vibratory motion input at their supports.

(e) The *design ground response spectrum* is a smooth response spectrum obtained by analyzing, evaluating, and statistically combining a number of individual response spectra derived from the records of significant past earthquakes.

(f) The *maximum (peak) ground acceleration* (for a given site) is defined as that value of the acceleration which corresponds to zero period in the design response spectra for that site. At zero period the design response spectra acceleration is identical for all damping values and is equal to the maximum (peak) ground acceleration specified for that site.

(g) *Normal mode - time history methods* use the normal mode theory and a time history of the input motion. When normal mode theory is used, the maximum response is determined by obtaining the combined response of all individual modes at a particular time.

(h) *Direct integration - time history methods* use numerical step-by-step integration of the equations of motion of a time history of the input motion.

(i) *Equivalent statical methods* means the use of a statical loading coefficient which gives a definite upper limit to the response.

(j) *Coupled structures and plant equipment* include those structures and plant equipment which, because of their mass and stiffness properties, significantly

Page 362

influence the dynamic response of each other and must be considered together in a dynamic analysis.

(k) *Uncoupled structures and plant equipment* include those structures and plant equipment which, because of their mass and stiffness properties, do not significantly influence the dynamic response of each other and can be considered in separate dynamic analysis.

(l) *Seismic systems* are all those structures for which loads induced by earthquake should be considered.

(m) *Rigid range* is used to describe those frequencies of structures, systems, or components whose natural frequencies are greater than some value at which dynamic response acceleration is essentially the same as the impact acceleration. For example, a response to the seismic design response spectra of Figs. N-1211(a)-1 and N-1211(b)-1 has unity amplification of acceleration above 33 Hz.

(n) *Spectrum consistent time history* is a time history which is artificially generated to essentially envelop a given design response spectrum.

N-1200 SEISMIC ANALYSIS

N-1210 EARTHQUAKE DESCRIPTION

N-1211 Ground Response Spectrum

(a) The *horizontal* component ground design response spectra of the Safe Shutdown Earthquake (SSE) or the Operating Basis Earthquake (OBE) on sites underlain by rock or by soil may be linearly scaled from Fig. N-1211(a)-1 in proportion to the maximum horizontal ground acceleration specified for the earthquake chosen. [Fig. N-1211(a)-1 corresponds to a

to the maximum horizontal ground acceleration specified for the earthquake chosen. [Fig. N-1211(a)-1 corresponds to a maximum horizontal ground acceleration of 1.0 g and accompanying displacement of 36 in. (914 mm).] The applicable multiplication factors and control points are given in Table N-1211(a)-1. For damping ratios not included in Fig. N-1211(a)-1 or Table N-1211(a)-1, a linear interpolation may be used.

(b) The *vertical* component ground design response spectra of the SSE or the OBE on sites underlain by rock or by soil may be linearly scaled from Fig. N-1211(b)-1 in proportion to the maximum horizontal ground acceleration specified for the earthquake chosen. [Fig. N-1211(b)-1 is based on a maximum horizontal ground acceleration of 1.0 g and accompanying displacement of 36 in. (914 mm).] The applicable multiplication factors and control points are given in Table N-1211(b)-1. For damping ratios not included in Fig. N-1211(b)-1 or Table N-1211(b)-1, a linear interpolation may be used.

N-1212 Time History

N-1212.1 Frequency Content of Time History.

The design ground response spectra used in the earthquake resistance design, such as those illustrated in Figs. N-1211(a)-1 and N-1211(b)-1 for the design of nuclear power plant facilities, are generally based on multi-component time history motions from a number of major earthquakes. There are no single recorded earthquake ground motions which have such uniform frequency distribution. However, it is often necessary to generate a spectrum-consistent time history motion whose response spectrum matches the design response spectrum for a given damping value. The purpose of developing such a spectrum-consistent time history motion is to provide the analyst with an acceptable basis for generating floor (in structure) response spectra and performing time history analysis of systems and components. Several acceptable approaches are presented below.

(a) *Modified Earthquake Records.* An acceptable approach is to modify the components of past earthquake records using spectral raising and suppressing techniques (Refs. 71 and 72).

Spectral raising is accomplished by adding to the original time history a harmonic function at the frequency of interest with a phase angle such that the response spectral value at this frequency will be increased to a desired amount; the time when the maximum vibratory motion occurred will be the same. In this way, the spectral characteristics of the modified time history will be similar to the original earthquake records. Consequently, statistical characteristics of past time history motions can be maintained as discussed in N-1213.

When the time history response spectrum is higher than the design response spectrum at a frequency, spectral suppressing can be carried out by passing the time history through a linearly damped oscillator connected in series with a second damper. This damping arrangement will reduce the response spectral value, locally at the natural frequency of the oscillator, to the desired amount.

This usually requires an iterative procedure. A repetitious application of the raising and suppressing techniques may be used to arrive at a time history motion whose response spectrum is sufficiently close to the design spectrum.

(b) *Synthesized Time History Motions.* Several methods may be used to generate time history motions without the direct use of an actual earthquake record. One method uses power spectral density functions to generate the time history motions. Power spectral density

(PSD) functions may be calculated for the strong motion portion of actual earthquake records by assuming that the strong motion portion is stationary and Gaussian. This (PSD) function may then be used to produce a sample of a pseudo-earthquake ensemble by filtering a white noise record with unit power density through a linear damped system (Ref. 73).

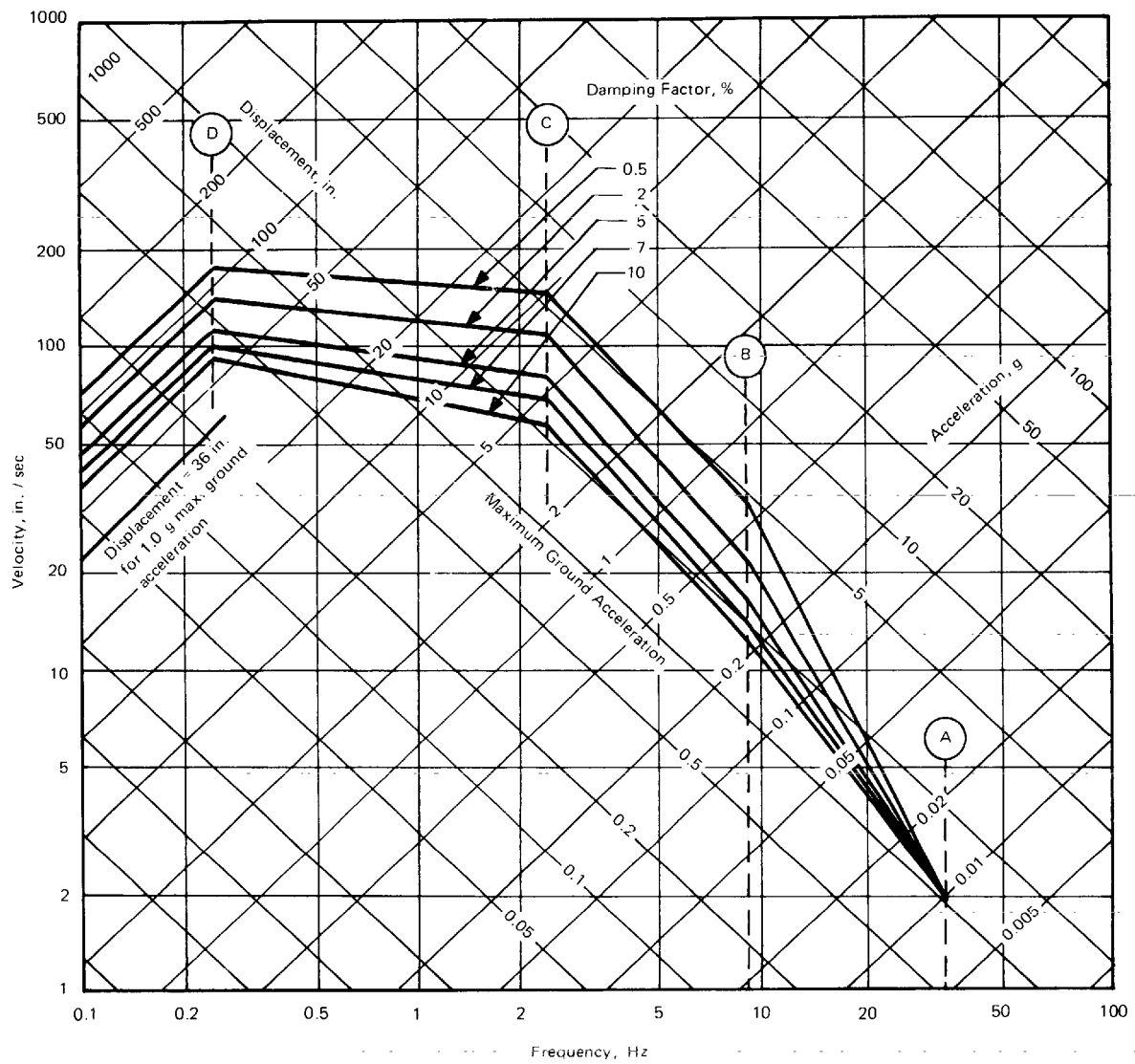


FIG. N-1211(a)-1 HORIZONTAL DESIGN RESPONSE SPECTRA SCALED TO 1 g
HORIZONTAL GROUND ACCELERATION

FIG. N-1211(a)-1 HORIZONTAL DESIGN RESPONSE SPECTRA SCALED TO 1 g HORIZONTAL GROUND
ACCELERATION

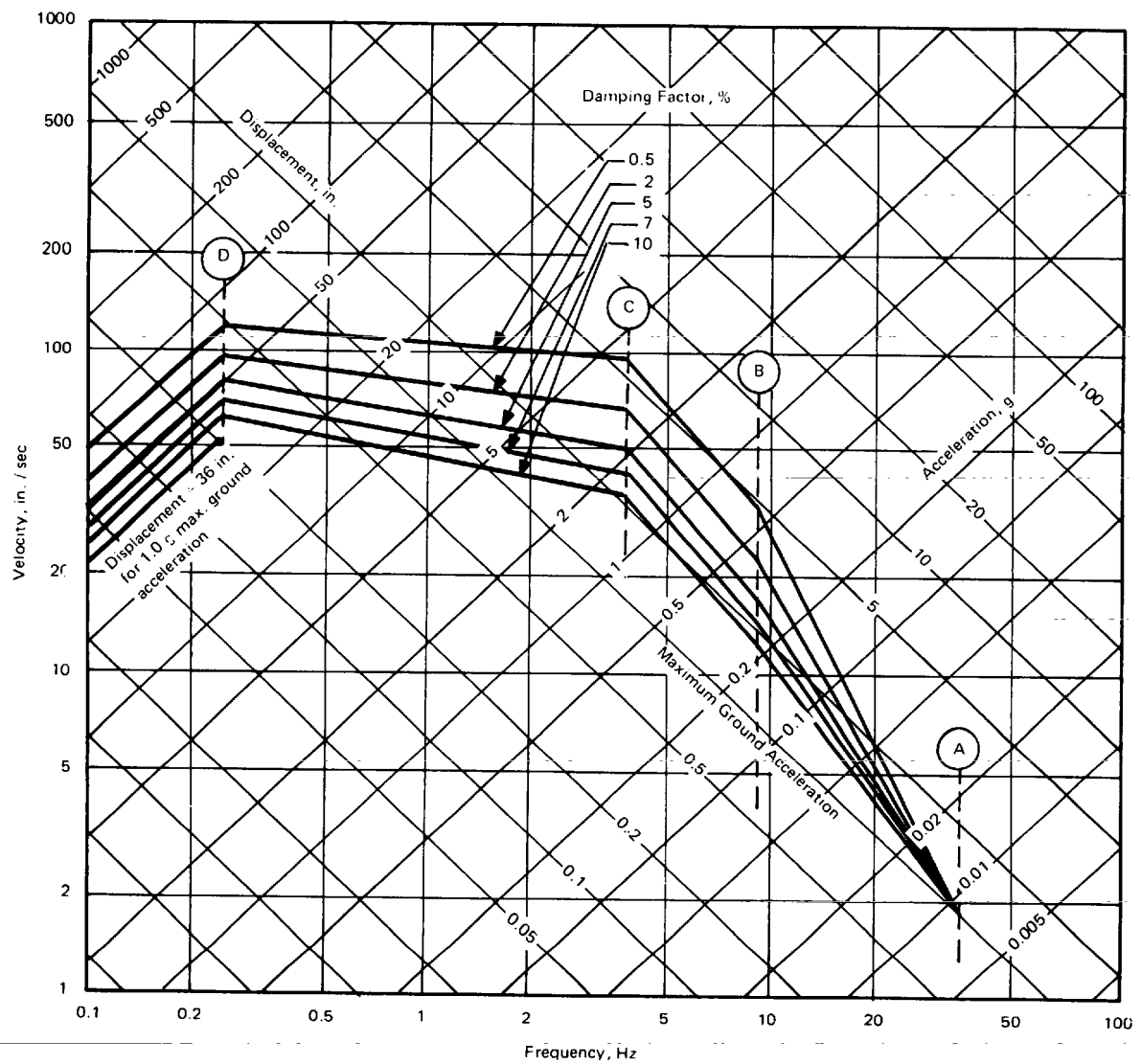


FIG. N-1211(b)-1 VERTICAL DESIGN RESPONSE SPECTRA SCALED TO 1 g HORIZONTAL GROUND ACCELERATION

FIG. N-1211(b)-1 VERTICAL DESIGN RESPONSE SPECTRA SCALED TO 1 g HORIZONTAL GROUND ACCELERATION

**TABLE N-1211(a)-1
HORIZONTAL DESIGN RESPONSE SPECTRA
RELATIVE VALUES OF SPECTRUM AMPLIFICATION FACTORS
FOR CONTROL POINTS**

Percent of Critical Damping	Amplification Factors for Control Points			
	Acceleration ^{1,2}			Displacement ^{1,2}
	A (33 Hz)	B (9 Hz)	C (2.5 Hz)	D (0.25 Hz)
0.5	1.0	4.96	5.95	3.20
2.0	1.0	3.54	4.25	2.50
5.0	1.0	2.61	3.13	2.05
7.0	1.0	2.27	2.72	1.88
10.0	1.0	1.90	2.28	1.70

NOTES:

- (1) Maximum ground displacement is taken proportional to maximum ground acceleration and is 36 in. for ground acceleration of 1.0 g.
- (2) Acceleration and displacement amplification factors are taken from recommendations given in Ref. 1 and discussed in Refs. 2 and 3.

TABLE N-1211(a)-1 HORIZONTAL DESIGN RESPONSE SPECTRA RELATIVE VALUES OF SPECTRUM AMPLIFICATION FACTORS FOR CONTROL POINTS

**TABLE N-1211(b)-1
VERTICAL DESIGN RESPONSE SPECTRA
RELATIVE VALUES OF SPECTRUM AMPLIFICATION FACTORS
FOR CONTROL POINTS**

Percent of Critical Damping	Amplification Factors for Control Points			
	Acceleration ^{1,2}			Displacement ^{1,2}
	A (33 Hz)	B (9 Hz)	C (3.5 Hz)	D (0.25 Hz)
0.5	1.0	4.96	5.67	2.13
2.0	1.0	3.54	4.05	1.67
5.0	1.0	2.61	2.98	1.37
7.0	1.0	2.27	2.59	1.25
10.0	1.0	1.90	2.17	1.13

NOTES:

- (1) Maximum ground displacement is taken proportional to maximum ground acceleration and is 36 in. for ground acceleration of 1.0 g.
- (2) Acceleration amplification factors for the vertical design response spectra are equal to those for horizontal design response spectra at a given frequency, whereas displacement amplification factors are $\frac{2}{3}$ those for horizontal design response spectra. These ratios between the amplification factors for the two design response spectra are in agreement with those recommended in Ref. 1 and discussed in Refs. 2 and 3.

TABLE N-1211(b)-1 VERTICAL DESIGN RESPONSE SPECTRA RELATIVE VALUES OF SPECTRUM AMPLIFICATION FACTORS FOR CONTROL POINTS

A second procedure which may be used is to pass Gaussian shot noise through selected filters (Ref. 74). This method may produce acceptable results if used in conjunction with the spectral raising and suppressing techniques described earlier.

Another acceptable procedure involves the superposition of continuous waves with the assumption that earthquake motion is stationary for the strong motion portion of the total time duration. The earthquake is characterized as the product of a normalized stationary process and a scaling factor that establishes the magnitude of the motion and its envelope shape which consists of three distinct parts: the buildup, the flat or stationary portion, and the motion decay. The random process is represented by a finite number of superimposed sine waves with distinct periods and randomly selected phase angles (Ref. 30).

Synthesized time history motions for the three perpendicular directions of an earthquake may not have time phase relationships similar to those of past earthquake records. The procedures of N-1213.1 may be used to check that time phasing is acceptable.

N-1212.2 Duration of Time History

(a) It has been observed (Ref. 51) that the earthquake duration effect on the response spectrum shape is small for periods shorter than 0.5 sec, which is the period range significant for nuclear power plant structures, systems and components.

(b) Although actual long duration earthquakes tend to excite a much wider range of frequencies, this effect is included

in the nuclear power plant design by using the smoothed, envelope type of design response spectra. The use of a design response spectrum in qualifying structures and components dictates that only maximum response amplitudes, be it displacement or stresses, are computed. The duration of ground motions, which is an influence in prolonging large amplitude structural response, may be important when fatigue life of the structures and components is considered. The fatigue effect is discussed in N-1214.

(c) The earthquakes used in producing the recommended response spectra [Figs. N-1211(a)-1 and N-1211(b)-1] occurred almost exclusively in the California area originating along the Circumpacific Belt. They are referred to as type 2 earthquakes in Ref. 51. These type 2 earthquakes are associated with moderate distances from the focus and occur only on firm ground. They last for only a moderate time. The type 2 earthquakes are unlike those referred to as type 3 which occur on soft soil such as the Mexico City earthquakes of July 6, 1964, and which have a much longer duration.

(d) Maximum accelerations of type 2 earthquakes generally occur in the first 10 sec of strong shaking. For instance, the north-south component acceleration recorded at the El Centro earthquake, May 18, 1940, shows that the maximum horizontal ground acceleration of 0.33 g occurs at about 2 sec after the instrument started recording.

(e) Time history analysis is necessary to qualify systems and components which exhibit highly nonlinear characteristics, such as the opening and closing of large gaps between members. Long seismic inputs can waste computation resources. Duration of the artificial time histories should be sufficient to allow the structure enough time to achieve its maximum response. For developing response spectra, the input time history used should be chosen long enough so that the resultant response spectra do not significantly change if the time history is increased. For developing spectrum-consistent time histories, the resultant time history should be long enough so that further increases in its length will not produce significantly different response spectra.

(f) Generally the minimum duration of the strong seismic motion required may be taken as 6 sec for Code components. If this minimum 6 sec strong motion duration is used, then a buildup duration of about 4 sec is recommended to precede the strong motion. The buildup region may be taken as the time duration from where motion is zero to the time where stationarity or strong motion begins. In cases where it is uncertain as to the minimum strong motion duration required to produce maximum structural response, the analysis may be extended to longer strong motion durations such as 10 sec in order to evaluate whether significant response increases occur above those of the 6 sec duration. The method in Ref. 71 may be used when required to include shorter or longer periods of vibratory energy in an artificial time history.

N-1213 Directional and Time Phase Considerations

Three orthogonal components of earthquake excitations are normally considered for nuclear power plant design. Rotational ground motion in the three directions, however, may be neglected. The triaxial input excitations are characterized by the relative magnitudes of

Page 367

the peak accelerations of the three excitations, and the relative values of the response spectra over the frequency range of interest (N-1211). Time histories which are consistent with the design response spectra may be developed through methods discussed in N-1212 and which essentially envelop the design response spectra. Since these artificial time histories may not have time phase relationships similar to those of past earthquake records, the procedures of N-1213.1 may be used to check that time phasing is acceptable.

N-1213.1 Time Phase Relationships.

The peak acceleration of the three orthogonal synthetic time histories generally need not occur at the same time. In order to stimulate natural earthquake occurrences, the correlation of the synthesized time histories may be evaluated by calculating the cross correlation coefficients and the coherence functions (Refs. 4, 5, and 6). The artificially generated time histories are acceptable if both their cross correlation coefficients and their coherence functions are approximately equal to the respective functions for past earthquake records. An absolute value of the correlation coefficient less than 0.16 is acceptable. For the coherence function the numerical values ranging between 0.0 and 0.3 with an average of approximately 0.2 are acceptable.

N-1214 Cyclic Criteria

(a) An acceptable cyclical load basis for fatigue analysis of earthquake loading of equipment and components is 10

equivalent maximum stress cycles per earthquake.

(b) The equivalent maximum stress cycle is defined as the full range including plus or minus seismic load calculated by equivalent static or response spectrum modal analysis techniques.

(c) The total usage factor contribution is based upon the number of earthquakes considered for the component.

N-1220 METHODS OF DYNAMIC ANALYSIS

N-1221 Modeling Techniques for Dynamic Analysis

In the course of preparation.

N-1222 Time History Method

(a) The structural system to be analyzed can be generally classified into two forms, linear and nonlinear. In the linear system the structure is idealized in such a way that the responses and motion retain a linear relation with the applied loads. A nonlinear structural dynamic system may be caused by either a material nonlinearity (i.e., a nonlinear stress-strain relationship of the material), a geometrical nonlinearity (an excessive deformation, a support gap, etc. which significantly changes the geometry of the system), or a mixture of the two.

(b) Dynamic analysis for either a linear or nonlinear system is based on the solution of a set of simultaneous, differential equations of motion with given initial and boundary conditions. Acceptable methods are presented for solution to linear and nonlinear equations in N-1222.

N-1222.1 Linear

(a) The response of a multi-degree-of-freedom linear structural system is described by the differential equation of motion expressed in matrix form:

$$(1) [M] \{\ddot{x}\} + [C] \{\dot{x}\} + [K]x = \{f\}$$

where

M	= mass matrix
C	= matrix of viscous damping coefficients
K	= stiffness matrix for the mass points of the linear elastic structure
f	= force vector and function of time representing external loading at mass points
x	= displacement vector
$\dot{x}$	= velocity vector
$\ddot{x}$	= acceleration vector

In all typical linear matrix formulations, matrices M , C , and K are symmetric.

(b) For a seismic analysis where ground motion is the source of excitation, f in Eq. (1) can be replaced by $[M] \{\ddot{Z}\}$, where $\ddot{Z}$ is the acceleration of ground motion in the same direction of x which is the relative displacement with respect to the ground motion. For systems excited at multiple support locations, further modification of the force vector is necessary (see N-1228).

(c) The differential equation of motion may be solved either analytically or numerically. A rigorous analytical solution of the simultaneous linear differential equations is often impractical and unnecessary. Simplification of the damping matrix may be made to facilitate computations.

(d) For example, in the special case of proportional damping (i.e., when the damping matrix is reduced to a linear combination of the mass and stiffness matrices), the classical method of modal analysis may be applied since Eq. (1) can be decoupled.

(e) See N-1230 for acceptable treatments of damping. A numerical solution using step-by-step integration method may be applied to a set of coupled as well as uncoupled differential equations. The direct integration method does not require the process of uncoupling modes; therefore, no calculation of natural frequencies and mode shapes is necessary. The direct integration method permits the handling of proportional damping where this treatment is required.

N-1222.1.1 Method of Modal Superposition (Ref. 8)

N-1222.1.1.1 Modal Analysis.

The method of modal analysis usually assumes that a modal matrix be defined such that

$$[\phi]^T [M] [\phi] = [I]$$

$$[\phi]^T [K] [\phi] = [\omega^2] \quad (2)$$

$$[\phi]^T [C] [\phi] = [2\xi\omega]$$

(2) where the right-hand sides are diagonal matrices, ϕ is the modal matrix, ω is the natural frequency of the structure, and ξ is the modal fraction of critical damping. This formation uses damping matrices that are proportional.

Let $\{\eta\}$ be the normal coordinates such that the displacement $\{x\}$ can be defined by the transformation

$$(3) \{x\} = [\phi] \{\eta\}$$

Equation (1) can be written by means of this transformation as

$$(4) \{\ddot{\eta}\} + 2\xi\omega \{\dot{\eta}\} + \omega^2 \{\eta\} = [\phi]^T \{f\}$$

which represents a decoupled system of individual modal equations. Response in each mode may be obtained by solving the differential equations individually for the corresponding mode. The total response of the structure is therefore the result of combining the responses of all its component modes.

The equations of motion for a linear system may be uncoupled by means of a transformation to a system of normal coordinates provided that the damping matrix C is a linear combination of M and K matrices.

N-1222.1.1.2 Complex Frequency Response Method.

As an alternative approach to the method of modal analysis described above, the complex frequency response method may be used to determine dynamic response of the system represented by Eq. (1).

The complex frequency response method requires that the complex frequency responses of the system be determined first and the seismic excitations be transformed into its frequency domain. The time histories of the response may then be found by inverting the response transforms.

Corresponding to every normal coordinate η_r of Eq. (4), a pair of Fourier transforms may be found:

$$G_r(\Omega) = \int_{-\infty}^{\infty} \eta_r(t) e^{-i\Omega t} dt \quad (5)$$

$$Q_r(\Omega) = \int_{-\infty}^{\infty} f_r(t) e^{-i\Omega t} dt$$

(5)

where

$$f_r(t) = \{\phi_r\}^T \{f(t)\}$$

The Fourier transforms of the excitation and response are related according to

$$(6) G_r(\Omega) = H_r(\Omega) Q_r(\Omega)$$

and

$$H_r(\Omega) = \frac{1}{1 - (\Omega/\Omega_r)^2 + i2\xi(\Omega/\Omega_r)} \quad (7)$$

(7)

The r th mode response is given by evaluating the Fourier integral:

$$\eta_r(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} H_r(\Omega) Q_r(\Omega) e^{i\Omega t} d\Omega \quad (8)$$

(8)

and the time history response of the system in the physical coordinate is given by

$$\{x(t)\} = \sum_{r=1}^{\eta} \{\phi_r\} \eta_r(t) \quad (9)$$

(9)

Standard fast Fourier transform techniques are available for expedient evaluation of $Q_r(\Omega)$ and $\eta_r(t)$ of Eqs. (6) and (8), respectively (Ref. 9).

Page 369

N-1222.1.2 Method of Direct Integration

(a) This is a numerical method directly applied to the solution of the differential equations of motion of linear structural system, Eq. (1), in a step-by-step manner. No uncoupling procedure is necessary to compute the responses. The damping matrix need not be proportional.

(b) There are many acceptable schemes available for numerical integration of the equations of motion such as Newmark β -method (Ref. 10), Houbolt method (Ref. 11), and Wilson θ -method (Ref. 12).

(c) Using the matrix formulation by Chan, Cox, and Benfield (Ref. 13) and Newmark β -method, Eq. (1) may be transformed into a finite difference equation in recurrence form involving displacement:

$$[D] \{x_{n+1}\} = [B] \{x_n\} - [F] \{x_{n-1}\} + \beta h^2$$

$$\left\{ f_{n+1} + \left(\frac{1}{\beta} - 2 \right) f_n + f_{n-1} \right\} \quad (10)$$

(10)

where

$[D]$	$= [M] + (h/2)[C] + \beta h^2[K]$
$[B]$	$= 2[M] - (1 - 2\beta)h^2[K]$
$[F]$	$= [M] - (h/2)[C] + \beta h^2[K]$
h	= length of the time interval used in the direct integration procedure
β	= parameter of Newmark β -method in reflecting the type of acceleration function assumed between two time stations and numerical stability of the procedure
n	= the number of time intervals lapsed

(d) The dynamic responses of a structure at any instant of time may be calculated from the time history of excitations and the previous structural responses.

(e) The direction integration method has the advantage of simplicity in computation and elimination of the eigenvalue problem. This method may also be extended to deal with the nonlinear problems.

N-1222.2 Nonlinear

(a) The linear time history analysis discussed in N-1222.1 is based on the assumptions that external forces are independent of the displacement and velocity, the stress-strain relationship is linear, and the strain-displacement relationship is linear. Many problems of practical consequences exist for which these assumptions are not valid. Some acceptable numerical methods to analyze such nonlinear problems are discussed below.

(b) The following nonlinearities may be introduced into the system:

- (1) material nonlinearities (plasticity);
- (2) geometric nonlinearities (large displacement);
- (3) combination of material and geometric nonlinearities (impact and friction).

(c) The differential equation of motion for nonlinear problems is

$$(11) [M_p]\{U''\} + [C_p]\{U'\} + [K_p]\{U\} = \{P_p\}$$

where

M_t	= time-dependent mass
C_t	= damping
K_t	= stiffness matrices
U	= displacement
U'	= velocity
U''	= acceleration
P_t	= force arrays

The left-hand side of Eq. (11) may be made linear by introducing

$$\begin{aligned}
 [M_t] &= [M] + [M_{nl}] \\
 [C_t] &= [C] + [C_{nl}] \\
 [K_t] &= [K] + [K_{nl}]
 \end{aligned}
 \tag{12}$$

(12)

where

M	= time-independent mass
C	= proportional damping
K	= stiffness matrices
M_{nl}	= time-dependent mass
C_{nl}	= damping
K_{nl}	= stiffness matrices

As an example, the compressible fluid flow in a pipe or a moving mass acting on a structure contributes to $[M_{nl}]$ and the closing and opening of gaps contribute to $[C_{nl}]$ and $[K_{nl}]$. Substituting Eq. (12) into Eq. (1) yields

$$(13) \quad [M] \{U''\} + [C] \{U'\} + [K] \{U\} = \{F\}$$

where

$$\{F\} = \{P_t\} - [M_n]\{U'''\} - [C_n]\{U''\} - [K_n]\{U\}$$

Time history methods to solve Eq. (11) or (13) fall into two major categories: (1) mode superposition, and (2) direct integration.

N-1222.2.1 Mode Superposition

(a) The use of normal modes for linear time history method is discussed in N-1222.1. Mode superposition techniques may also be used for the nonlinear problems

Page 370

(Refs. 14, 15, and 16). A problem of a pendulum having a large amplitude is discussed in Ref. 14. Reference 15 presents an analysis of a structure including the following nonlinear characteristics: variable-stiffness elements, contact (compression only) elements, time-varying boundary conditions, and nonmodal and nonlinear damping elements. A ring problem involving large geometric nonlinearities and plastic strains is discussed in Ref. 16.

(b) Let $\{\phi_i\}$ and $\{\omega_i\}$ be the i th orthonormal eigenvector and natural frequency, respectively:

$$(14) [M] \{U'''\} + [K] \{U\} = 0$$

A transformation

$$(15) \{U\} = [\phi] \{q\}$$

is introduced in Eq. (13). The resulting uncoupled equation is as follows:

$$(16) [I] \{q'''\} + [2\xi_j\omega_j] \{q'\} + [\omega_j^2] \{q\} = \{p\}$$

where

I	= identity matrix
	$= [\phi]^T [M] [\phi]$
ϕ	= set of significant eigenvectors
q	= generalized displacement vector
ξ_j	= j th modal damping ratio
ω_j	= j th natural frequency
P	= generalized force
	$= [\phi]^T \{F\}$

(c) Eq. (16) may be solved by either explicit numerical integration schemes such as the fourth order Runge-Kutta method (Ref. 17), Hamming's predictor-corrector method (Ref. 17), or by the analytical integration scheme (Ref. 14). These numerical methods are conditionally stable and available as library programs equipped with an automatic time step adjustment feature. These methods provide a stable solution if the integration time step is appreciably smaller than the smallest period associated with Eq. (16). In the analytical integration method, the force vector F is approximated over the time step Δt . This allows for Duhamel integral type solutions for Eq. (16).

(d) The generalized forces in Eq. (16) are updated at each time increment. If the initial stiffness matrix has a relatively large bandwidth and a large number of eigenvectors are not required for the analysis, it is likely that the mode superposition approach will be quite economical as compared with the direct integration procedures discussed in N-1222.2.2. In cases where the applied load distribution is extremely complex or its time variation contains significant high frequency components, or both, it is necessary to include many modes to obtain adequate accuracy by mode superposition. In these cases the direct integration procedure may be more efficient. This procedure is discussed in N-1222.2.2.

N-1222.2.2 Direct Integration.

Direct numerical integration methods can be applied to Eq. (11) or (13). When applied to Eq. (11), the calculation

of time-dependent matrices is necessary at each integration time step. When applied to Eq. (13), the time-independent matrices may be calculated once at the beginning of the numerical solution and the time-dependent force array is calculated at each time step. These methods are classified into two groups: explicit schemes and implicit schemes. The explicit schemes are hampered by both numerical instability and convergence problems while the implicit schemes suffer only from convergence problems. These schemes are discussed in N-1222.2.2.1 and N-1222.2.2.2.

N-1222.2.2.1 Explicit Schemes.

These schemes convert the differential equations of motion to a set of linear algebraic equations with unknown state variables (at the present time) which are independent of one another. Acceptable explicit schemes include: Runge-Kutta method (Ref. 17), predictor-corrector method (Ref. 17), Nordsieck integration method (Ref. 18), and central difference method (Ref. 19).

As the above methods are conditionally stable, they have a disadvantage of requiring small time step sizes. The first three methods can be made to operate with the variable time step, while the fourth one is a constant time-step procedure. Garnet and Armen (Ref. 20) demonstrate a one dimensional wave propagation problem solution with the aid of a predictor-corrector method, i.e., the modified Adams method. In Ref. 21 the Nordsieck integration scheme is demonstrated to solve nonlinear vibration problems in reactor components. Wu and Witmer (Ref. 22) analyzed the problem of large transient elastic-plastic deformation of structures using the central difference method.

N-1222.2.2.2 Implicit Schemes.

These schemes convert the differential equations of motion to a set of linear simultaneous algebraic equations and require a matrix inversion to step the solution forward. Acceptable implicit schemes include: Newmark's generalized acceleration method, Wilson's θ method, Nastran's integration method, and Houbolt's method.

(a) *Acceptable implicit schemes:*

(1) *Newmark's Generalized Acceleration Method* (Refs. 10 and 23). The nodal point velocities and displacements are given by the following equations:

$$(17) \{U'_{n+1}\} = \{U'_n\} + (1 - \gamma)(\Delta t)\{U''_R\} + \gamma(\Delta t) \{U''_{n+1}\}$$

and

$$(18) \{U_{n+1}\} = \{U_n\} + (\Delta t) \{U'_n\} + (1/2 - \beta)(\Delta t)^2\{U''_n\} + \beta(\Delta t)^2 \{U''_{n+1}\}$$

Equations (17) and (18) are substituted in Eq. (13), which is expressed at the present time point $(n + 1)$. This gives the following:

$$\begin{aligned}
& \left[[M] + \gamma(\Delta t)[C] + \beta(\Delta t)^2[K] \right] \{U''_{n+1}\} \\
& = \{F_{n+1}\} - \left[(1 - \gamma)(\Delta t)[C] \right. \\
& \quad \left. + (1/2 - \beta)(\Delta t)^2[K] \right] \{U''_R\} \\
& \quad - \left[[C] + (\Delta t)[K] \right] \{U'_n\} - [K] \{U_n\} \quad (19)
\end{aligned}$$

(19)

This set of algebraic simultaneous equations in the unknown accelerations is solved and used with Eqs. (17) and (18) to obtain the velocity and displacement at the present time. The parameter γ in Eq. (19) is a damping parameter. Artificial positive damping is introduced if $\gamma > 0.5$ and artificial negative damping if $\gamma < 0.5$. For linear problems, the method is unconditionally stable if $\beta > (2\gamma + 1)^2 / 16$ (Ref. 12). For $\gamma = 1/2$, $\beta > 1/4$ gives unconditional stability. For systems with nonlinearities or nonproportional damping or both, there is no analytical expression available for unconditional stability. So to provide a margin of stability for these systems $\beta > 1/4$ is considered for $\gamma = 1/2$. The value of γ slightly larger than 0.5 damp out the highest (and least important) modes while preserving the lower ones. The Newmark method for $\gamma = 1/2$ (no numerical damping) and $\beta = 1/6$ (linear acceleration) is conditionally stable. The Wilson modified method (to make it unconditionally stable) is discussed next.

(2) Wilson's θ Method (Ref. 12). To obtain the solution at the present time $(n + 1)$, this method assumes that the acceleration varies linearly over the time interval $\tau = \theta \Delta t$, where $\theta > 1.0$. With the aid of Eq. (19), $\beta = 1/6$ and $\gamma = 1/2$, solution at time point $(n + \theta)$ is obtained. Then the acceleration, velocity, and displacement at the time point $n + 1$ are given by the following expressions:

$$\{U''_{n+1}\} = (1 - 1/\theta)\{U''_n\} + (1/\theta)\{U''_{n+\theta}\}$$

$$\{U'_{n+1}\} = \{U'_n\} + \frac{\Delta t}{2} \{ (U''_n + U''_{n+1}) \}$$

$$\begin{aligned} \{U_{n+1}\} = \{U_n\} + \Delta t \{U'_n\} + \frac{\Delta t^2}{6} (U''_{n+1} \\ + 2U''_n) \end{aligned} \quad (20)$$

(20)

The last two equations are obtained from Eq. (18) with the value of β and γ specified above. This method is unconditionally stable for $\theta > 1.37$ (Ref. 12); for $\theta = 1.4$, the numerical damping is less than 1% provided 22 steps are taken within the natural period of the mode of interest (Ref. 25).

(3) *Nastran's Integration Method* (Ref. 26). In this method the acceleration and velocity are expressed in central finite difference form. They are expressed as follows:

$$\{U''_n\} = \frac{\{U_{n+1}\} - \{2U_n\} + \{U_{n-1}\}}{(\Delta t)^2}$$

$$\{U'_n\} = \frac{\{U_{n+1}\} - \{U_{n-1}\}}{2(\Delta t)} \quad (21)$$

(21)

The displacement and the forcing function are expressed as the weighted average of the corresponding magnitudes at the three successive time points $n-1, n, n+1$. Substitution of these expressions in Eq. (13) expressed at time point n gives:

$$\begin{aligned}
& \left[\frac{1}{(\Delta t)^2} [M] + \frac{1}{2(\Delta t)} [C] + \frac{1}{3} [K] \right] \{ U_{n+1} \} \\
&= \frac{1}{3} \{ F_{n+1} + F_n + F_{n-1} \} + \left[\frac{2}{(\Delta t)^2} [M] - \frac{1}{3} [K] \right] \{ U_n \} \\
&+ \left[-\frac{1}{(\Delta t)^2} [M] + \frac{1}{2(\Delta t)} [C] - \frac{1}{3} [K] \right] \{ U_{n-1} \} \quad (22)
\end{aligned}$$

(22)

This set of algebraic simultaneous equations in the unknown displacements is solved and used to find velocity and acceleration.

This scheme is a special form of the Newmark method, Eq. (18) for $\beta = 1/3$ and $\gamma = 1/2$ (Ref. 13). The value $\beta = 1/3$ provided some margin of stability

Page 372

and for $\gamma = 1/2$ the artificial damping is zero. Note that the load vector F is averaged over three adjacent time steps in the same manner that K is averaged. This is done in order to provide statically correct solutions for massless degrees of freedom.

(4) *Houbolt's Method* (Ref. 11). In this method a third-order interpolating polynomial which fits the known displacements at the three previous time points and the unknown displacement at the present time point is formulated. The expressions for acceleration and velocity are given as follows:

$$\begin{aligned}
\{U''_{n+1}\} &= \frac{1}{(\Delta t)^2} [2\{U_{n+1}\} - 5\{U_n\} \\
&\quad + 4\{U_{n-1}\} - \{U_{n-2}\}] \\
\{U'_{n+1}\} &= \frac{1}{6(\Delta t)} [11\{U_{n+1}\} - 18\{U_n\} \\
&\quad + 9\{U_{n-1}\} - 2\{U_{n-2}\}] \quad (23)
\end{aligned}$$

(23)

The Eqs. (23) are substituted in Eq. (13) which is expressed at the present time point $n + 1$. This gives:

$$\begin{aligned}
& \left[\frac{2}{\Delta t^2} \left(\frac{11}{6\Delta t} \right) [C] + [K] \right] \{U_{n+1}\} \\
& = \{F_{n+1}\} + \left[\frac{5}{\Delta t^2} [M] + \frac{3}{\Delta t} [C] \right] \{U_n\} \\
& \quad - \left[\frac{4}{\Delta t^2} [M] + \frac{3}{2\Delta t} [C] \right] \{U_{n-1}\} \\
& \quad + \left[\frac{1}{\Delta t^2} [M] + \frac{1}{3\Delta t} [C] \right] \{U_{n-2}\}
\end{aligned}$$

This set of algebraic simultaneous equations in the unknown displacements is solved and used to find velocity and acceleration.

This method is unconditionally stable for linear problems and introduced artificial damping (the amount of such damping increases with the ratio of time step to natural period of the system). The artificial damping is less than 1% provided 50 time steps are taken within the natural period of the mode of interest (Ref. 12). Thus, the Houbolt method effectively removes higher mode response from the system.

(b) *Approximation of Load Vectors.* All four direct integration methods discussed in the previous section require that the forces at the time point $n+1$ be known in order to calculate the displacements at that time. These loads, because of the presence of the nonlinear terms, are a function of the displacements which are to be calculated. So, it is not possible to evaluate these terms exactly. These forces may be approximated with the aid of the first-order Taylor series expansion about the motion at time point n as follows:

$$\{F(t, U)_{n+1}\} = \{F(t, U)_n\} + \frac{\delta}{\delta t} \{F(t, U)_n\} (\Delta t)$$

$$= 2\{F(t, U)_n\} - \{F(t, U)_{n-1}\}$$

This expression has an inherent error of order $(\Delta t)^2$ which is the same as the Houbolt and Nastran method (Ref. 27). This expression corresponds to a linear extrapolation of the loads at the two previous time increments which is equivalent to a numerical differentiation. This introduces round off error (noise) which will set a low bound on the integration time step.

(c) *Convergence.* For nonlinear systems, the following two steps are recommended to ensure convergence of the solution to the proper value.

(1) Iterative schemes, based on the residual force array derived from the equation of motion at the present time point $n + 1$ may be used to obtain convergence. This residual, obtained by transferring all the terms in Eq. (13) to the right-hand side, is a measure of how well the dynamic equilibrium is satisfied at the present time point $n + 1$. The time-dependent matrices and force arrays, in Eqs. (11) and (13), respectively, are modified based on the calculated solution at time point $n + 1$ and the iterative scheme is continued until the dynamic equilibrium is satisfied to a prescribed tolerance. References 25, 28, and 29 discuss this approach to improve efficiency in nonlinear solutions.

(2) Successive computation of the time history, employing successively smaller values of the integration time step, may also be used to ascertain convergence.

In the wave propagation problems, the response may contain the spurious oscillations (Refs. 20 and 25), which are due to the finite element discretization, and are not eliminated by reducing the time step Δt . These oscillations may often be reduced by employing more uniform element size.

(d) *General Remarks.* No best choice of numerical method has been identified for nonlinear problems. Discussions which are helpful to indicate the advantages and limitations of these previously discussed methods are contained in Refs. 13, 20, 22, 23, and 27.

Experience obtained from the solution of actual problems is the most reliable indicator of which of the

Page 373

different integration schemes is superior for a particular problem. Experience and checks of methods adopted for a similar type of physical problem where a correct solution is available is recommended to establish validity for a particular nonlinear method.

N-1222.3 Time History Broadening.

To account for the effect of possible frequency variation of the structure, the same time history data may be used with at least three different scaled time intervals: Δt (the reference interval) and $(1 \pm \Delta f/f_j)\Delta t$, for the analysis of equipment, where f_j is the fundamental structural frequency and Δf_j is a parameter defining the frequency variation due to uncertainties. This variation of the time scale interval has a similar effect to widening the spectral peak when generating the smoothed response spectrum. If one of the equipment frequencies f_e is within the range $f_j \pm \Delta f_j$, it is recommended that the time history also be used with additional scaled time intervals of $[1 \pm (f_e - f_j)/f_j]\Delta t$.

N-1223 Response Spectrum Method

N-1223.1 Modal Combination.

In the response spectrum method, the peak values of particular responses of interest (displacement, acceleration, shear, moment, etc.) are determined for each mode. The total response may be obtained by combining the peak modal responses by the square root of sum of squares (SRSS) method. Mathematically this is expressed as follows:

$$R = \pm \left[\sum_{k=1}^n R_k^2 \right]^{1/2} \quad (24)$$

(24)

where

R	= the total response of interest (strain, displacement, stress, moment, shear, etc.) based on the SRSS method of combining the individual peak modal responses
R_k	= the peak response of interest due to the k th mode
n	= the number of significant modes

The above method may be used to determine the particular response for all significant modes regardless of frequency spacing.

N-1223.2 Combination of Effects Due to Triaxial Excitation

(a) In the response spectrum method of analysis, the natural frequencies, mode shapes, and the load for each mode are first determined. The load for each mode for unit generalized response is the product of the stress matrix, the mode shapes, and the mode participation factors. When this product is multiplied by the generalized response determined from the spectrum curves, the load for each natural mode results.

(b) The following assumptions may be used in combining the loads of each natural mode and for each direction.

(1) The peak responses of the different modes due to any one excitation do not occur at the same time.

(2) The peak generalized responses due to the three different earthquake excitations for the same mode do not occur at the same time.

(3) The peak stresses due to different modes and due to different excitations generally do not occur at the same location on the structure nor at the same angular orientation.

(c) These assumptions are consistent with the use of the SRSS method to compute the resultant responses. It is necessary to use the SRSS method only on scalar components because the SRSS of components orthogonal to each other results in magnitudes equivalent to vector sums thus implying simultaneous occurrence.

(d) The following general procedure should be used to combine the seismic responses due to triaxial excitation:

$$R_{ij} = \pm \left[\sum_{k=1}^3 R_{ijk}^2 \right]^{1/2} \quad (25)$$

(25)

where

R_{ijk}

= maximum, co-directional seismic response of interest (strain, displacement, stress, moment, shear, etc.) associated with coordinates i and j due to earthquake excitation in the k th direction

R_{ij}

= seismic response of interest for design (strain, displacement, stress, moment, shear, etc.) obtained by the SRSS rule to account for the nonsimultaneous occurrences of R_{ijk}

N-1224 Component or Equipment Testing

In the course of preparation.

N-1225 Simplified Dynamic Analysis

N-1225.1 Seismic Load Coefficient Method for Piping System Analysis

N-1225.1.1 Simplified Seismic Load Coefficient Method Using Floor or Amplified Response Spectra as the Seismic Design Basis Input

(a) Piping System Loads. A simplified seismic load coefficient method for earthquake resistant design for

Page 374

equivalent seismic inertia induced resultant piping stresses, displacements, loads, and support reaction loads may be used to describe the earthquake input with a format as follows:

$$(26) F_{phi} = K_{hi} S_{ami} W$$

$$(27) F_{pv} = K_v S_{ami} W$$

where

F_{phi}

= equivalent static inertia force applied to the piping and piping components in the i th horizontal direction as defined in N-1225.2

F_{pv}

= equivalent static inertia force applied to the piping and piping components in the vertical direction as defined in N-1225.2

K_{hi}

= the load coefficient applied to the piping and piping

components in the i th horizontal direction. The value of K_{hi} shall be determined as follows:

For Soil Sites: $V_s < 3500$ ft/sec

$$K_{hi} = 1.0; l_{hi} < 3.5 l_v$$

$$K_{hi} = 0.65; 3.5 l_v \leq l_{hi} \leq 5.0 l_v =$$

$$K_{hi} = 0.4; l_{hi} < 5.0 l_v$$

For Rock Sites: $V_s > 3500$ ft/sec

$$K_{hi} = 1.0; l_{hi} < 2.5 l_v$$

$$K_{hi} = 0.6; 2.5 l_v \leq l_{hi} \leq 4.0 l_v$$

$$K_{hi} = 0.4; l_{hi} < 4.0 l_v$$

Piping systems with l_{hi} in more than one of the categories listed above shall use the highest K_{hi} value applied to two lateral support spans on either side of the span requiring the highest K_{hi} value.

K_v = the load coefficient applied to the piping in the vertical direction. The value of K_v shall be determined as follows:

For Soil Sites: $V_s < 3500$ ft/sec

$$K_v = .75; l_{hi} < 4.0 l_v$$

$$K_v = 1.0; l_{hi} > 4.0 l_v$$

For rock Sites: $V_s > 3500$ ft/sec

$$K_v = 1.0$$

Piping systems with l_{hi} in more than one of these categories listed above shall use the highest K_v values applied to two lateral support spans on either side of the span requiring the highest K_v value.

S_{ami} = peak acceleration of applicable amplified or floor response spectra in the i th direction (in g's)

l_{hi} = span in the i th direction between lateral supports measured along the axis of the pipe. Lateral supports added to the piping system next to large inline components whose weights equal or exceed the weight of the pipe between nominal dead weight supports contained in Table NF-3611.1, such as valves, strainers, etc., do not need to be considered in the

l_v	determination of l_{hi} value = deadweight vertical support span from Table NF-3611.1 for the nominal pipe size for the piping system under consideration
V_s	= building foundation media shear wave velocity
W	= the total piping dead load (weight) which exists during the postulated seismic event. This includes piping weight, water weight and insulation. The units of the term W must be consistent with those of the term F_{phi} and F_{pv} above. When the piping system under consideration contains more than one pipe size K_{hi} and K_v factors shall be separately determined for and applied to each nominal pipe size in the piping system. In addition, if the K_{hi} and K_v values change as a result of a pipe size change, the highest K_{hi} , K_v values at the point of piping size change shall be applied to the first two lateral support spans at the point piping size change having the lower K_{hi} K_v values.

(b) *Special Considerations for Support Reactions.* In using this method to determine piping supports loads for seismic events, the specification of a minimum lateral and vertical support design load is required. This minimum design load is a function of pipe size and shall be determined as follows:

$$R_{Lmin} = (MSLF)(w') \left[\sum_{i=1}^2 (S_{ami})^2 \right]^{1/2} \quad (28)$$

$$R_{Amin} = (MSLF)(w') \left[\sum_{i=1}^2 (S_{ami})^2 \right]^{1/2} \quad (29)$$

(28 - 29)

where

The S_{ami} values are the peak accelerations of the applicable amplified or floor response spectra in each of two orthogonal horizontal directions (units are g's)

$$R_{vmin} = (MSLF)(w')(S_{ami})$$

where:

S_{ami} is the peak acceleration of the applicable amplified or floor response spectra in the vertical direction.

The remaining parameters are defined as follows:

$MSLF$	= the Minimum Support Load Factor as defined in Table N-1225.1.1(b)-1 (MSLF has the units of ft)
--------	--

Page 375

R_{Lmin}	= Minimum Lateral Seismic Support Design Support Load (R
------------	---

R_{Amin}	L_{min} has the units of lb ρ) = Minimum Axial Seismic Support Design Load for these axial supports not in the vertical direction. For axial supports in the vertical direction the minimum support design load shall be determined as R_{Vmin} (R_{Amin} has units of lb ρ)
R_{Vmin}	= Minimum Vertical Seismic Support Design Load (R_{Vmin} has the units of lb ρ)
w'	= the total piping dead load per unit length of the piping which exists during a seismic event. This includes piping weight, water weight, insulation weight, etc. (w' has the units of lb ρ /ft).

**TABLE N-1225.1.1(b)-1 MINIMUM
SUPPORT LOAD FACTOR**

Nominal Pipe Size [ϕ], NPS	MSLF (ft)
$\phi \leq 2$	8.5
$2 < \phi \leq 4$	8.0
$4 < \phi \leq 6$	7.5

TABLE N-1225.1.1(b)-1 MINIMUM SUPPORT LOAD FACTOR

In instances where Seismic Support Design Loads determined using the methodology of N-1225.1(a) are less than R_{Lmin} , R_{Amin} or R_{Vmin} the support design load shall be specified as R_{Lmin} , R_{Amin} or R_{Vmin} as determined in this subarticle.

(c) *Inline Component Extended Structures.* The seismic applied accelerations at the center of gravity (cg) of inline component extended structures may be determined as follows:

$$av_h = \left[\sum_{i=1}^2 (0.9S_{ami})^2 \right]^{1/2} \quad (30)$$

(30)

when

The S_{ami} values are the peak accelerations of the applicable amplified or floor response spectra in each of two orthogonal horizontal directions.

$$av_v = 1.2 S_{ami} \quad (31)$$

(31)

when:

The S_{ami} value is the peak of the applicable amplified floor response spectra in the vertical direction.

The remaining parameters are defined as follows:

av_h	= the total acceleration applied to the inline component extended structure center of gravity (cg) in the horizontal direction
av_v	= the acceleration applied to the inline component extended structure center of gravity (cg) in the vertical direction

The application of the equations (30) and (31) to determine Inline Component Extended Structures applied accelerations shall be limited to $W_v h^2 / w'$ values less than or equal to 185,000 ft-in², when:

W_v	= weight of the inline component extended structure considered at it's center of gravity (cg) location (lb _p)
h	= height from the pipe centerline to inline component extended structure center of gravity (cg) (inches)
w'	= is as previously defined

For inline components when the extended structure vertical (axial) axis does not correspond to global vertical axis, the method is still applicable but care must be taken to insure that S_{ami} and equations (30) and (31), when applied, correspond to the inline component local vertical (axial) and lateral axes.

correspond to the inline component local vertical (axial) and lateral axes.

This method for inline piping component extended structure acceleration prediction is applicable only to those inline piping components where the extended structure of the inline component has a frequency greater than 20 hz. The inline piping component frequency determination can be made by analysis, test, or judgement, and when making this frequency determination, the inline piping component body shall be or shall be assumed to be rigidly constrained.

(d) This method is limited to NPS 6 and smaller.

N-1225.2 Analysis Using the Seismic Load Coefficient Method

When seismic forces F_{phi} or F_v are determined from the equations of N-1225.1.1(a), they shall be assumed as statically applied inertia loads acting along three orthogonal axes defined relative to the piping system with one of these axes being in the vertical direction. The piping system seismic analysis shall be performed independently for each direction of excitation with the loads applied in the same sense. Resultant internal forces, moments or stresses in the piping products and piping supports determined from seismic loads in the three directions, may be combined by the square root sum of squares basis and will be considered as having both a (+) and (-) sign. In developing the piping system analytical models for this method, consideration shall be given to appropriately simulating the effects of localized concentrated mass effects assumed from such

Page 376

piping products as flanges, inline instrumentation, valves (including extended structures), etc.

The seismic forces defined by the equations of N-1225.1.1(a) consider only inertia effects. They do not include the effects of relative or differential motions between piping supports and motions of equipment to which the piping is attached. These effects are typically referred to as seismic anchor motions.

For this piping analysis method the piping supports may be assumed to be zero displacement points in the direction of restraint.

N-1226 Floor Spectrum Generation

(a) Nuclear facility structures are approximated by mathematical models to permit analysis of responses due to earthquake motions. Considering the large number of degrees of freedom that would be necessary and the possible ill-conditioning of the resulting stiffness matrix if the complete plant were idealized as a single mathematical model, the plant is usually separated into several separate subsystems for analysis purposes. There will usually be one or more primary structural models which support one or more secondary systems. Also, different models of the same structure may be required for different purposes. Specifically, the dynamic model used to generate the seismic excitation data for subsequent, separate analyses of the secondary systems may not be suitable for the detailed, localized stress analysis of the primary structure.

(b) Most equipment will have negligible interaction effects on the primary structure as in the case of equipment with relatively small mass and high frequency, and will only need to be included in the mass distribution of the primary system model. There are, however, major equipment systems, such as a reactor coolant system, whose stiffness, mass, and resulting frequency range should be considered for representation in the building model to account for possible dynamic interaction effects. Some guidelines for determining the extent of interaction are given in Refs. 31 through 33.

(c) Equipment may be analyzed by combining the complete equipment model with the support structure model and applying the proper excitation to the base of the support structure. In this method no separate equipment support excitations need be generated because the equipment will be excited directly through the structure (Ref. 34).

(d) For most equipment a separate analysis of the secondary system may be performed using output from the building analysis. If building to equipment interaction is significant, then the equipment should be included in the mathematical model of the structure. The representation of the equipment which is included in the building model should be adequate to consider major interaction effects, but need not be as detailed as the mathematical model used in a separate analysis of the equipment.

(e) For equipment which is not analyzed as part of the building structural model, the response may be obtained by separate analysis using floor response spectra curves, time history excitations, or an appropriately defined power spectral

density function at the support locations of the equipment in the structure.

N-1226.1 Response Spectra

(a) Both horizontal and vertical response spectra may be computed from the time history motions of the structure at the various floors or other equipment support locations of interest (Ref. 35). The spectrum ordinates should be computed at sufficient frequency intervals to produce complete and accurate response spectra. Spectrum peaks would normally be expected to occur at the frequencies of the peaks on the ground motion spectrum and at the natural frequencies of the supporting structures. In cases involving equipment mounted on equipment, the frequencies of all supporting structures should be included.

(b) Table N-1226-1 provides some systematic methods which may be used for choosing spectrum frequencies. Another acceptable method is to choose a set of frequencies such that each frequency is within 10% of the previous one and then add the natural frequencies of the supporting structures to the set.

(c) A more simplified acceptable method for constructing floor response spectra from the ground spectrum is given in Refs. 36 and 37.

N-1226.2 Spectral Peaks.

Studies (Refs. 38 and 39) have shown that, in general, the calculation of response of a piece of equipment having a frequency equal to a frequency of the supporting structure will be conservative if the spectrum at the equipment support is generated using a model of the supporting structure which does not include the equipment. This is because the exact resonance of an uncoupled analysis is not possible in the coupled case where the resonant frequencies tend to shift away from each other when the models are coupled. Further, it has been shown in Ref. 39 that undamped peak amplification for singly supported equipment structures cannot exceed a maximum $\sqrt{J/m}$, where J is the modal mass for each mode of the primary structure and m is the mass of the supported subsystem. Since this limit is a function of the mass of the particular subsystem, the peak response

Page 377

may be calculated on a case-by-case basis. This rule is recommended only for relatively simple systems.

TABLE N-1226-1
SUGGESTED FREQUENCIES, Hz, FOR CALCULATION OF GROUND AND FLOOR RESPONSE SPECTRA

Ground Spectra ¹		Floor Spectra ²	
Frequency Range	Increment, Hz	Frequency Range	Increment, Hz
0.5–3.0	0.10	0.5–1.6	0.10
3.0–3.6	0.15	1.6–2.8	0.20
3.6–5.0	0.20	2.8–4.0	0.30
5.0–8.0	0.25	4.0–9.0	0.50
8.0–15.0	0.50	9.0–16.0	1.0
15.0–18.0	1.0	16.0–22.0	2.0
18.0–22.0	2.0	22.0–34.0	3.0
22.0–34.0	3.0		

NOTES:

- (1) Calculate response at all frequencies within the ranges shown, at the corresponding increments (results in 72 frequencies).
- (2) Calculate response at all frequencies within the ranges shown, at the corresponding increments (results in 46 frequencies); also calculate response at all natural frequencies of the supporting structures with the overall range.

TABLE N-1226-1 SUGGESTED FREQUENCIES, Hz, FOR CALCULATION OF GROUND AND FLOOR RESPONSE SPECTRA

N-1226.3 Spectrum Peak Broadening

(a) To account for the effect on structural frequency variation of the possible uncertainties in the material properties of the structure and soil, and the approximations in the modeling techniques used in seismic analysis, the initially

computed floor response spectra are usually smoothed, and peaks associated with the structural frequencies are widened. A recommended method of determining the amount of peak widening, associated with the structural frequency, is described below.

(b) Let f_j be the j th mode structural frequency which is determined from the structure model. The variation in the structural frequency is determined by evaluating the individual frequency variation due to the variation in each parameter that is of significant effect, such as the soil modulus, material density, etc. The total frequency variation $\pm \Delta f_j$ is then determined by taking the SRSS of a minimum variation of $0.05f_j$ plus the individual frequency variation $(\Delta f_j)_n$ that is:

$$\Delta f_j = \sqrt{(0.05f_j)^2 + \sum (\Delta f_j)_n^2}$$

(c) A value of $0.10f_j$ is recommended if the actual computed value of Δf_j is less than $0.10f_j$. Figure N-1226-1 shows a sample of such a smoothed floor spectrum curve. Note that the broadened peak is bounded on each side by lines which are not vertical but parallel to the lines forming the original spectrum peak.

(d) An alternative method for the broadening of the structural peaks can be based on a probabilistic approach, as discussed in Ref. 40. In the particular case where there is more than one equipment or piping frequency located within the frequency range of a widened spectrum peak that is associated with a structural frequency f_j , the floor spectrum curve may be more realistically applied in accordance with the following criterion. Based on the fact that the actual natural frequency of the structure can possibly assume only one single value within the frequency range defined by $f_j \pm \Delta f_j$, but not a range of values, only one of these equipment or piping modes can respond with a magnitude indicated by the peak spectral value.

Therefore, seismic analysis of the equipment or piping systems using the broadened floor design response spectra may be accomplished by the following alternative method which can be used for equipment when analytical techniques are justified for predicting the natural frequencies.

Determine the natural frequencies $(f_e)_n$ of the system to be qualified in the broadened range of the maximum spectrum acceleration peak.

If no equipment or piping system natural frequencies exist in the $\pm 15\%$ interval associated with the maximum spectrum acceleration peak, then the interval associated with the next highest spectrum acceleration peak shall be selected and used in the following procedure.

Consider all N natural frequencies in the interval

$$f_j - 0.15f_j \leq (f_e)_n \leq f_j + 0.15f_j$$

where

f_j

= the frequency of maximum acceleration in the unbroadened spectra

n

= 1 to N

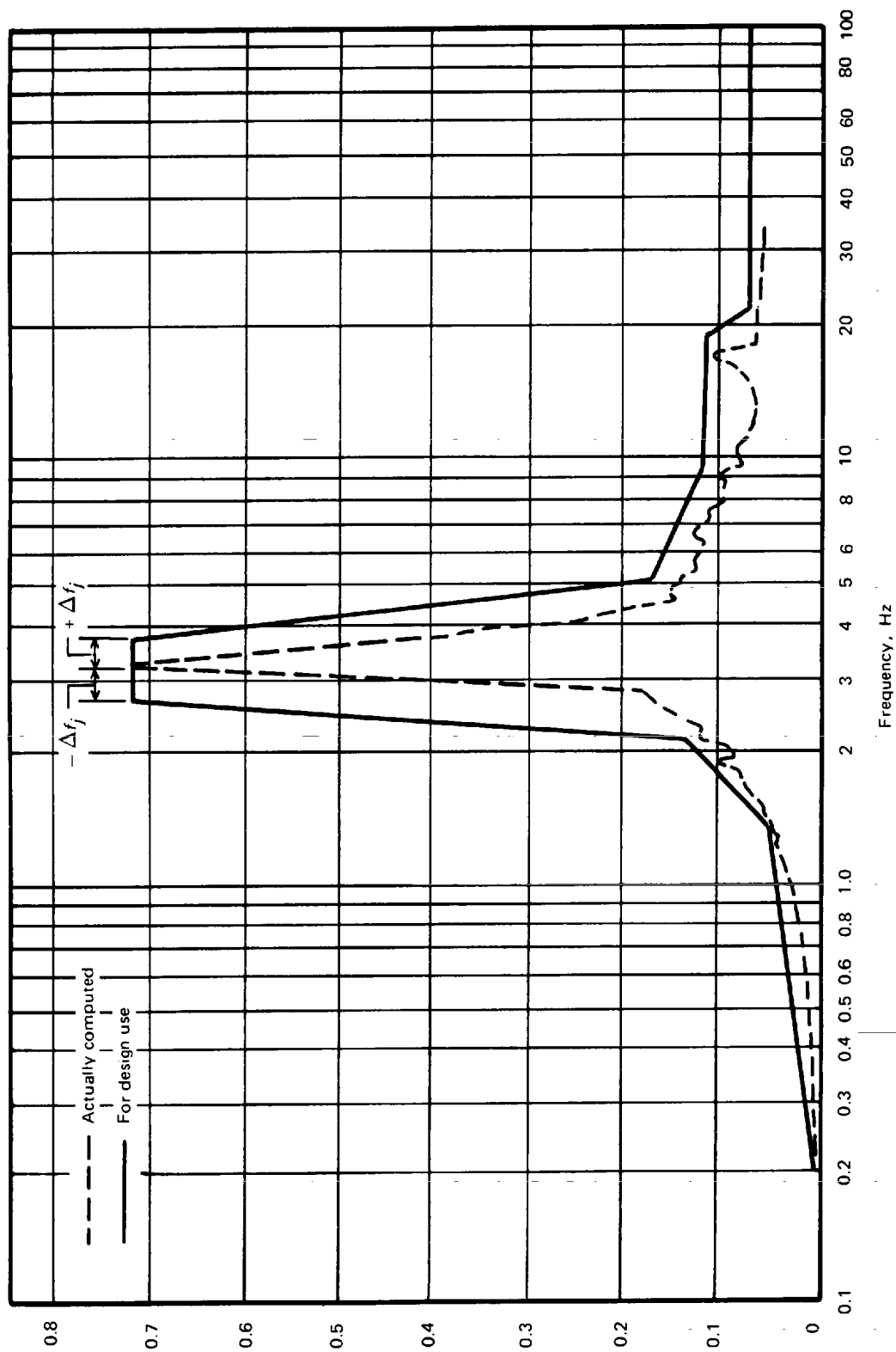


FIG. N-J226-1 RESPONSE SPECTRUM PEAK BROADENING AND PEAK AMPLITUDE

FIG. N-1226-1 RESPONSE SPECTRUM PEAK BROADENING AND PEAK AMPLITUDE

The system shall then be evaluated by performing $N + 3$ separate analyses using the unbroadened floor design response spectrum and the unbroadened spectrum modified by shifting the frequencies associated with each of the spectral values by a factor of +0.15; -0.15; and

$$\frac{(f_e)_n - f_j}{f_j}$$

where

$$n = 1 \text{ to } N$$

The resultants of these separate seismic analyses shall then be enveloped to obtain the final resultant desired (e.g., stress, support loads, acceleration, etc.) at any given point in the system. If three different floor spectrum curves are used to define the response in the two horizontal and the vertical directions, then the shifting of the spectral values as defined above may be applied to these three spectrum curves.

The criterion is illustrated by the following example. Figure N-1226-2, sketch (a) represents the peak broadening on the floor spectrum curve associated with the j th mode structural frequency. Let there be two equipment or piping frequencies $(f_e)_1$ and $(f_e)_2$ that are within the frequency interval of $f_j \pm 0.15f_j$, Fig. N-1226-2, sketch (b). Thus N equals two and therefore five separate floor response spectra must be considered. The unbroadened floor response spectrum as indicated in Fig. N-1226-2, sketch (a) would be the first floor spectrum considered. The unbroadened floor response spectrum modified by shifting all of the frequencies associated with the spectral acceleration values by a factor of -0.15 is illustrated in Fig. N-1226-2, sketch (c). In Fig. N-1226-2, sketches (d) and (e) illustrate the modifications made to the unbroadened floor response spectrum by shifting a factor of

$$\frac{(f_e)_1 - f_j}{f_j} \quad \text{and} \quad \frac{(f_e)_2 - f_j}{f_j}$$

respectively.

Figure N-1226-2, sketch (f) illustrates the modifications made to the unbroadened floor response spectrum by shifting by a factor of +0.15. For this example, the five separate seismic analyses are performed with the individually modified floor response spectrum curves.

The required resultants, stresses, support loads, accelerations, moments, forces, etc., associated with each of the five separate seismic analyses are then obtained. As any of the five modified spectra has an equal probability of occurrence, the resultant utilized to evaluate the seismic loadings shall be the envelope values from the five separate seismic analyses.

N-1227 Multiple Input Response Spectra Analysis

If a structural system is being analyzed by the response spectra method and is supported at intermediate locations with different characteristic response spectra, then the dynamic analysis performed should take into consideration the different response spectra. The effect of relative seismic anchor displacements between the intermediate anchor points should also be considered.

N-1227.1 Inertial Effects Due to Multiple Response Spectra Input.

The effect on a structural system of multiple supports with different characteristic response spectra may be accounted for by selecting a single spectra which will effectively produce the critical maximum responses due to different acceleration existing at anchor points and intermediate restraint points of the system. This may be conservatively accomplished by enveloping the response spectra for the different seismic anchor and restraint locations. Other procedures may be used, if applicable. Acceptable alternative procedures are given in Refs. 7, 43, 44, and 45.

For a structural system which is restrained in different buildings, the response spectra of the restraint point should be enveloped.

N-1227.2 Stresses Due to Relative Seismic Support Displacements

(a) When determining stresses the effects of relative seismic support movements should be considered. When these effects are considered significant, they may be obtained by performing a static structural analysis of the system including anchor movements. For structural systems with several possible combinations of anchor movements, any of the following methods may be used for determining the stresses due to relative support displacements.

(1) Stresses resulting from the differential movement of supports may be calculated for each significant mode using the modal displacement of the supports obtained from the structural response calculations. The maximum model responses are then combined following any of the acceptable methods described in this Appendix. If no support structure modal information is available, then the absolute sum of the displacements may conservatively be used.

(2) If the system is supported on independent structures, then the absolute sum of displacements in

Page 380

each direction should be used unless more detailed analyses are used in accordance with N-1700. Pages 381-381

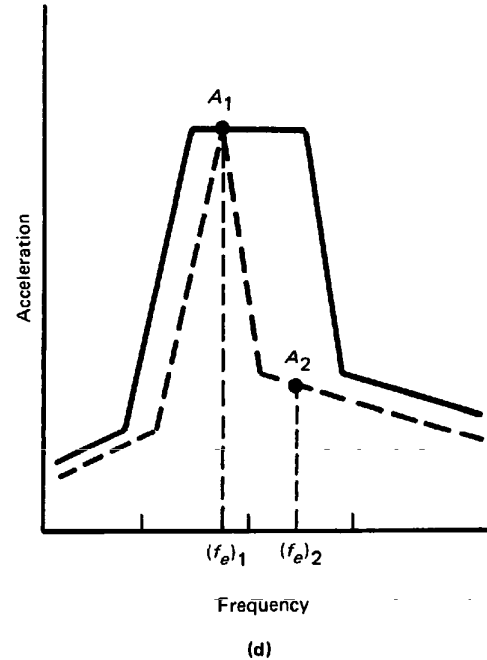
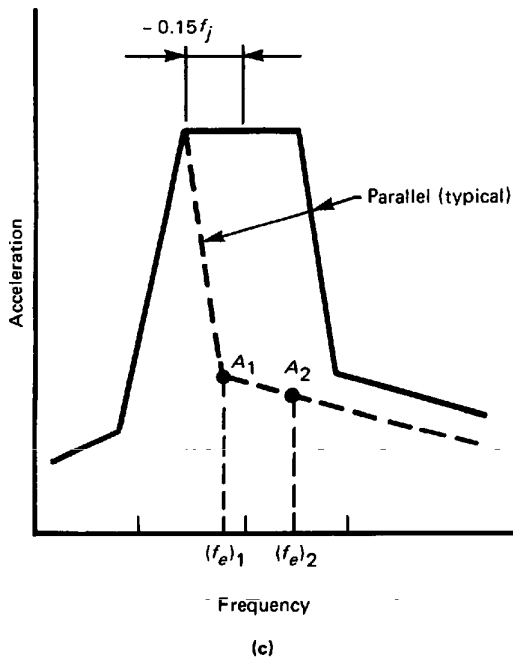
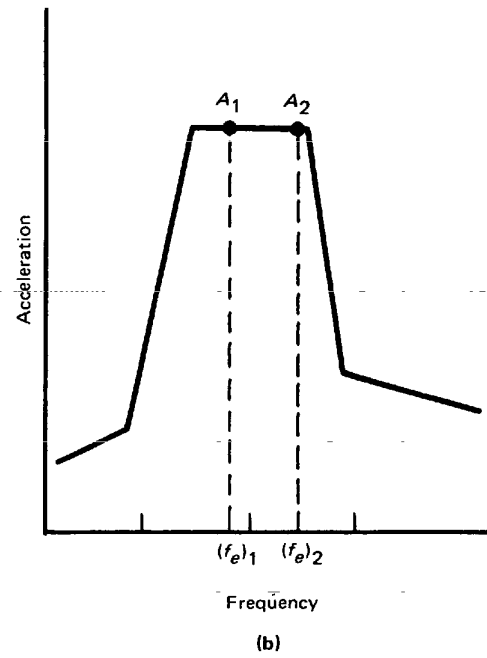
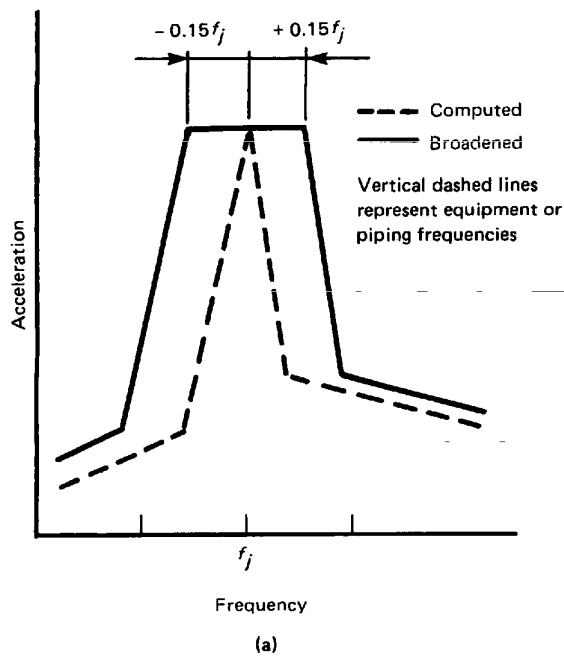


FIG. N-1226-2 USE OF FLOOR SPECTRA WHEN SEVERAL EQUIPMENT FREQUENCIES ARE WITHIN THE WIDENED SPECTRAL PEAK

FIG. N-1226-2 USE OF FLOOR SPECTRA WHEN SEVERAL EQUIPMENT FREQUENCIES ARE WITHIN THE

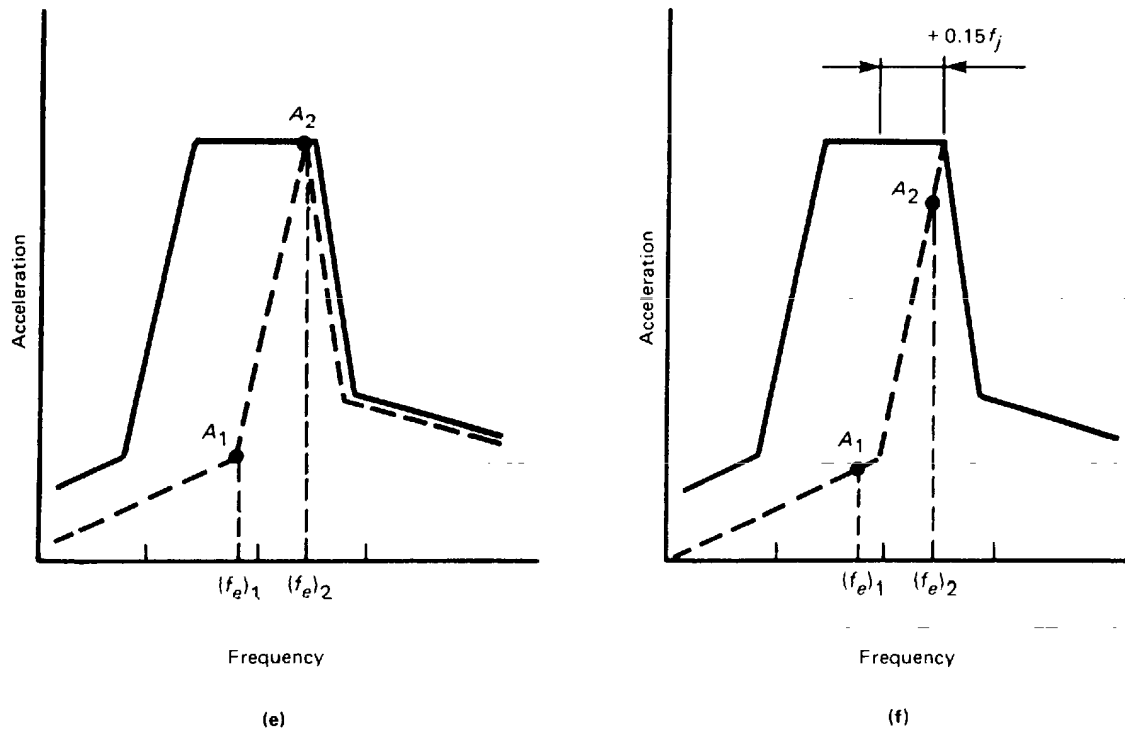


FIG. N-1226-2 USE OF FLOOR SPECTRA WHEN SEVERAL EQUIPMENT FREQUENCIES ARE WITHIN THE WIDENED SPECTRAL PEAK (CONT'D)

FIG. N-1226-2 USE OF FLOOR SPECTRA WHEN SEVERAL EQUIPMENT FREQUENCIES ARE WITHIN THE WIDENED SPECTRAL PEAK (CONT'D)

(3) If a displacement time history of the supporting structure is available, the procedures given in N-1228.4 may be used.

(b) Other detail considerations may be specified for dynamic analysis of Section III components, such as NB-3600 for piping, and these component related rules should be considered in the dynamic analysis.

N-1228 Multiple Time History Excitations

For structural systems supported at several locations, the responses due to simultaneous excitations by different motions at each support may be determined exactly by time history methods, as in N-1228.1. Having performed a time history response analysis, reaction loads and motions may also be determined on a time history basis, as in N-1228.2. Since the inertial effects may be considered to produce primary stresses and the differential support motions may be considered to produce secondary stresses, as in NB-3650, the inertial effects may be determined separately from the differential support movement effects, as in N-1228.3.

N-1228.1 Time History Response Analysis

(a) Several different acceptable methods have been presented in the literature (Refs. 7, 43, and 44) for solving the equations of motion for a structural system excited by multiple simultaneous forcing functions. Since the basic problem to be solved must satisfy the fundamental principles of dynamics, the differences between the various methods are primarily in the approach of the solution process. One method of solution is summarized here to provide insight into the basics of time history analysis for multiple excitations.

(b) The general matrix form of the undamped coupled equations of motion may be written (Refs. 7 and 45) as follows:

$$(32) MX'' + KU = F$$

where X'' represents the absolute acceleration of the mass point dynamic degrees of freedom, and U represents

Page 382

those displacements of the mass and support point dynamic degrees of freedom which would tend to cause distortions in the system. Rigid body translations or rotations are included in the mass acceleration terms on the left-hand side of the equation. Such rigid body motions would not tend to distort the system and accounted for by defining one of the system support points to be the *datum* support, and describing the motion of all other *nondatum* supports as motions relative to the datum support.

(c) Equation (32) can be expanded to give

$$\begin{bmatrix} M_m & 0 \\ 0 & M_s \end{bmatrix} \begin{Bmatrix} X''_m \\ X''_s \end{Bmatrix} + \begin{bmatrix} K_{mm} & K_{ms} \\ K_{sm} & K_{ss} \end{bmatrix} \begin{Bmatrix} U_m \\ U_s \end{Bmatrix} = \begin{Bmatrix} 0 \\ F_s \end{Bmatrix} \quad (33)$$

(33)

where

M_m

= a diagonal submatrix of the system model lumped masses

M_s

= a submatrix of inertia terms associated with the support joints of the system. For the purposes of this analysis, $M = 0$ because there is no mass lumped at support joints

F_s

= the reaction forces at the system support points due to the response of the system to the motion of the support structure

K

= the stiffness matrix of the system model condensed in a manner such that only mass point elements (subscript m) and active, nonreleased, nondatum support elements (subscript s) remain in the matrix

U_m

= displacement of mass point dynamic degrees of freedom relative to the datum support in each coordinate direction

U_s

= displacement of nondatum. support points relative to the datum support

X''_m

= absolute acceleration of mass point dynamic degrees of freedom of the model

X''_s

= absolute acceleration of the system support points

(d) The time history support motions imposed at the nondatum supports include only such displacements as would tend

to cause distortions in the system. Rigid body translation or rotation of the supporting structure would not distort the system being analyzed; therefore, such rigid motions of the supporting structure are removed by computing the nondatum support relative motions as follows:

$$(34) U_s = X_s - X_d - R_s \theta$$

where

U_s	= displacements of nondatum support points relative to the datum support in each direction of excitation
X_s	= absolute displacements of nondatum supports in each direction of excitation
X_d	= absolute displacements of datum supports in each direction of excitation
R_s	= a matrix of three vectors representing distances from the datum support point of the nondatum support points
θ	= rigid body rotations of the supporting structure about each of the three coordinate axes

(e) The first equation of the set of Eqs. (33) yields:

$$(35) M_m X_m'' + K_{mm} U_m + K_{ms} U_s = 0$$

(f) A separation of variables can be achieved by defining the absolute acceleration of a mass point in terms of acceleration relative to the datum support, such that:

$$(36) U_m'' = X_m'' - \gamma X_{sd}'' - R_m \theta''$$

where

γ	= matrix defining the direction of each respective translational dynamic degree of freedom such that:
γ_{ij}	= 1, if the i th dynamic degree of freedom is in the direction of the j th direction of support translation
γ_{ij}	= 0, if the i th dynamic degree of freedom is not in the direction of the j th direction of support translation
X_{sd}''	= the absolute accelerations of the datum support in each coordinate direction
R_m	= a matrix of three vectors representing distances from the datum support point to the mass points for each of the rotational components
θ	= rotational accelerations of the datum support (g) Equation (35) then becomes

$$(37) M_m U_m'' + K_{mm} U_m = -M_m X_{sd}'' - M_m R_m \theta'' - K_{ms} U_s$$

(h) At this point it is to be noted that the equations of motion are in a form expressing three dimensional response of the system mass points due to multiple translational and rotational support excitations in one or more coordinate directions. Normally, the rotations will consist of two components representing rocking about two orthogonal horizontal coordinate axes. The equations, however, are also valid for rotation about the vertical axes. It should be noted again that U

(i) The coupled equations of motion, Eq. (37), may be solved by one of the methods of direct integration, or, introducing the normal mode coordinate transformation:

$$(38) U_m = \phi q$$

where

$$\begin{array}{ll} \phi & = \text{the matrix of eigenvectors of the supported system} \\ q & = \text{the normal mode coordinate} \end{array}$$

(j) Then making the usual assumption of proportional damping for the modes of the supported system, the equations of motion can be uncoupled and written in the following form:

$$\begin{aligned} q'' + 2\xi\omega q' + \omega^2 q = & \\ & - (\phi' M_m \phi)^{-1} (\phi' M_m \gamma X''_{sd} \\ & + \phi' M_m R_m \theta' + \phi' K_{ms} U_s) \end{aligned} \quad (39)$$

(39)

where

$$\begin{array}{ll} \omega^2 & = \text{diagonal matrix of eigenvalues} \\ 2\xi\omega & = \text{diagonal matrix of modal damping terms} \end{array}$$

(k) The right-hand side of Eq. (39) contains no damping terms in a rigorous sense only if the modal damping is proportional to stiffness. However, Ref. 46 points out that the contribution of these terms to earthquake forces can be expected to be small. This term is usually neglected for systems exhibiting structural damping characteristics within the range of the values in Table N-1230-1.

N-1228.2 Time History Reaction Analysis

(a) Having solved the dynamics problem for the time histories of the mass point motions, the resultant reactions at locations throughout the system can be determined for each time step by imposing the deflections on the structure in a series of static problems; one static solution for the deflected shape at each time step. Although this approach is analytically valid, it is generally not practical because of the many thousands of solutions required for the number of time steps in a typical seismic analysis. The problem may be reduced to a single static deflection analysis by applying unit displacements to each mass and support point to determine a set of influence coefficients for each desired reaction. The given support displacements and computed mass point displacements at each time step are multiplied by the set of

influence coefficients to perform a complete reaction analysis of the system at each time step.

(b) The desired components of reaction (force, moment, stress, or deflection) are computed at each time step as follows:

$$(40) R(t) = C_m U_m(t) + C_s U_s(t)$$

where

$R(t)$	= a vector of reaction components at time t
C_m	= a matrix of mass point unit displacement influence coefficients (one column per mass point and one row per reaction component)
C_s	= a matrix of nondatum support point unit displacement influence coefficients (one column per nondatum support and one row per reaction component)
$U_m(t)$	= a vector mass point relative displacements at time t
$U_s(t)$	= a vector of nondatum support relative displacements at time t

(c) In a similar manner, the absolute acceleration of any point in the system may be computed by multiplying the mass point and support relative accelerations by the influence coefficients for displacement reactions, and adding in the datum support rigid body rotational and translational absolute accelerations as follows:

$$R''(t) = \gamma X''_{sd}(t) + C_m U''_m(t) + C_s U''_s(t) + R_p \theta''(t) \quad (41)$$

(41)

where

$R''(t)$	= a vector of absolute acceleration components at time t
$X''_{sd}(t)$	= the translational absolute acceleration of the datum support at time t
C_m	= a matrix of mass point unit displacement influence coefficients for components of displacement reactions
$U''_m(t)$	= a vector of mass point accelerations relative to the datum at time t
C_s	= a matrix of nondatum. support unit displacement influence coefficients for components of displacement reactions
$U''_s(t)$	= a vector of nondatum support relative accelerations at time t
γ	= a vector defining the direction of excitation, such that:
γ_{ij}	= 1, if the j th component of reaction is in the direction of j th support motion

R_P	= 0, if the jth component of reaction is not in direction of the jth support motion = a matrix containing distances to the reaction point from the datum
-------	--

$\theta'(t)$	= the rotational absolute acceleration of the datum support at time t
--------------	---

(d) This method, therefore, permits the calculation of any desired force or moment, or nonmass point motion on a time history basis.

(e) The ability to calculate time history acceleration of nonmass locations in the system permits the subsequent generation of response spectra at any arbitrary point in the system without the necessity of lumping mass at these points.

N-1228.3 Separation of Inertial and Relative Anchor Movement Stress Effects

(a) The terms of the C_s coefficients matrix can be found by applying a unit displacement to each nondatum support in turn, holding all other supports and mass points fixed, and calculating the desired reaction at a given location. The reactions found in this manner are the combined effect of inertial and relative displacement stress producing effects, suitable for meeting the appropriate Code requirements, such as Eq. (10) of NB-3653.1 for Class 1 piping.

(b) Alternatively, one may break up the C terms into two terms C_{s1} and C_{s2} such that

$$(42) R(t) = C_m U_m(t) + C_{s1} U_s(t) + C_{s2} U_s(t)$$

or

$$(43) R_1(t) = C_m U_m(t) + C_{s1} U_s(t)$$

and

$$(44) R_2(t) = C_{s2} U_s(t)$$

where

$R_1(t)$	= a vector of stress reaction components at time t due to inertial responses
$R_2(t)$	= a vector of stress reaction components at time t due to relative support motions
C_{s1}	= a matrix of influence coefficients due to holding all supports fixed and applying the set of forces to all mass points which would be required to hold the mass point in place due to a unit displacement of each nondatum support in turn
C_{s2}	= a matrix of influence coefficients to a unit displacement of each nondatum support in turn, allowing all mass points to respond freely as static degrees of freedom in the structure

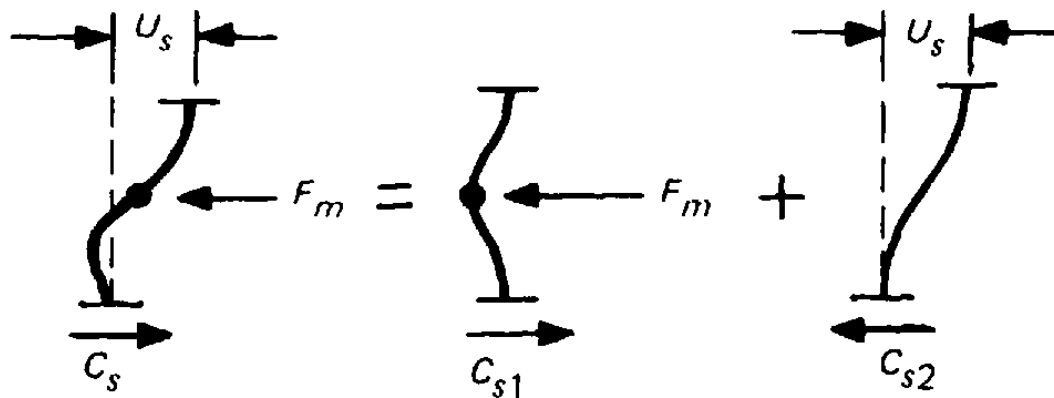


FIG. N-1228.3-1 COEFFICIENTS FOR A COMPONENT OF SHEAR FOR A UNIT DISPLACEMENT OF A NONDATUM SUPPORT

FIG. N-1228.3-1 COEFFICIENTS FOR A COMPONENT OF SHEAR FOR A UNIT DISPLACEMENT OF A NONDATUM SUPPORT

(c) The coefficients for a component of shear for a unit displacement of a nondatum support may be visualized as shown in Fig. N-1228.3-1.

(d) The C_{s1} term therefore represents inertial effect produced by the differential support motion, and the C_{s2} term represents the relative displacement effect of the differential support motion. The separate stresses determined in this manner may be used to meet the appropriate Code requirements, such as Eq. (9) of NB-3652 for Class 1 piping.

N-1228.4 Envelope Excitations

(a) Where the responses are calculated using a single time history excitation for a multiply supported system, the response spectrum of the single time history used should envelop the spectra for the individual support motions. The secondary stress effects of differential support motions may then be determined by a separate static analysis where either:

(1) the set of maximum displacements over all time for each support are applied simultaneously in a single analysis; or

(2) the displacements of each support are applied to perform an analysis for each time step, accounting for sign.

(b) Where the maximum displacements over all time are used in a single analysis, then:

(1) for systems supported at multiple locations on the same floor/wall where one flexural mode dominates, the relative displacement set for the dominant mode may be used, where justified;

(2) for systems supported at multiple locations on different floor/walls or on different structures where different flexural modes can dominate, the displacement may be applied statically as prescribed in N-1227.

(c) Note that, in general, different support displacement sets may be required to obtain conservative

secondary stress effect at different locations within a system, depending on the complexity of a given system.

N-1230 DAMPING

N-1231 Damping Values

(a) Motions in a structural system will dissipate energy from the system. The phenomenon of this kind of energy loss is called damping. In a structural system, sources of energy loss may be due to: a structural damping, which is caused by internal friction within the material or at connections between elements of a structural system; a viscous damping, which is caused by motions in a fluid; Coulomb damping which results from the sliding friction motion of a body on another surface. The following equation of motion is generally used for structural systems and components:

$$(45) [M] \{X''\} + \{D\} + [K] \{X\} = \{F\}$$

where

M	= mass matrix
K	= stiffness matrix
D	= damping force vector
X	= displacement vector
X'	= velocity vector
X''	= acceleration vector
F	= force vector

(b) The damping force $\{D\}$ represents the energy losses of the system. To evaluate these losses, the following alternative mathematical expressions are recommended for the vector $\{D\}$.

(1) Viscous damping:

$$(46) \{D\} = [C] \{X'\}$$

where $[C]$ is a viscous damping matrix. The damping force is proportional to the velocity.

(2) Hysteretic damping:

$$(48) \{D\} = i\nu[K] \{X\}$$

where ν represents the structural damping factor (Ref. 47). This damping is also called complex damping. The damping force is proportional to the amplitude of the displacement and opposite in direction to the velocity:

$$(48) \{D\} = g(abs[K] \{X\}) sgn \{X'\}$$

where g is a damping coefficient (Ref. 48). This damping is also called the Reid's damping. The damping force is proportional to the resisting force due to deformation and in the opposite direction of the velocity in harmonic motion.

**TABLE N-1230-1
DAMPING VALUES
Percent of Critical Damping**

Structure or Component	Earthquake Magnitude	
	Operating Basis Earthquake	Safe Shutdown Earthquake
Equipment and large diameter piping systems, ¹ > 12 in. diam.	2	3
Small diameter piping systems, ≤ 12 in. diam.	1	2
Welded steel structures	2	4
Bolted steel structures	4	7
Prestressed concrete structures	2	5
Reinforced concrete structures	4	7

NOTE:

(1) Includes both material and structural damping. If the piping system consists of only one or two spans, with little structural damping, use values for small diameter piping.

TABLE N-1230-1 DAMPING VALUES Percent of Critical Damping

(3) Coulomb damping:

$$(49)\{D\} = \pm \mu \{N\}$$

where μ is the coefficient of friction and N is the normal force vector. The sign is chosen to be opposite the velocity. The damping force is due to friction and proportional to the normal force.

(4) General dashpot damping:

$$(50) \{D\} = \alpha \{X\} (\text{abs}\{X\})^{n-1}$$

where α is a damping constant and n is an integer. This damping force is due to the turbulence and the dashpot geometry.

(c) These expressions permit the simulation of the energy loss for a particular problem. It is extremely difficult to give an accurate analytical expression for the different forms of damping in complex structural systems. The analyst may select a simple expression, such as viscous or hysteretic damping, to solve the problem by assuming that the energy losses are equivalent; i.e., viscous damped system introduced in the analysis will have the same energy loss per cycle as the real structure.

Page 386

(d) To establish an equivalent viscous damping matrix $[C]$ for the system, experimental data is usually required. Important experimental results, which indicate that energy losses increase with stress or displacement amplitude, or both, have been compiled in existing literature (Refs. 49 and 50). The incorporation of this behavior to the equivalent viscous damping in the transient analysis will usually lead to an expression of the damping force which will make the equations of motion nonlinear. To avoid this inconvenience, conservative modal damping values may be used for nuclear systems and structures for OBE and SSE condition loads, respectively. Table N-1230-1 shows the modal damping values recommended. Damping values higher than the ones given in Table N-1230-1 may be used in a dynamic analysis if the basis is justified.

(e) Methods of incorporating the damping in structural dynamics are usually dependent on the mathematical convenience. The energy loss per cycle is simulated by a convenient mathematical scheme; frequently viscous damping expressions are adopted in the analysis. In N-1232 and N-1233, methods of proportional and nonproportional dampings are discussed and the physical interpretations associated with each method is also examined.

N-1232 Proportional Damping

(a) Consider a viscously damped system of the following form:

$$(51) [M] \{X''\} + [C] \{X'\} + [K] \{X\} = \{F\}$$

Let $[\phi]$ be the modal matrix of the undamped system of

$$(52) [M] \{X''\} + [K] \{X\} = \{0\}$$

such that

$$(53) [\phi]^T [M] [\phi] = [I]$$

and

$$[\phi]^T [K] [\phi] = [\omega^2]$$

where

$[\phi]^T$	= transpose of the matrix $[\phi]$
I	= identity matrix
ω^2	= diagonal matrix
ω_i	= circular frequencies

(b) If the matrix $[C]$ in Eq. (51) can be diagonalized by the undamped normal modes (i.e., $[\phi]^T [C] [\phi]$ is a diagonal matrix), then the damping matrix $[C]$ is called the proportional damping matrix; otherwise, it is called the nonproportional damping matrix.

(c) Reference 52 has illustrated that the matrix $[C]$ can be diagonalized when it is a linear combination of $[M]$ and $[K]$ matrices. Caughey (Ref. 53) has derived more general conditions under which the matrix $[C]$ can be diagonalized.

(d) For proportional damping the equations of motion may be uncoupled into a set of independent one degree of freedom systems. In this case, the damping ratio associated with the different modes can be determined.

(e) Among the category of proportional dampings, two types of damping matrix $[C]$ are commonly adopted; namely, the

mass and stiffness damping and the orthogonal modal damping. Both types of damping are discussed in N-1232.1 and N-1232.2.

N-1232.1 Mass and Stiffness Damping (Ref. 53)

(a) In this damping, the matrix $[C]$ is assumed to be proportional either to the mass matrix $[M]$ or to the stiffness matrix $[K]$ or to a linear combination of the two. That is, it can be written as follows:

$$(54) [C] = \alpha[M] + \beta[K]$$

where

α and β	= two real constants
$\alpha[M]$	= mass damping
$\beta[K]$	= stiffness damping

(b) In using the mass and stiffness damping, damping values of the entire system are determined by the two constants α and β . To determine the value of α and β , one can control the damping ratios for two frequencies.

(c) Let ω_r and ω_s be the two frequencies that we want to have a damping ratio of ξ_r and ξ_s respectively. Then α and β may be determined (Ref. 54) as follows:

$$\begin{aligned}\alpha &= 2\omega_r\omega_s(\xi_s\omega_r - \xi_r\omega_s)/(\omega_r^2 - \omega_s^2) \\ \beta &= 2(\xi_r\omega_r - \xi_s\omega_s)/(\omega_r^2 - \omega_s^2)\end{aligned}\tag{55}$$

(55)

Then, for an arbitrary frequency ω_i the damping ratio ξ_i can be computed by eliminating α and β and is given as:

$$\begin{aligned}\xi_i &= \frac{1}{(\omega_r^2 - \omega_s^2)} \left[\frac{\omega_r\omega_s}{\omega_i} (\xi_s\omega_r - \xi_r\omega_s) \right. \\ &\quad \left. + \omega_i(\xi_r\omega_r - \xi_s\omega_s) \right]\end{aligned}\tag{56}$$

(56)

where

is due to mass damping and.

$$\frac{1}{(\omega_r^2 - \omega_s^2)} \times \omega_i (\xi_r \omega_r - \xi_s \omega_s)$$

is due to stiffness damping.

(d) The application of the mass and stiffness damping concept is illustrated by a following numerical example. Consider a structural system with frequencies of $f_n = n$ Hz for $n = 1, 2, \dots, 25$. For a damping ratio of $\xi_{10} = 0.05 = \xi_{20}$ at frequencies $f_{10} = 10$ Hz and $f_{20} = 20$ Hz and by using Eq. (56), the damping ratios for the other modes may be computed. For example, at the frequencies of 5, 15, and 25 Hz, the corresponding damping ratios are $\xi_5 = 0.075$, $\xi_{15} = 0.047$, and $\xi_{25} = 0.055$.

(e) It should be noted that in Eq. (56), the damping ratio is the sum of the contributions due to the mass and stiffness damping. Using mass damping $\alpha \neq 0$, $\beta \neq 0$, the damping ratio will decrease with increase of the frequency. On the other hand, using stiffness damping $\alpha = 0$, $\beta \neq 0$, the damping ratio will increase with the increase of the frequency.

(f) Mass damping introduces the damping forces that are proportional to the velocities of each mass point in the system. Mass damping may be used to represent the energy loss due to impact and friction. Stiffness damping introduces the damping forces that are proportional to the time rate of deformation. Stiffness damping can be used to represent the structural damping. While the mass damping introduces the damping forces due to the rigid body motion (displacements without deformations) of the system, the stiffness damping does not.

(g) In seismic analysis of a structural system, the equation of motion is generally formulated in terms of the displacements with respect to the base. If the damping ratios are established for the two significant frequencies, the mass and stiffness dampings may be adopted. The damping ratios for the other frequencies are computed with the aid of Eq. (56). If only stiffness damping is used, and for the significant frequency Ω_r , the established damping ratio is ξ_r , then

$$\beta = \frac{2\xi_r}{\omega_r} \text{ and } \xi_i = \xi_r \frac{\omega_i}{\omega_r}$$

where ξ_i is the damping ratio for the modal frequency ω_i .

N-1232.2 Orthogonal Modal Damping (Ref. 54).

In the orthogonal modal damping method, the damping matrix $[C]$ in Eq. (51) is not formulated in advance. After solving the eigenvalue problem, the system or uncoupled equations are assumed to have the form

$$q''_i + \xi_i(2\omega_i)q'_i + \omega_i^2 q_i = f_i$$

$$i = 1, 2, \dots, N \quad (57)$$

(57) where the second term in Eq. (57) is added to account for the damping. The damping ratio for each frequency is free to be determined by the analyst without any mathematical restriction. The damping ratio assigned to one mode will have no effect on the damping ratios of the others; the modes are orthogonal. These ratios can be obtained from the experimental results. This method is used often in solving viscously damped systems. The example problems for the various damping methods discussed here are given in Ref. 55.

N-1233 Nonproportional Damping

In the foregoing discussion of the proportional damping (N-1232), the damping of a structural system was assumed to have a form that couplings do not exist between the classical modes of vibrations; i.e., the mode shapes obtained from the solution of a free vibration of the undamped system. This approach is appropriate for the correlation of test data for a structural system composed of a single material, or damping mechanism which is homogeneous throughout the system. However, for a system which is composed of different materials, such as a reactor coolant loops, containment building, and soil foundation, the damping mechanism of one type of material may be considerably different from the other. In order to have a better simulation of the damping, it is useful to construct a damping matrix which reflects the material composition rather than the mathematical convenience (Refs. 56 and 57). The damping matrix so constructed will no longer be diagonalized by the classical modes. The term *nonproportional damping* is used for this type of damping. In nonproportional damping, the matrices $[M]$, $[K]$, and $[C]$ are used to solve the complex frequencies and mode shapes. From the complex frequencies, damping ratios associated with each mode can readily be computed. Unlike proportional damping, the matrix

[C] of a nonproportional damping system cannot be formulated simply by specifying a set of damping ratios, unless a mathematical process of successive approximations is performed. Due to the mathematical complexity involved in the complex frequencies and mode shapes solution, the process of assigning a set of damping ratios with respect to the complex modes becomes impractical. For certain types of structures such as reactor coolant loops, the system exhibits a pronounced modal behavior (Ref. 58). Instead of using a set of damping ratios based on the complex frequencies and modes, the classical modes and frequencies may be used to avoid the mathematical complexity. N-1233.1 and N-1233.2 describe acceptable methods for the formulation of a nonproportional damping matrix for a structural system which is composed of different materials.

N-1233.1 Composite Mass Damping and Stiffness Damping

(a) In the proportional damping, Eq. (51) of N-1232, the system damping matrix is assumed to be a linear combination of the system mass and stiffness matrices, without any distinction of the material damping property. Different sets of proportional constants for mass and stiffness may be assumed to formulate a system damping matrix. Using the concept of mass and stiffness damping, the energy dissipation function D for the system can be written as follows:

$$D = \frac{1}{2} \sum_{i=1}^{nc} (\alpha_i \{X'\}_i^T [M]_i \{X'\}_i + \beta_i \{X'\}_i^T [K]_i \{X'\}_i) \quad (58)$$

(58)

where

$[M]_i$	= mass matrix of subsystem i
$[K]_i$	= stiffness matrix of subsystem i
α_i	= mass proportional constant of subsystem i
β_i	= stiffness proportional constant of subsystem i
nc	= number of subsystems

For the systems with constant damping values, α_i and β_i are the same for all elements. However, when the system is composite, which consists of subsystems with different damping values, α_i and β_i are different for different subsystems but constant within each subsystem. These constants may be established for each subsystem as discussed in N-1232.1.

(b) This decomposition to allow different damping constants α_i and β_i to be used for each different subsystem may be based on the damping values recommended in Table N-1230-1.

(c) To determine the constants α_i and β_i , the frequencies and modes of the free undamped vibration of the i th subsystem are used as a basis. The mathematical process involved is similar to the one of stiffness and mass damping described in N-1232.1 except the constants α and β are different for each material or subsystem.

(d) Using Eq. (58), the equation of motion of a viscously damped system has the following form:

$$[M]\{X'\} + \sum_{i=1}^{nc} (\alpha_i[M]_i + \beta_i[K]_i)\{X'\} + [K]\{X\} = \{F\} \quad (59)$$

(59)

(e) Equation (59) may be integrated directly to obtain the response. If normal mode method is used, Eq. (59) may be solved by neglecting the modal coupling effect to decouple the equations of motions on the normal mode basis.

(f) Let $\{\phi\}$ be the modal matrix of the undamped system of Eq. (59) and $\{\phi_j\}$ be the j th modal vector. With the aid of the orthogonality conditions, the equation of motion for the j th mode can be written in the following form:

$$\begin{aligned} & \{\phi_j\}^T [M] \{\phi_j\} q''_j + \{\phi_j\}^T \sum_{i=1}^n (\alpha_i[M]_i + \beta_i[K]_i) \{\phi\} \{q'_j\} \\ & + \{\phi_j\}^T [K] \{\phi_j\} q_j = \{\phi_j\}^T \{F\} \end{aligned} \quad (60)$$

(60)

where q''_j is the j th generalized coordinate. The second term on the left-hand side of Eq. (60) contains the coupling terms. If these coupling terms are neglected, Eq. (60) reduces to the following equation:

$$[\phi_j]^T [M] \{\phi_j\} \ddot{q}_j + \{\phi_j\}^T \sum_{i=1}^n$$

$$(\alpha_i [M]_i + \beta_i [K]_i) \{\phi_j\} \dot{q}_j$$

Page 389

$$+ \{\phi_j\}^T [K] \{\phi_j\} q_j = \{\phi_j\}^T \{F\} \quad (61)$$

(61)

or

$$\begin{aligned}
 q''_j + 2w_j \left(\frac{\sum_{i=1}^{nc} \{\phi_j\}^T \alpha_i [M]_i \{\phi_j\}}{2\omega_j \{\phi_j\}^T [M] \{\phi_j\}} \right. \\
 \left. + \frac{\sum_{i=1}^{nc} \omega_j \{\phi_j\} \beta_i [K]_i \{\phi_j\}}{2\{\phi_j\}^T [K] \{\phi_j\}} \cdot q_j \right) \\
 + \omega_j^2 q_j = \frac{\{\phi_j\}^T \{F\}}{\{\phi_j\}^T [M] \{\phi_j\}} \quad (62)
 \end{aligned}$$

(62)

Consequently, the effective damping for the j th mode is as follows:

$$\xi_j = \frac{\sum_{i=1}^{nc} \{\phi\}^T \alpha_i [M]_i \{\phi_j\}}{2\omega_j \{\phi_j\}^T [M] \{\phi_j\}} + \frac{\sum_{i=1}^{nc} \omega_j \{\phi_j\}^T \beta_i [K]_i \{\phi_j\}}{2\{\phi_j\}^T [K] \{\phi_j\}} \quad (63)$$

(63)

or

$$\xi_j = \frac{\sum_{i=1}^{nc} \alpha_i \left(\begin{array}{c} \text{max. kinetic energy for } i\text{th} \\ \text{subsystem in the } j\text{th mode} \end{array} \right)}{2\omega_j (\text{max. kinetic energy for the system})} + \frac{\sum_{i=1}^{nc} \beta_i \left(\begin{array}{c} \text{max. strain energy for } i\text{th} \\ \text{subsystem in the } j\text{th mode} \end{array} \right)}{2 (\text{max. strain energy for the system})} \quad (64)$$

(64)

(g) Equation (63) can be greatly simplified if either α_i or β_i is assumed to be zero. This assumption may be used in the structural analysis for seismic loads where damping is generally assumed proportional either to the kinetic energy distribution of the subsystems or to the strain energy stored.

(h) Once the damping ratio ξ_j is known, the analysis can be carried out using a time history or response spectrum technique.

N-1233.2 Subregional Modal Damping

(a) In dynamic analysis of soil-structure interaction, the modal damping value of the soil is often higher than that of the superstructure. In addition, the modal damping values of the various subsystems, building, loop, etc., of the superstructure may be different. There are several acceptable approximate methods to simulate this subregional modal damping characteristic. These methods are briefly discussed here. One method from Ref. 15 is to relate composite damping to absolute displacement Eq. (65), while another method (Ref. 59) is to relate it to relative displacement Eq. (66):

$$\xi_j = \frac{\sum_{i=1}^{nc} \{\phi_j\}^T \beta_i [M]_i \{\phi_j\}}{\{\phi_j\}^T [M] \{\phi_j\}} \quad (65)$$

$$\xi_j = \frac{\sum_{i=1}^{nc} \{\phi_j\}^T \beta_i [K]_i \{\phi_j\}}{\{\phi_j\}^T [K] \{\phi_j\}} \quad (66)$$

(65 - 66)

where

ξ_j	= % critical damping for j th mode
nc	= number of subsystems
$\{\phi_j\}$	= j th eigenvector
$[M]$	= total system mass matrix
$[K]$	= total system stiffness matrix
$[M]_i$	= mass matrix of i th subsystem
$[K]_i$	= stiffness matrix of i th subsystem
β_i	= % critical damping associated with i th subsystem

(b) Another acceptable approximate method employs mass and stiffness damping for each subsystem. This method calculates coefficients α and β , Eq. (55) of N-1232, for a subsystem such that its modal damping is simulated in the frequency range of interest. The damping matrices of all the subsystems are assembled to formulate a total system damping matrix. Another acceptable approach to generate a total damping matrix is discussed in Ref. 62.

(c) All the methods discussed above are approximate. More accurate techniques are also acceptable. A more rigorous method to formulate a damping matrix for a total system is based on the modal synthesis procedure. This procedure is

explained by Hurty (Ref. 56). Various investigators have developed another method (Ref. 63) modifying this procedure. In this procedure, the total system having nonproportional damping is divided into subsystems, each having proportional damping. Each subsystem is represented by its modal mass, damping, and stiffness matrices. As each subsystem has a proportional damping, the associated modal damping matrix is formulated without any approximation. The modal matrices of all the subsystems are assembled and the displacement compatibility at subsystem interfaces are satisfied. The resulting equations of motion are solved

Page 390

and with the aid of a transformation matrix, actual response is obtained. References 57, 64, and 65 give the details of the application of this method.

(d) The total damping matrix developed by the preceding methods represents the viscous damping. An acceptable alternative formulation for damping, derived in Ref. 66, is an equivalent modal damping ratio which represents the viscous damping in the swaying spring and the hysteretic damping in the rest of the soil-structure system (the superstructure and the rocking spring).

N-1234 Linear Hysteretic Damping

(a) In this paragraph the linear hysteretic damping of the Reid's model (Ref. 48) will be discussed. This nonlinear model leads to well posed mathematical problems for transient and steady-state oscillations of all kinds. The damping forces of the Reid's model are assumed to be proportional to the internal forces of the structure but in phase with the associated velocities. By using the Reid's damping model, the equation of motion [Eq. (45) of N-1231] becomes:

$$(67) [M]X'' + g \{ (abs [K] \{X\}) \times (sgn \{X'\}) \} + [K] \{X\} = \{F\}$$

where

g	= damping coefficient
$abs[K] \{X\}$	= the absolute value of each component
$sgn\{X'\}$	= the algebraic sign of the velocity $\{X'\}$

(b) The Reid's damping model has the following characteristics (Ref. 67):

(1) the energy loss per cycle in a harmonic motion is proportional to the coefficient g and square of the amplitude of displacement and independent of the frequency;

(2) for light damping ($g^2 \ll 1$) the Reid's damping model will be equivalent to the classical modal damping with a damping ratio of $\xi = g/2\pi$ for each mode of vibration.

(c) Similar to the case of composite mass damping and stiffness damping, the damping coefficient g in Eq. (67) may also be considered as the elemental basis for a structural system which is composed of materials with different damping values.

N-1300 FLOW-INDUCED VIBRATION OF TUBES AND TUBE BANKS

N-1310 INTRODUCTION AND SCOPE

The flow-induced vibration (FIV) potential of structures has been known for a long time (Refs. 79 through 84). FIV analyses are required to determine the adequacy of a design, or in areas of uncertainty, to be aware of the need for experimental verification (Refs. 85 and 86) if high reliability of the component is a necessity. FIV may be due to any one of several excitation mechanisms because power systems include many types of flexible components subject to a variety of fluid flows, such as pipe, channel, and jet flows followed by mixing in plenums and heat exchangers. Since a single component is often subjected to different turbulent flows from several directions because of the influence of adjacent structures and boundaries, FIV analyses for more than one excitation mechanism is not unusual.

The quantitative data and correlations available to perform FIV analyses are unique to the flow geometry created by each component. More quantitative information and design methods are available for some components than others. In particular, the circular cylinder has been studied most. N-1320 through N-1340 of this Appendix are presented to illustrate one or more acceptable steps for the FIV analysis of arrays of cylinders subject to the three most significant excitation mechanisms. The

general methods employed are applicable to other types of components, but the data are specifically for single cylinders and cylindrical arrays. Because of the large number of FIV mechanisms, the methodology of analysis is referenced, but enough information is given to understand a mechanism and make design calculations. Because of the developing nature of the subject, more than one set of design data or methods may be recommended with the implication to the designer to use either the more appropriate or the more conservative predictions.

Semiempirical correlations based on experimental data, but guided by the equations of motion, often form the basis of a design method. The state-of-the-art regarding description of the FIV mechanisms is that many mathematical models have been proposed for fluid-structure coupling forces, but general agreement on the physics of many of the phenomena has not been attained, although models simulating the behavior may be available.

N-1311 Definitions

In this section some commonly used terminologies in flow-induced vibration analysis are defined and briefly described.

Page 391

(a) *Fluid forces* can be defined into two broad categories to describe FIV excitation mechanisms (Refs. 79 through 83). Fluid excitation forces are created by the incident flow on a structure, and they would occur, in some form, even without structural motion. Fluid structure coupling forces are induced by structural motion, and they occur in both flowing and nonflowing fluids.

(b) *Added mass and added damping* have been successfully used to characterize the fluid-structure coupling forces created by the motion of a structure in a nonflowing fluid (Refs. 87 through 93)). Added mass and added damping increase the effective mass and damping of a structure vibrating in a fluid. In addition, the presence of a dense fluid between otherwise unconnected, adjacent structures can couple their vibrations and result in significantly different natural frequencies, mode shapes, and damping from those obtained in a vacuum. For a low density fluid (e.g., air); the added mass is often negligible.

(c) In a *weakly coupled fluid-structure system*, the FIV excitation mechanism causes small structural motion and the fluid forces induced by the structural motion can be linearly superimposed onto the fluid excitation forces which are largely independent of the structural motion. The fluid-structure coupling forces can be expressed to a first order of approximation in terms of added mass, stiffness, and damping matrices. The fluid excitation forces can be determined separately from the coupling forces either by analysis or by model tests with only the hydraulics simulated.

Examples of FIV excitation mechanisms producing weakly coupled fluid-structure systems are incident flow turbulence and turbulent boundary layers over rods, plates, and shells (Refs. 81 and 82)); some wake flows produced by flow across bluff bodies; and many sources of acoustic noise (Refs. 80 and 95)). In these cases, the fluid excitation energy is generated at some point in the fluid circuit and the structure is the recipient of the energy. The forces due to flow turbulence and attached boundary layers typically are broadband random, while separated wake flows that roll into periodically shed vortices can produce very discrete frequency forces (Refs. 82, 87, and 97).

(d) In a *strongly coupled fluid-structure system*, the FIV excitation mechanism causes the structural motion to become large enough to change the flow field; some of the fluid forces amplify, rather than inhibit, the structural motion that produced them. Clearly distinguishing between fluid-structure coupling forces and fluid excitation forces is difficult in strongly coupled fluid-structure systems. In general, the coupling forces are highly nonlinear functions of structural motion and flow velocity.

(e) *Fluid-elastic instability* of closely packed heat exchanger tube bundles (Refs. 80, 81, 82, and 88) is an example of a strongly coupled fluid-structure system. The motion of each tube affects the fluid forces and the motion of the other tubes to produce self-excitation. The occurrence of the instability has been interpreted as due to adverse changes in the structural mass, damping, and fluid-structure coupling force (Ref. 88). However, most of the expressions for predicting the onset of instability are based on compilations of direct measurements of the critical velocities at the onset of instability.

(f) *Cross flow* is a flow perpendicular to the structural longitudinal axis. Cross flow is one example where an FIV mechanism is produced that can create either a weakly or a strongly coupled fluid-structure system. Vortex shedding in the wake of a tube in cross flow produces both fluid excitation forces and fluid-structure coupling forces that amplify structural motion. For ideal cross flow, where a long, smooth surface tube is isolated in uniform (2-D) cross flow with little or no turbulence in the approaching flow stream, very periodic, two-dimensional vortices are shed. These vortices

produce alternating lift forces normal to the tube axis and flow and are nearly as large as the steady, flow direction drag forces, if the Reynolds number, based on the tube diameter, is below 2×10^5 (Refs. 82, 87, and 89). If the vortex shedding frequency is sufficiently different from the structural natural frequencies, the alternating lift forces act as fluid excitation forces only. However, if the vortex shedding frequency and one of the structural natural frequencies are sufficiently close to each other and the fluid excitation forces can produce large enough motion, then coupled fluid-structure forces occur, which apparently further amplify the motion. Enough experimental data are available to bound the fluid excitation forces, but the representation of the coupled fluid structure forces is still being researched. Most of the representations are based on highly phenomenological models that stimulate, to various degrees, a small amount of data covering only a narrow range of idealized conditions.

(g) The *joint acceptance* is a measure of the probability that a structure vibrating in one mode will remain in the same mode when excited by a random force; the *cross acceptance* is a measure of the probability that a structure vibrating in one mode will change to another mode when excited by a random force. For many applications only the joint acceptance is assumed to be important. When mode shapes are normalized to unity, the sum of the joint acceptances is equal to 1

Page 392

(see N-1342.1). Therefore, the assumption that the joint acceptance is equal to 1 gives conservative estimates of structural responses.

N-1312 Nomenclature

C_n = reduced damping in n th mode
 C_L = lift coefficient
 D = cylinder diameter
 E = Young's modulus
 f_n = natural frequency of n th vibration mode, hertz
 f_s = frequency of periodic vortex shedding, hertz
 F = force
 G_f = single-sided power spectral density of the forcing function, in (force/length)² per Hz
 G_i^f = G_f spectrum for the i th span of a multi-span tube
 G_y = single-sided power spectral density of response
 H_j = transfer function of j th vibration mode
 I = area moment of inertia
 J^2 = joint acceptance
 J_{jk}^2 = cross acceptance for the j th and k th vibration modes
 $(J_{jk}^i)^2$ = acceptance for the i th span
 ℓ_c = axial correlation length
 $= 2 \int_0^{\ell_c} r(x') dx'$ where $r(x')$ is the correlation function and x' is the separation distance
 ℓ_c^i = correlation length in the i th span
 L_e = cylinder length subject to vortex shedding
 L_i = span length
 m = mass per unit length
 m_A = added fluid mass per unit length
 m_c = contained fluid mass per unit length
 m_f = cylinder displaced fluid mass/length
 m_s = structural mass per unit length
 m_t = total mass per unit length of tube
 $= m_A + m_c + m_s$
 M_j = modal mass
 M_n = effective modal mass/length for n th vibration mode
 n = vibration mode, $n = 1$ is fundamental mode
 p = pressure
 P = tube pitch
 $=$ distance between tube centers
 q = dynamic pressure, $(1/2)\rho V^2$
 Re = Reynolds number, VD/ν
 R_p = Cross correlation of the pressure field
 S = Strouhal number, $f_s D/V$
 S_f = cross spectral density of the forcing function on a cylinder, (force/length)² per Hz
 S_{fp} = power spectral density of the forcing function
 S_p = cross spectral density of the pressure field
 S_y = power spectral density of cylinder response
 t = time

TERMLIST

- U_c = convection velocity
 V = mean velocity
 x = axial distance
 y_n^* = maximum displacement in n th vibration mode
 $\bar{y}^2$ = mean square response of a cylinder
 α_n = amplification factor in n th vibration mode
 γ_n = mode shape factor in n th vibration mode
 Γ = coherence of forcing function on a cylinder
 Γ^i = coherence for i th span
 δ_m = mass-damping parameter, $2\pi\xi_n m_t / \rho D^2$
 δ_n = log decrement for n th vibration mode
 $\quad = 2\pi\xi_n$
 ξ_n = fraction of critical damping for n th mode
 ρ = fluid mass density
 ϕ_n = n th vibration mode shape
 ϕ_n^* = maximum value of ϕ_n
 θ = angle between direction of flow and normal to tube axis
 ν = kinematic viscosity
 Ω = frequency, radiant/sec

TERMLIST

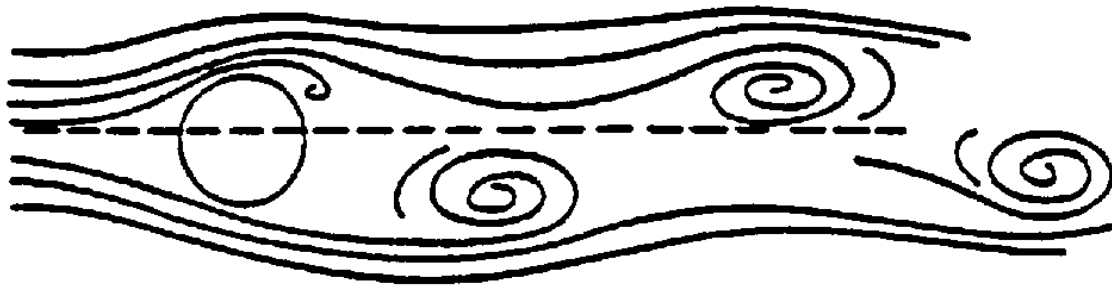


FIG. N-1321-1 VORTICES SHED FROM A CIRCULAR CYLINDER

FIG. N-1321-1 VORTICES SHED FROM A CIRCULAR CYLINDER

N-1320 VORTEX SHEDDING

N-1321 Vortex Shedding From a Fixed Bluff Body

For a bluff body in uniform cross flow, the wake behind the body is no longer regular, but contains distinct vortices of the pattern shown in Fig. N-1321-1 for a circular cylinder. The vortices are shed alternatively from each side of the body in a regular manner and give rise to an alternating lift force. Experimental studies of this vortex shedding process have shown (Refs. 94 and 95) that the frequency in hertz of the alternating lift force can be expressed as:

$$(68)f_s = SV/D$$

Some common types of bodies or structures for which vortex shedding occurs are shown in Fig. N-1321-2. The following discussions are based on the circular

Page 393

cylinder; however, the concepts apply equally well to other bluff bodies.

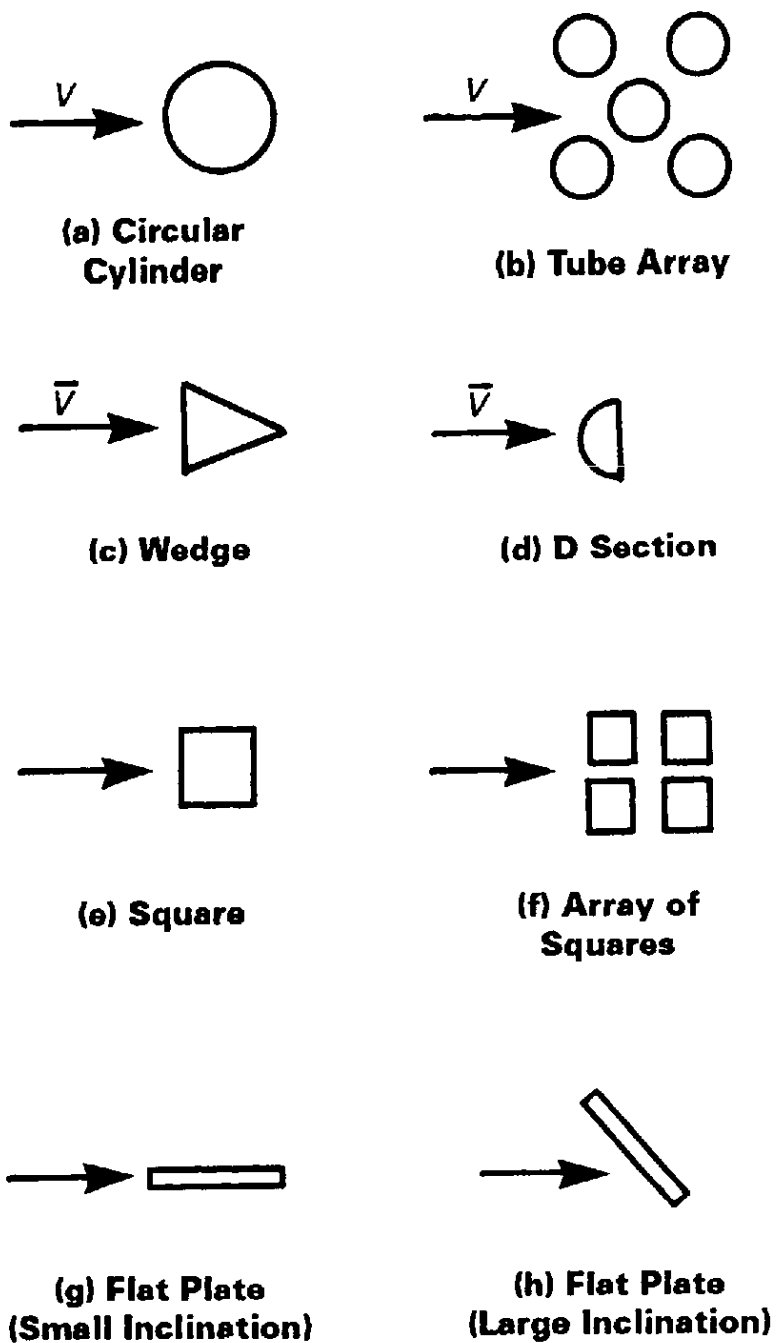


FIG. N-1321-2 SOME TYPICAL CROSS SECTIONS OF BLUFF BODIES THAT CAN EXPERIENCE VORTEX SHEDDING

FIG. N-1321-2 SOME TYPICAL CROSS SECTIONS OF BLUFF BODIES THAT CAN EXPERIENCE VORTEX SHEDDING

The oscillating lift force produced on an isolated single cylinder of diameter D and length L by uniform cross flow can be expressed as (Refs. 96 and 97):

$$(69) F = C_L J q D L [\sin (2\pi f_s t)]$$

where C_L , f_s , and J are functions of the Reynolds number Re and must be determined experimentally. In uniform cross flow, the energy of vortex shedding occurs over a very narrow frequency band with a center frequency f_s except over a transition band of Reynolds number (2×10^5 to 3×10^6) where the character of the frequency content may vary from almost periodic to completely random. The measured Strouhal number is $SB 0.2$ for $10^3 < Re < 2 \times 10^5$; for larger Re , experimental values of S and C_L show considerable scatter.

The alternating vortex fluid forces are not generally correlated over the entire cylinder length L . As a consequence, two limiting cases of the joint acceptance exist for a uniform rigid-body-mode (Ref. 97).

$$\begin{aligned} J^2 &= \ell_c / L && \text{if } \ell_c \ll L \\ &= 1 && \text{if fully correlated} \end{aligned} \quad (70)$$

(70)

The correlation length in the lift direction for stationary cylinders has been found to be approximately 3 to 7 diameters ($3D < \ell_c < 7D$), for $10^3 < Re < 2 \times 10^5$ (Ref. 87). For larger Reynolds numbers, the correlation lengths for stationary cylinders can be expected to be even smaller because the attached boundary layer becomes fully turbulent. J^2 is usually much less than 1 for long stationary cylinders. Motion of the cylinder at the frequency of vortex shedding substantially increases the correlation length (Refs. 82 and 87) as discussed in N-1323 and N-1324.

Vortex shedding also induces a force in the stream-wise or drag direction. The drag force occurs at twice the vortex shedding frequency for single cylinders (Ref. 87). However, the magnitude of the oscillating drag force is typically an order of magnitude smaller than the oscillating lift force.

N-1322 Practical Cross Flow

The case of ideal cross flow is rarely found except in the laboratory. Many practical conditions reduce the effectiveness and strength of vortex shedding as an excitation mechanism:

(a) If the body is located in a turbulent flow, or if the tube surface is rough, the turbulence tends to widen the band of shedding frequencies and decrease the energy at the dominant shedding frequency (Ref. 129).

(b) If the cylinder is inclined to the flow, the shedding frequency can be adequately predicted by employing the component of flow velocity normal to the cylinder axis

$$(71) f_s = (SV/D) \cos \theta$$

where θ is the angle between the direction of flow and the normal to the cylinder axis. Inclined flow tends to reduce the magnitude of the vortex shedding forces (Ref. 98).

(c) Spanwise variations in flow velocity imply that the vortex shedding frequency also varies in the spanwise direction. This effect will generally reduce the magnitude of the net vortex shedding excitation.

(d) There is some evidence (Refs. 99, 100) that vortex shedding does not occur in two-phase flow and that vortex shedding is only a concern in single-phase flows.

(e) While the vortex shedding characteristics discussed above have general applicability, the effects of adjacent bodies have not been specifically included. Studies of two (Ref. 101) or more circular cylinders show that vortex shedding does occur, but its character is very sensitive to the relative location and spacing of the cylinders. For the important case of tube arrays, the values of S , J , and C_L to be employed in Eq. (69) of N-1321 are much more uncertain than for single cylinders, as is evident by the considerable scatter in the experimental data (Refs. 100, 102, 103, 104, 105, 139, and 140).

N-1323 Flexible Cylinders

When the vortex shedding frequency f_s is sufficiently different from the structural natural frequencies, a condition called off-resonance, the representation of the vortex shedding lift force by F given in Eq. (69) of N-1321 is valid, and is conservative if $C_L = 1$ and $J = 1$ is chosen. This conservative representation of the force can be extended to nonuniform loading, and modal response can be employed to simplify the analysis of cylinders where many modes are active. Normally, off-resonance response is small. However, as resonance is approached, large motions are encountered.

In the case of a single flexible or resiliently supported tube, once vibration begins the shedding frequency and the tube natural frequency can become synchronized if the two are sufficiently close. For a spring-supported cylinder in an air stream, it was shown (Ref. 106) that the velocity range over which synchronization persists depends upon the damping parameter, $m_t \delta_t / \rho D^2$. In Fig. N-1323-1, the shaded area is the region of synchronization. The ordinate, $V/f_n D$, is a reduced velocity, where f_n is the natural frequency of the spring-mounted cylinder. Note, in particular, that with increasing $m_t \delta_t / \rho D^2$ the reduced velocity range over which synchronization persists decreases, and no synchronization occurs for $m_t \delta_t / \rho D^2 < 32$. Outside the shaded area, the cylinder experiences an alternating lift force at the vortex shedding frequency for a stationary cylinder, as given previously in Eq. (69) of N-1321.

The consequences of synchronization are many. As the flow velocity is either increased or decreased so that the vortex shedding frequency approaches the structure frequency, the following will occur.

(a) The vortex shedding frequency shifts to the structural natural frequency, i.e., it synchronizes with or "locks-in" to the structural frequency even if the flow velocity or the structural frequency is varied within the range of synchronization as indicated in Fig. N-1323-1.

(b) The spanwise correlation of the vortex shedding forcing function increases rapidly as structural response increases.

(c) The lift force becomes a function of structural amplitude.

(d) The drag force on the structure increases.

(e) The strength of the shed vortices increases.

Within the synchronization band, substantial resonant vibration in lightly damped structures often occurs. Vibration amplitudes up to three diameters peak-to-peak have been observed in dense fluids, such as water, over cables and tubing. The vibrations are predominantly transverse to the flow and they are self-limiting (Refs. 82, 87, and 94).

Large-amplitude, synchronized vibrations in the drag direction have been observed for a single cylinder in water. These oscillations initiate at relatively low flow velocities corresponding to subharmonic frequencies of vortex shedding, i.e., at $1/4$, $1/3$, or $1/2$ the flow velocity required for synchronization according to Eq. (68) of N-1321 (Refs. 107 and 108). However, the synchronization in the drag direction is not as strong as in the lift direction, and usually occurs only for lightly damped structures in dense fluids (Refs. 87 and 110). Lock-in has not been observed in two-phase flow or deep (more than a few rows) inside a closely spaced tube bundle.

N-1324 Design Procedures for a Circular Cylinder

Whenever possible, lock-in operating conditions should be avoided, but complex designs often make this impossible. Thus, criteria are given for which lock-in can be avoided, and off-resonance structural dynamic analysis can be employed, as well as design procedures to calculate the response during lock-in.

N-1324.1 Avoiding Lock-In Synchronization.

Lock-in for a single cylinder can be avoided by one of the following four methods (Refs. 82, 106, 108, and 109). For tube arrays, only (a), (b), and (c) are applicable methods, and V must be the flow velocity in the minimum gap (P - D).

(a) If the reduced velocity for the fundamental vibration mode ($n = 1$) satisfies:

$$(72) V/f_n D < 1$$

then both lift and drag direction lock-in are avoided.

Page 395

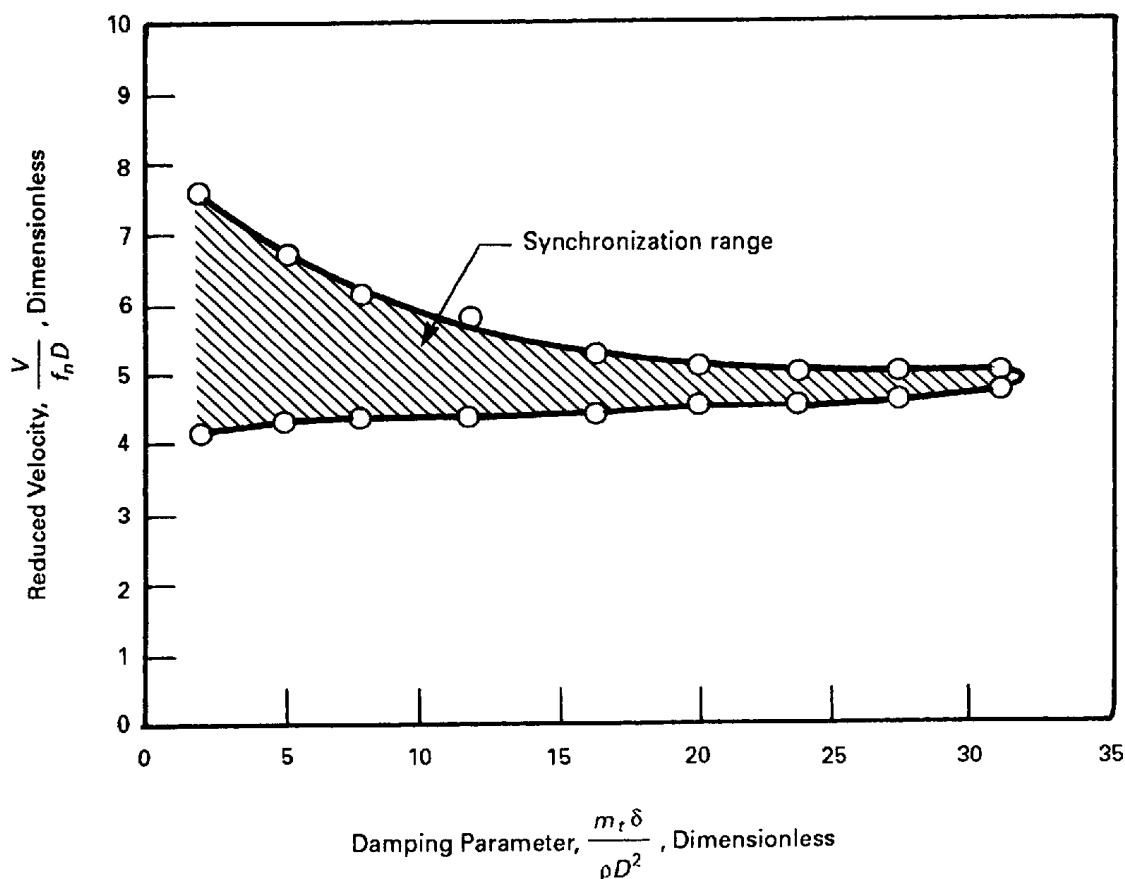


FIG. N-1323-1 SYNCHRONIZATION OF THE VORTEX SHEDDING FREQUENCY AND THE TUBE NATURAL FREQUENCY FOR A SINGLE, FLEXIBLY-MOUNTED CIRCULAR CYLINDER. SYNCHRONIZATION OCCURS WITHIN THE SHADED REGION. (REF. 106)

FIG. N-1323-1 SYNCHRONIZATION OF THE VORTEX SHEDDING FREQUENCY AND THE TUBE NATURAL FREQUENCY FOR A SINGLE, FLEXIBLY-MOUNTED CIRCULAR CYLINDER. SYNCHRONIZATION OCCURS WITHIN THE SHADED REGION. (REF. 106)

(b) If for a given vibration mode the reduced damping is large enough

$$(73) C > 64$$

then lock-in will be suppressed in that vibration mode.ⁿ

(c) If for a given vibration mode

$$(74) V/f_n D < 3.3$$

and

$$(75) C_n > 1.2$$

then lift direction lock-in is avoided and drag direction lock-in is suppressed.

(d) If the structural natural frequency falls in the ranges $f_n < 0.7f_s$ or $f_n > 1.3f_s$ then lock-in in the lift direction is avoided in the n th mode.

The reduced damping C_n is calculated according to

$$C_n = \frac{4\pi\xi_n M_n}{\rho D^2 \int_{L_e} \phi_n^2(x) dx} \quad (76)$$

(76)

where $\xi_n = \delta_n/2\pi$ is the fraction of critical damping measured in air and M_n is the generalized mass

$$M_n = \int_0^L m(t) \phi_n^2(x) dx \quad (77)$$

(77) with ϕ_n the n th mode shape function and $m_t(x)$ is the cylinder mass per unit length. The range L_e in the denominator implies that the integration is over only the region of the cylinder length subject to lock-in cross flow. Note that m_p is calculated according to:

$$(78) m_t(x) = m_s(x) + m_c(x) + m_A(x)$$

For an isolated cylinder, m_A is the displaced fluid mass. If sections of the cylinder are close to other bodies, then the possibility of increased added mass and fluid damping must be taken into account (Refs. 81, 82, 90 to 93).

N-1324.2 Vortex-Induced Response.

Off resonance, the response can be calculated using standard methods (Ref. 96) of forced-vibration analysis and Eq. (69) for the forcing function (Refs. 82 and 89). The resultant response is ordinarily small. If operating conditions are such that lock-in cannot be avoided or suppressed, then the resonant vortex induced response must be calculated. Three approaches for calculating the response are recommended for three classes of structures and flows: single uniform cylinder in uniform flow, tube arrays, and nonuniform cylinders in nonuniform flow.

(a) *Uniform Structure and Flow.* If a uniform cylinder is subject to uniform cross flow over its span, then both the vortex shedding frequency and the vortex force are constant over the span of the cylinder. The periodic vortex induced lift force is given by Eq. (69) of N-1321. At lock-in, the vortex shedding frequency equals the natural frequency of the n th vibration mode, $f_s = f_n$ and the cylinder response is given by (Refs. 82 and 89)

$$\frac{y_n^*}{D} = \frac{C_L J \phi_n^*}{16 \pi^2 S^2 [m_i \xi_n / (\rho D^2)]} \quad (79)$$

(79)

This equation provides a conservative upper bound estimate to the amplitude of periodic vortex-induced vibration if the lift coefficient is taken as unity, $C_L = 1$, and the vortex shedding is fully correlated along the span of the cylinder, $J = 1$. Other values of C_L and J may be used in circumstances where experimental data are available. However, Eq. (79) with $C_L = 1$ and $J = 1$ has been found to give overly conservative predictions owing to the tendency of the actual lift coefficient to decrease at vibration amplitudes exceeding 0.5 diameter and the lack of perfect spanwise correlation at lower amplitudes. To obtain less conservative predictions, three semiempirical nonlinear methods are given in Table N-1324.2(a)-1. The mode shape factor γ generally varies between 1.0 and 1.3 (Ref. 82) and C_n is determined according to Eq. (76) of N-1324.1 using ξ_n determined in air.

(b) *Within Tube Arrays.* Coherent vortex shedding has been found to exist only in the first few rows in arrays of cylinders with center-to-center spacing less than 2 diameters, and the design procedures for a single cylinder are applicable using the velocity in the minimum gap ($P-D$). Within the array vortex shedding exists over a broad range of frequencies rather than at a single distinct frequency. The response within the array is generally less than that of a comparable single cylinder. The techniques that have been developed to predict vibration within the array are based on the theory of random vibration and are given in N-1340.

**TABLE N-1324.2(a)-1
SEMIEMPIRICAL CORRELATIONS FOR PREDICTING
RESONANT VORTEX-INDUCED VIBRATION
AMPLITUDE**

Reference	Predicted Resonant Amplitude
111	$\frac{y_n^*}{D} = \frac{1.29\gamma}{[1 + 0.43 (2\pi S^2 C_n)]^{3.35}}$
82	$\frac{y_n^*}{D} = \frac{0.07\gamma}{(C_n + 1.9)S^2} \left[0.3 + \frac{0.2}{(C_n + 1.9)S} \right]^{1/2}$
110	$\frac{y_n^*}{D} = \frac{0.32}{[0.06 + (2\pi S^2 C_n)^2]^{1/2}}$

TABLE N-1324.2(a)-1 SEMIEMPIRICAL CORRELATIONS FOR PREDICTING RESONANT VORTEX-INDUCED VIBRATION AMPLITUDE

(c) *Nonuniform Structures and Flow.* Many cylindrical structures have nonuniform distribution of mass and stiffness, and they are exposed to flow velocities that vary over the span. In this case, only a part of the span of structure will resonate with vortex shedding and contribute to the excitation.

One method for treating nonuniform structures in nonuniform flows is:

- (1) determine the natural frequencies and mode shapes of the structure;
- (2) determine the spanwise distribution of the flow;

(3) identify portions of the structure that can resonate with vortex shedding for each mode. This can be done by calculating the spanwise distribution of the vortex shedding frequency and estimating the potential for resonance by a band of plus or minus 30% from this frequency.

(4) Apply a lift force given by Eq. (69) of N-1321 with $f_n = f_s$ and $C_L = 1$ to those segments of the span that are resonant.

Procedures (1) through (4) are illustrated in Refs. 89 and 112. For a uniform cylinder in uniform cross flow, assumption (4) of complete correlation and $C_L = 1$ gives overly conservative predictions. Other values

Page 397

for C_L may be used where experimental data are available.

N-1330 FLUID-ELASTIC INSTABILITY

Many FIV mechanisms exist wherein as energy supplied to the system is increased, usually as increased flow velocity, a critical value is attained at which a large increase in response occurs. Continued increases in the supplied energy results in continued static or dynamic divergences (rapid increases) of the response. In general, fluid-elastic instability is a result of strong coupling between the structure and the fluid.

N-1331 Instability of Tube Arrays in Cross Flow

Fluid flow across an array of elastic tubes can induce a dynamic instability that can result in very large amplitude vibrations once a critical cross flow velocity is exceeded. Often, motion is limited only by tube-to-tube impacting. The flow of fluid over the tubes results in both fluid excitation and fluid-structure coupling forces on the tubes. The fluid-structure coupling excitation forces fall into several groups:

(a) forces that vary approximately linearly with displacement of a tube from its equilibrium position (displacement mechanisms) (Ref. 113);

(b) fluctuations in the net drag forces induced by the oscillating tube's relative velocity with respect to the mean flow (fluid damping mechanism) (Ref. 88); and

(c) combinations of the above forces that exhibit step changes as a certain amplitude is exceeded because of the abrupt shift in the point of flow separation (jet switch mechanism) (Ref. 114). Instability may result from any or all of these fluid forces which are functions of the tube motion.

The general characteristics of tube vibration during instability are as follows.

(d) *Tube Vibration Amplitude.* Once a critical cross flow velocity is exceeded, vibration amplitude increases very rapidly with flow velocity V , usually as V^n where $n = 4$ or more, compared with an exponent in the range $1.5 \leq n \leq 2.5$ below the instability threshold. This can be seen in Fig. N-1331-1, which shows the response of an array of metallic tubes to water flow. The initial hump is attributable to vortex shedding that tends to produce larger amplitudes in water flow than air flows.

(e) *Vibration Behavior With Time.* Often the large amplitude vibrations are not steady in time, but rather beat with amplitudes rising and falling about a mean value in a pseudorandom fashion (Ref. 115).

(f) *Synchronization Between Tubes.* Most often the tubes do not move as individuals, but rather move with neighboring tubes in somewhat synchronized orbits, as shown in Fig. N-1331-2. This behavior has been observed in tests both in water and air (Refs. 113, 115, 116, and 117), with orbit shapes ranging from near circles to near straight lines. As the tubes whirl in their oval orbits they extract energy from the fluid. The stiffness mechanism requires motion of the adjacent tubes, but the damping mechanism does not.

(g) *Influence of Structural Variations.* Restricting the motion or introducing frequency differences between one or more tubes often increases the critical velocity for instability (Refs. 115, 116, and 118). Such increases are generally no greater than about 40%. Often the onset of instability is more gradual in a tube bank with tube-to-tube frequency differences than in a bank with identical tubes which are free to vibrate.

N-1331.1 Prediction of the Critical Velocity.

Dimensional analysis considerations imply that the onset of instability is governed by the following dimensionless groups: the mass ratio $m/\rho D^2$; the reduced velocity V/fD ; the damping ratio ξ_p , measured in the fluid; the pitch to

diameter ratio P/D ; the array geometry (see Fig. N-1331-3), and the Reynolds number VD/ν . In this section, V is the flow velocity in the gaps between the tubes, and is determined by the product of $P/(P-D)$ and the (approach) flow velocity that would occur if the tubes were not present. Note the added mass part of m_t may be much larger than the displaced fluid mass because of the confining effect of adjacent tubes (Refs. 81, 90, and 92). Also, for most cases, the flow is fully turbulent ($VD/\nu > 2000$) and the Reynolds number is not expected to play a major role in the instability. In such cases, the reduced critical velocity for the onset of instability can be expressed as a function of the remaining nondimensional parameters.

The relationship between the parameters can be investigated theoretically or experimentally. One general form that has been used to fit experimental data is:

$$(80) V_c/f_n D = C (m_t/\rho D^2)^a (2\pi\xi_n)^b$$

where C and the indices a and b are functions of the tube array geometry. Experimental data suggest that a and b fall in the range $0.0 < a, b < 1.0$ (Refs. 115, 116, 119, 138, and 139).

N-1331.2 Recommended Formula.

Mean values for the onset of instability can be established by fitting

Page 398

semiempirical correlations to experimental data. The correlation form chosen is

$$(81) V_c/f_n D = C [m_t (2\pi\xi_n)/\rho_{gr} D^2]^a$$

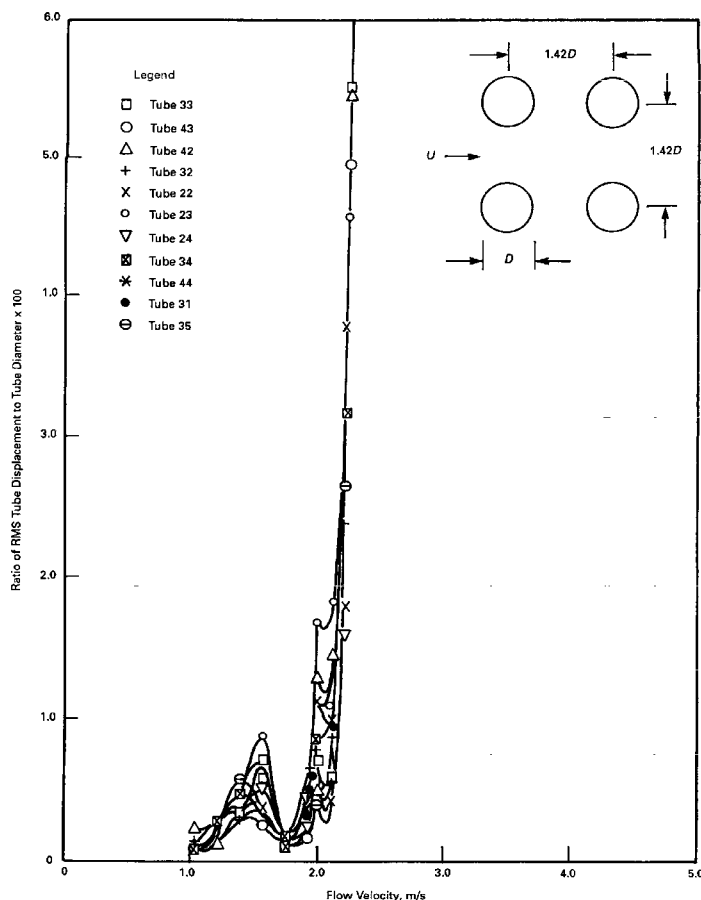


FIG. N-1331-1 RESPONSE OF A TUBE BANK TO CROSS FLOW (REF. 115)

FIG. N-1331-1 RESPONSE OF A TUBE BANK TO CROSS FLOW (REF. 115)

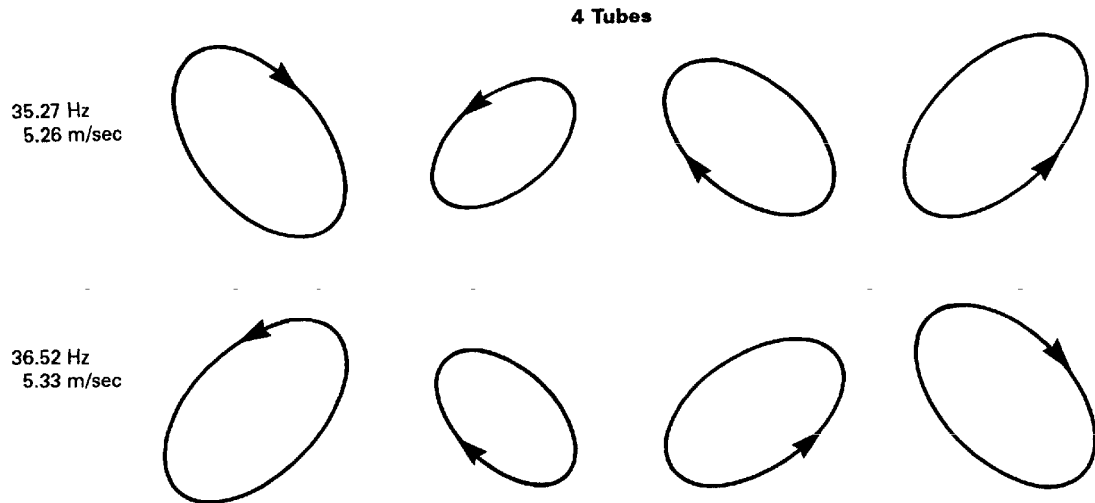


FIG. N-1331-2 TUBE VIBRATION PATTERNS AT FLUIDELASTIC INSTABILITY FOR A FOUR-TUBE ROW (REF. 118)

FIG. N-1331-2 TUBE VIBRATION PATTERNS AT FLUIDELASTIC INSTABILITY FOR A FOUR-TUBE ROW (REF. 118)

where,

U_c

= critical cross flow velocity

f_n

= natural frequencies of the immersed tube For uniform cross flow, the tubes will be stable if the representative cross flow velocity V is less than the critical velocity V_c . If the flow is nonuniform over the tube lengths, an equivalent uniform cross flow gap velocity can be defined as either the maximum cross flow velocity, or the modal weighted velocity:

$$V_e^2 = \int_0^L V^2(x) \phi_n^2(x) dx / \int_0^L \phi_n^2(x) dx \quad (82)$$

(82)

where $V(x)$ is the cross flow velocity at each axial location of the tube. The tubes will be stable if $V_e < V_c$ for all modes.

The available 170 data points for onset of instability (Ref. 120) are shown in Fig. N-1331-4. In the range $m(2\pi\xi_\eta)/\rho D^2 >$

0.7, there are sufficient data to permit fitting of Eq. (81) to data for each array type. The mean values of C are

	Triangle	Rotated Triangle	Rotated Square	Square	All
C_{mean}	4.5	4.0	5.8	3.4	4.0

Based on theory for the displacement mechanism (Ref. 113), which is active in this parameter range, $a = 0.5$ was chosen in these fits. For $m(2\pi\xi_n)/\rho D^2 < 0.7$, where the fluid damping mechanism is primarily active, neither the theory nor data are sufficient to establish values of C and a in Eq. (81). Conservative estimates of the mean values of $V_{\infty} f_n D$ for $m(2\pi\xi_n)/\rho D^2 < 0.7$ can be obtained using Eq. (81) with $a = 0.5$ and the mean C given in the table above. The use of Eq. (81) with $a = 0.5$ and $C = 3.3$ has been recommended (Refs. 80, 100) for the entire mass damping parameter range of Fig. N-1331-4.

N-1331.3 Suggested Inputs.

Accurately predicting the critical velocity requires scale model testing to determine the value of C and the damping ratio in each application, because practical flow and structural geometries contain features nonexistent in the simpler, controlled laboratory tests used to establish the data base of Fig. N-1331-4 (Ref. 120). Usually, industrial tube arrays (bundles) involve multiple spans with intermediate supports provided by plates with holes slightly larger than the tube diameter. Also, flow may pass

around the edge of the bundle and does not have the pure cross flow direction shown in Fig. N-1331-3, even within the bundle. Furthermore, when the vibration amplitude is small, such as that experienced during subcritical vibration, not all support plates are active. Damping ratios in this vibration mode are typically small, from 0.1% in gas to about 1% in steam or water. When the vibration amplitude is large, as characterized by the onset of instability, support plate-to-tube interaction greatly increases the damping ratio which can reach 5% or more.

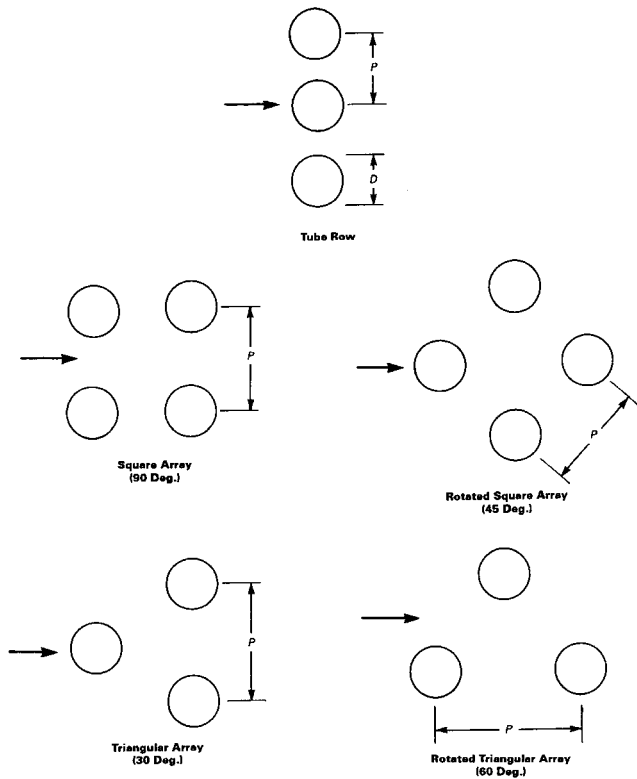


FIG. N-1331-3 TUBE ARRANGEMENTS

FIG. N-1331-3 TUBE ARRANGEMENTS

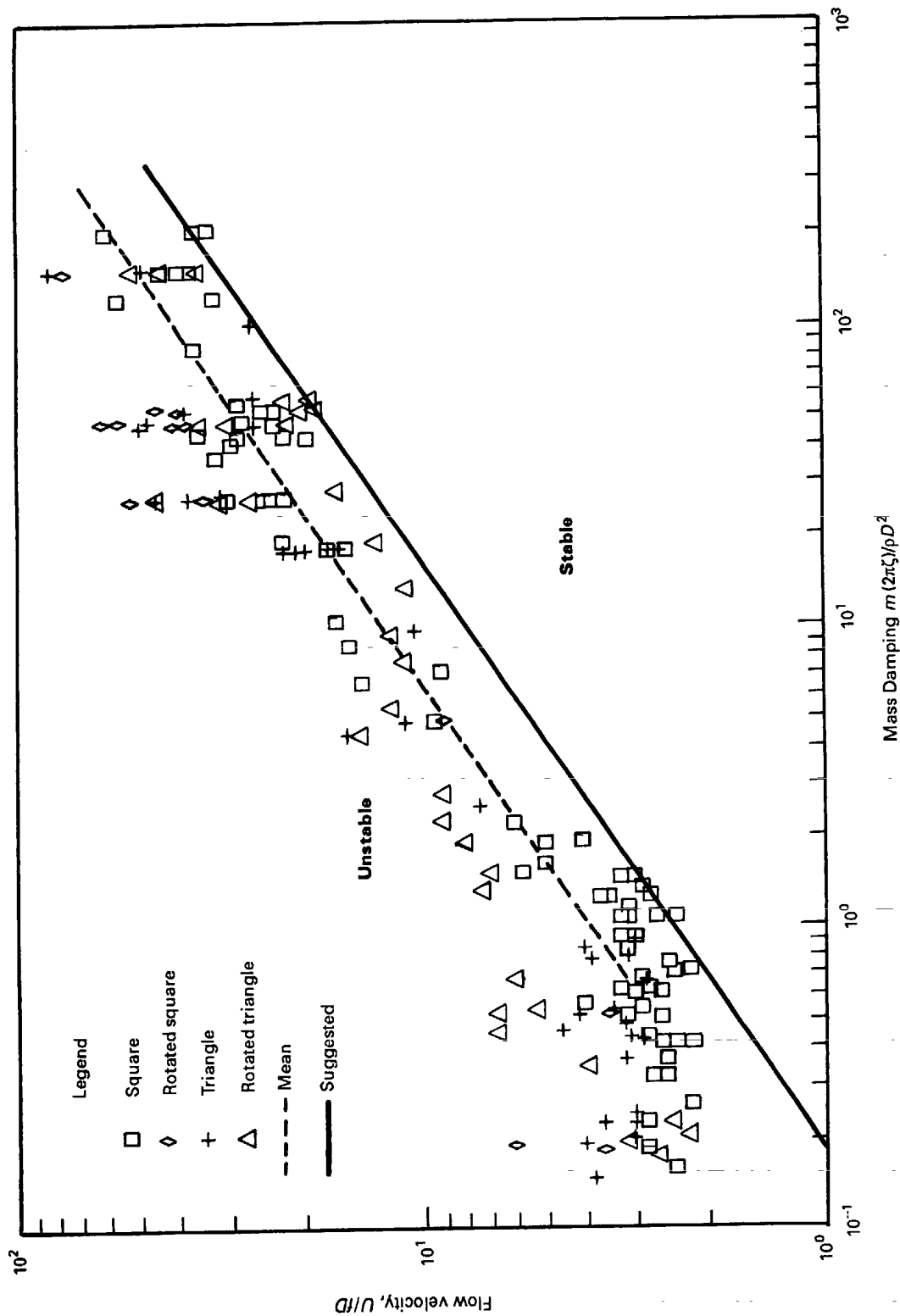


FIG. N-1331-4 STABILITY DIAGRAM

FIG. N-1331-4 STABILITY DIAGRAM

All the practical features discussed above tend to raise the critical flow velocity. Thus, the data base of Fig. N-1331-4 can be used to determine a conservative criterion for avoiding fluid-elastic instabilities of tube arrays: if the design equivalent uniform cross flow gap velocity [Eq. (82)] is less than the critical velocity [Eq. (81)] computed with the suggested design values defined by the solid line ($C = 2.4$, $a = 0.5$) in Fig. N-1331-4 and with a damping ratio of 0.5% in gas, or 1.5% in "wet" steam or liquid, then instability is almost certainly not a problem, and scale model testing will not be necessary. Otherwise, more accurate values of C and the immersed tube's damping ratios, or the critical velocity itself, must be determined by either model testing or from operational experience.

N-1340 TURBULENCE

In general, the coolant flow paths and flow rates promote and maintain turbulent flows that are optimal for purposes of heat transfer, but provide sources for structural excitation. Also, turbulence in the flow can affect the existence and strength of other excitation mechanisms associated with separating boundary layer flows (wakes), as discussed in N-1320 on vortex shedding. This section will concentrate on turbulence as a source of fluid excitation forces.

N-1341 Random Excitation

Where turbulent flow comes into contact with the surface of a structure some of the momentum in the flow is converted into fluctuating pressures. In addition to any forces produced by the mean flow component, random surface pressure fluctuations are produced by the turbulent velocity component. The time history of the surface pressure fluctuations, like the flow turbulence, is complex and amenable to description only on a statistical basis. However, the fluctuating pressure and the resulting flow-induced response usually can be regarded as ergodic and analyzed with a finite-time record not dependent upon the time origin.

For purposes of structural analysis and design, most useful information on the fluctuating pressures becomes available once the spatial spectral densities of the pressure field, $S_p(x_1, x_2, \Omega)$, are determined. The spectral density is the Fourier transform of the cross correlation of the pressure field

$$S_p(x_1, x_2, \Omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \left\{ \lim_{t_0 \rightarrow \infty} \frac{1}{2t_0} \int_{t_0}^{t_0+t} p(x_1, t) \right. \quad (83) \\ \left. \times p(x_2, t + \tau) d\tau \right\} e^{-i\Omega t} dt$$

(83) and provides information about the average products of components of the pressure $p(x, t)$ as a function of the circular frequency Ω in radian/sec for every possible pairing of structural points, x_1 , and x_2 , including the same point. S_p has units of (pressure)² (second). The frequency content of the spectra are band limited, from zero to a maximum frequency determined by the turbulence source. The magnitude of the power spectra increases when the energy of the turbulence at frequency Ω increases. The size of a region of the structure over which the pressures at different points are coherent, or has some cause-effect relationship, is interpreted as a correlation length of the pressure field, or the size of the associated turbulent eddy (Ref. 82).

Only select parts of the surface pressures are effective in exciting dynamic structural response: those parts with frequency content in narrow bands centered on the structural natural frequencies and with correlation lengths similar in size to the spatial wavelength of the associated vibration mode (Ref. 122). The resulting structural response occurs in the

narrow frequency bands with random amplitudes, and the widths of the frequency bands are determined by the system damping. Knowledge of the surface pressure statistics enables prediction of the associated structural response statistics utilizing the probabilistic theory of structural dynamics.

N-1342 Structural Response of Tubes and Beams

N-1342.1 Response to Homogeneous Turbulence Excitation.

The assumption of a linear structure is justifiable for the small vibrations associated with the turbulence excitation of weakly coupled fluid-structure systems, and the linear structural dynamic analysis theory for arbitrary random loading of beams is highly developed. Since the energy dissipation mechanism of turbulent flow rapidly smooths disturbances caused by

Page 403

the structural boundaries of and in the flow channel, the statistical character of turbulent cross flow often varies gradually over the total length of select spans of single tubes and tube bundles, especially within the bundles. Thus, in many applications, the assumption of a uniform mean velocity and homogeneous turbulence is reasonable.

Assuming a homogeneous and ergodic pressure field, the equations of motion can be uncoupled to allow solution by modal analysis (see N-1222). The expression for the power spectral density of the cylinder response is (Ref. 123)

$$S_y(x_1, x_2, \Omega) = S_{fo} L_j^3 \sum_{k=1}^{\infty} \sum_{j=1}^{\infty} \phi_j \phi_k J_{jk}^2 H_j H_k^* \quad (84)$$

(84)

The mode shapes $\phi_j(x)$ satisfy the orthogonality relation

$$\int_0^L m_t(x) \phi_i(x) \phi_j(x) dx = M_j \delta_{ij} \quad (85)$$

(85)

where M_j is the generalized mass, defined here to have the same dimensions as m_t . Thus, if m_p is constant, $M_j = m_t$ and the orthogonality condition reduces to

$$\int_0^L \phi_i(x) \phi_j(x) dx = \delta_{ij} \quad (86)$$

(86)

The transfer function for the j th mode is

$$H_j(\Omega) = [M_j(\Omega_j^2 - \Omega^2 + 2i\xi_j\Omega\Omega_j)]^{-1} \quad (87)$$

(87) where Ω_j and ξ_j are the modal natural frequency and damping, respectively. The acceptance integral is

$$J_{jk}^2(\Omega) = L^{-1} \int_0^L \int_0^L \phi_j(x_1) \Gamma(x_1, x_2, \Omega) \phi_k(x_2) dx_1 dx_2 \quad (88)$$

(88) where the complex coherence function is

$$(89) \Gamma(x_1, x_2, \Omega) = S_f(x_1, x_2, \Omega) / S_{f0}(\Omega)$$

and S_f is the cross spectral density of the turbulent forcing function per unit length between two different points on the cylinder's length, $x = x_1$ and $x = x_2$. When $x_1 = x_2 = x$, $S_f(x, x, \Omega) = S_{f0}(\Omega)$ is the power spectral density (or auto spectrum) that is independent of location for a homogeneous pressure field. The joint acceptance $J_{jj}(\Omega)$ reflects the relative effectiveness of the forcing function to excite the j th vibration mode while the cross acceptance $J_{jk}(\Omega)$, $j \neq k$, reflects contributions due to coupling between different modes. In general, the responses in two different modes are dependent upon each other.

The mean square response $\bar{y}^2(X)$ is the most useful measure for the amplitude or stress and strain design, and is found by integration of the power spectral density of the response, $S_y(x, \Omega) = S_y(x, x, \Omega)$ over the frequency band, or

$$\underline{y}^2(x) = \int_{-\infty}^{\infty} S_y(x, \Omega) d\Omega \quad (90)$$

(90) The distribution of the positive and negative peaks in displacement has been found for the fundamental mode of a rod in parallel flow to be Gaussian (Refs. 81, 82, and 124). Assuming a Gaussian fluctuating pressure distribution, a Rayleigh distribution is expected for the absolute amplitude of response (Refs. 82 and 125).

Based on physical reasoning and experimental data, the complex coherence function of the homogeneous turbulence pressure field for the tubes in cross flow has been characterized as (Refs. 122 and 126)

$$\begin{aligned} R(x_1, x_2, \Omega) = & \exp [-2|x_1 - x_2|/l_c] \\ & \times \exp [-i\Omega(x_1 - x_2) \sin \theta/U_c] \end{aligned} \quad (91)$$

(91)

where l_c is the correlation length, which is a measure of the coherence range of the turbulent pressure field; U_c is the convection velocity, or the velocity at which the turbulent eddies move with the flow; and θ is the angle between the direction of the flow and the normal to the axis of the tube. Note that $U_c/\sin \theta$ is the phase velocity of the pressure signal along the tube.

In the case of lightly damped structures with well-separated modes, cross modal contribution to the response can be ignored, and Eq. (90) can be analytically evaluated to be (Refs. 112 and 125):

$$-12\underline{y}^2(x) = \sum_j 2\pi\xi_j\Omega_j S_y(\Omega_j) = \sum_j \pi\xi_j f_j G_y(f_j) \quad (92)$$

(92)

In the second equality, the response is expressed in terms of the more commonly used engineering variables frequency f (in Hz) and the single-sided power spectral density G as a function of f , where

$$\begin{aligned}
 G(f) &= 4\pi S(\Omega) \quad \text{for } f = \Omega/2 > 0 \\
 &= 0 \quad \text{for } f < 0.
 \end{aligned} \tag{93}$$

(93)

Under the same assumption of light structural damping

Page 404

$$\underline{y}^2(x) = \sum_j \frac{LG_f(f_j) \phi_j^2(x)}{64 \pi^3 M_j^2 f_j^3 \xi_j} J_{jj}^2 \tag{94}$$

(94)

Where $G_f(f_j)$ is the single-sided power spectral density in (force/length)²/Hz generated by the turbulent pressure field at the natural frequency f_j of the j th vibration mode.

N-1343 Design Procedures for Tubes and Beams in Turbulent Cross Flow

In most situations, the component of turbulent flow normal to the axis of a cylinder is a more dominant excitation mechanism than the parallel component. The exception occurs when the flow direction is parallel or barely inclined to the cylinder axis. Thus, cross flow analysis using the component of flow normal to the cylinder should always be made, supplemented by the parallel flow analyses of N-1345 at small angles of inclination.

The theory in the subsections that follow can be applied to one-dimensional structures in general, but the specific information on the statistics of the pressure field must be limited to tubes (circular cylinders) until adequate information is available for other beam cross sections.

N-1343.1 Uniform Cross Flow.

In the simplest case of uniform cross flow over the entire length of a lightly damped, rigid cylinder with an evenly distributed total mass and spring supports at both ends, $\phi = L^{-1/2}$, $thgr_i = 0$ in Eq. (91), and the joint acceptance integral of Eq. (88), with $i = j = 1$, reduces to (Refs. 112 and 127)

$$J_{11}^2 \approx l_c/L, \quad l_c \ll L \quad (95)$$

(95)

The correlation length l_c in most cross flows over a tube (circular cylinder) is no more than three diameters (see N-1322). Also, although Eqs. (95) were derived for the fundamental mode of the transverse vibrations of a rigid, spring-supported cylinder, they can be used to estimate the joint acceptance of the fundamental mode of cylinders which are simply supported or clamped at both ends. Of course, in determining the RMS response with Eq. (94), the mode shapes corresponding to the actual boundary conditions and normalized according to Eq. (86) are used. For other boundary conditions and higher modes, the joint acceptance integral will have to be evaluated either numerically (most cases) or in closed form from Eq. (91). Since $J_{11}^2 \leq 1.0$, (Ref. 127), an upper bound response estimate can be found by setting all the $J_{jj} = 1.0$ in Eq. (94).

TEXT

The random characteristics of the forces exerted on the tubes by the turbulent flow must be obtained from tests. Two expressions for the power spectral density of the turbulent force per unit length on tubes in a tube array are:

$$G(f) = [C_R(f)\rho V_g^2 D/2]^2 \quad (\text{Ref. 100}) \quad (96)$$

(96)

and

$$G(f) = [C_L(f)\rho V_g^2 D/2]^2 (D/V_g) \quad (\text{Ref. 128}) \quad (97)$$

(97)

where the gap velocity V_g is related to the velocity upstream of the tubes, V_∞ , by

$$(98) V_g/V_\infty = P/(P-D)$$

The coefficient $C_R(f)$ in Eq. (96) has units of $\text{sec}^{-1/2}$ and is given in Fig. N-1343-1 as a function of the frequency f . Therefore, the application of Eq. (96) should be limited to the parameter range for which the data were taken, namely, high turbulent water flow (1 to 2 m/sec) entering closely spaced heat exchanger tubes of 12 to 19 mm in diameter. The decrease in $C_R(f)$ with penetration into the bundle is attributed to the highly turbulent inlet flow and possible vortex excitation observed in the first few tube rows. Data for the nondimensional lift coefficient $C_L(f)$ of Eq. (97) have not been obtained for as many tube array configurations (Refs. 141 and 142), but use of this alternative expression may predict less conservative responses (Ref. 142).

For an isolated tube in cross flow, which is not subject to conditions of lock-in vortex shedding (see N-1323), the power spectral density $G_f(f)$ and the correlation length are strong functions of the turbulence created in the incident flow stream by the upstream structures. Relatively small amounts of turbulence can cause significant reductions in the effectiveness of vortex shedding as an excitation mechanism, and all periodicity can be eliminated with sufficiently strong incident turbulence. For given turbulence intensities and scale lengths of the incident flow, $G_f(f)$ is available (Ref. 129) and the correlation length l , may be approximated by the scale length of the incident flow. In the absence of specific information about the incident flow, the random turbulence coefficient for the upstream tube in Fig. N-1343-1(a) can be used to estimate $G_f(f)$ for most isolated tubes in cross flow because of the wide variety of incident flow conditions contained in the data base. In the latter case, the velocity used in Eqs. (96) and (97) should be the free stream velocity of the flow.

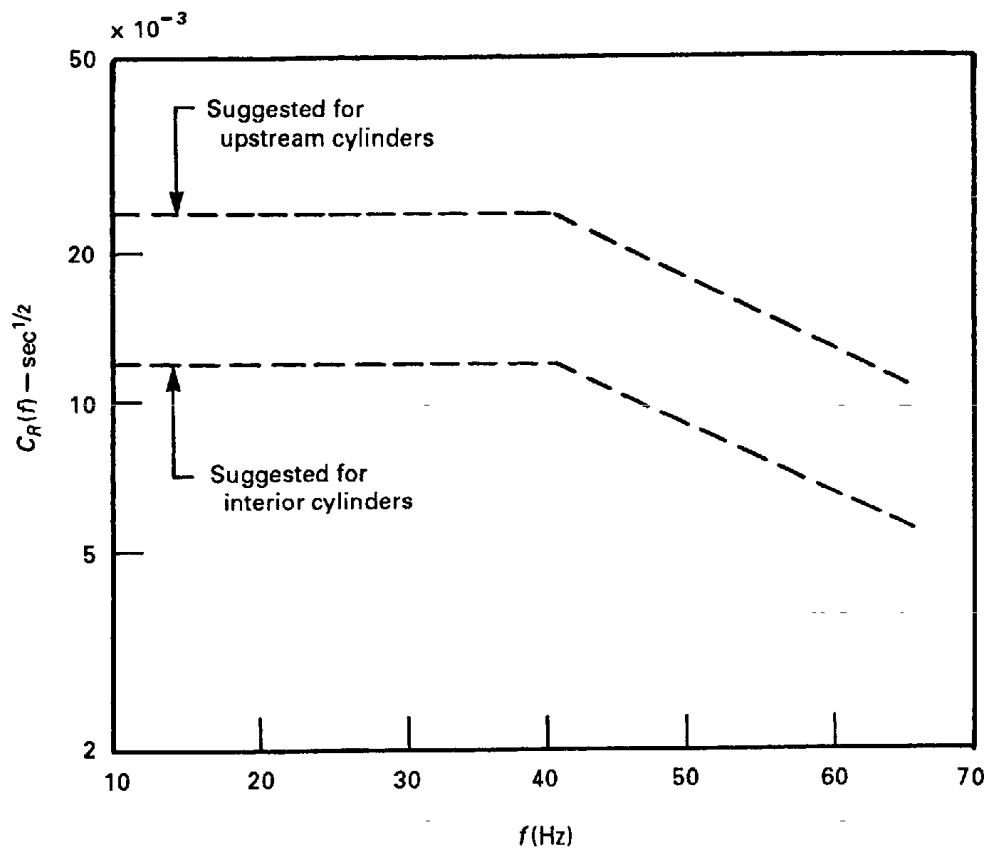


FIG. N-1343-1 RANDOM EXCITATION COEFFICIENT FOR ARRAYS IN CROSS FLOW (REF. 100)

FIG. N-1343-1 RANDOM EXCITATION COEFFICIENT FOR ARRAYS IN CROSS FLOW (REF. 100)

If upstream structures produce well defined vortices, strong excitation mechanisms may be created on isolated cylinders more than twenty diameters downstream (Ref. 130). Such configurations should be avoided.

N-1343.2 Multiple Spans of Uniform Cross Flow.

In many applications, a cylinder is subject to one or more partial spans of uniform, but different, velocity and density cross flows that are uncorrelated with each other or with the flow over the remainder of the cylinder's length. These conditions often exist when baffles are used to channel different density flows in the interior of the pressure vessels (heat exchangers, reactors, etc.). The mean square response for such conditions can be determined by simple generalizations of the results given in N-1342.2 for homogeneous turbulence excitation.

Since the uniform cross flow over the span of length L_i is uncorrelated with the uniform cross flows over the other spans, $G_f J_{jj}^2$ in Eq. (94) can be calculated (Ref. 127) by summing the products of the locally defined spectra G_f^i and joint acceptances $(J_{jj}^i)^2$ over all

TEXT

the spans i over which there is significant cross flow. Thus, the mean square response becomes

TEXT

$$\bar{y}^2(x) \approx \sum_j \sum_i \frac{L_i G_f^i(f_j) \phi_j^2(x)}{64 \pi^3 M_j^2 f_j^3 \xi_j} (J_{jj}^i)^2 \quad (99)$$

(99)

where

$$G_f^i(f_j) = G_f(f_j) \int_0^{L_i} \phi_j^2(x) dx \quad (100)$$

(100)

$(J_{jj}^i)^2$ are determined with Eq. (88) using that part of ϕ_j , denoted by ϕ_j^i , that is active over the i th span with length L_i . As discussed in N-1343.1, if ϕ_j^i is similar to the fundamental mode shape of a one-span beam with simple or clamped supports at each end, then $(J_{jj}^i)^2 \approx \ell_c^i/L_i$. The correlation lengths inside a tube bundle are smaller than that for an isolated tube, being about 1–2 tube diameters. After specifying $G_f^i(f)$ and using Eqs. (96) and (97) for instance, the mean square response can be determined.

TEXT

Page 406

N-1343.3 Nonuniform Cross Flow.

In industrial heat exchangers, the cross flow velocities are seldom uniform over the entire length, or even one span of the tubes. While an average cross flow velocity can be used to estimate the force spectra in Eqs. (96), (97), and (98), when the velocity distribution is available, better estimates can be obtained by using mode shape-weighted power spectral densities similar to the generalized forces used in deterministic analysis (Ref 127):

$$G_f(f_j) = (D/2)^2 C_R^2(f_j) \int_0^L [\rho U^2(x)]^2 \phi_j^2(x) dx \quad (101)$$

(101) for a single-span tube of uniform mass density and

$$G_f^i(f_j) = (D/2)^2 C_R^2(f_j) \int_0^{L_i} [\rho_i U^2(x)]^2 \phi_j^2(x) dx \quad (102)$$

(102)

for a multi-span of spanwise uniform mass density. These estimates are not rigorously derivable, but they will lead to more accurate estimates of response, especially when the peaks in the velocity distributions are close to the antinodes of the vibration modes.

N-1344 Vortex-Induced Vibrations in a Tube Bundle

The existence of vortex shedding deep in a tube bundle is much less clearly defined than for a single cylinder. Experimental measurements involving tube bundles showed that even if a resonance peak exists in the dynamic pressure power spectral density, it is much broader and not as well defined as in the case of a single tube. Furthermore, these peaks are bounded by the pressure power spectral density given by Eq. (96). However, if lock-in vortex-induced vibration occurs in a particular span, the forcing function and the tube mode shape will be fully correlated and in-phase for that span. This means that the span joint acceptance, $J_{jj}^i = 1.0$. To be conservative, a lock-in vortex-induced vibration amplitude deep in a multi-span tube bundle can be calculated by substituting $J_{jj}^i = 1.0$ into Eq. (99), for all spans and all modes where lock-in cannot be avoided or suppressed according to N-1324.1.

TEXT

Classical vortex shedding does occur in the boundary tubes. For the first two to three rows of tubes in a tube bundle, vortex-induced vibration analysis following the procedure outlined in N-1320 is recommended.

N-1345 Cylinders in Axial Flow

Turbulence generally is a much weaker excitation mechanism in axial flow compared with cross flow, where the flow separates from the vibrating body. Also, axial flow is a source of flow damping which increases with flow rate (Refs. 81, 82, and 131). As a result, RMS vibration amplitudes of tubes in axial flow are typically only a few percent of the tube diameter.

The surface pressure fluctuations that excite a tube in axial flow are due to many sources: local turbulence created by the shear flow in the developing boundary layer; free stream turbulence created by upstream disturbances (grid supports, abrupt changes in channel size, elbows, valves, etc.) that quickly attenuate downstream of the disturbance; localized acoustic noise (waves); and system acoustic noise that can propagate long distances (Ref. 136). For pipes and single rods in annuli subject only to fully developed flow, relatively general experimental characterizations of the homogeneous pressure fields are possible (Ref. 131), because they depend only on the local channel geometry and the flow rates. However, general characterizations have not been developed that account for upstream disturbances and adjacent bodies, although many specific systems have been studied (Refs. 131 through 137). Evidently, accurate predictions can be made when the pressure field is characterized in the same system as the response is measured, but the predictions from system to system may vary by an order of magnitude for the same axial flow velocity. Because response is usually much easier to measure than the pressure fluctuations necessary to characterize a pressure field, especially a nonhomogeneous one, empirical correlations of response have been developed for important component geometries (Refs. 99 and 137). The component and prototype tests upon which the correlations are based include all component geometries and excitation sources. Of course, the use of these correlations must be limited to the type of components and parameter variations for which they were developed.

N-1345.1 Recommended Design Procedures

(a) When the characterization of the pressure field is available, then the response of the structure can be predicted by the general method outlined in N-1342. But, unlike cross flows, the convection velocity U_c is important and must be known in axial flow before the acceptance integral, Eqs. (88) and (91), can be evaluated. In axial flows, it is not generally true that the larger the correlation length, ϵ , the larger the response as in cross flows. Rather, the response is governed by the matching of the structural mode shape and the phase-coherence of the pressure field (Refs. 112 and 122), in addition to its power spectral density.

(b) Regardless of whether a pressure field characterization is available, the maximum amplitude of motion

Page 407

can be estimated to within an order of magnitude using the empirical correlation (Ref. 99)

$$\frac{y^*}{D} = \left[\frac{5 \times 10^{-4} K_N}{\alpha^4} \right] \left[\frac{u^{1.6} \epsilon^{1.8} Re^{0.25}}{1 + u^2} \right] \times \left[\frac{D_h}{D} \right]^{0.4} \left[\frac{\beta^{2/3}}{1 + 4\beta} \right] \quad (103)$$

(103) if the cylinder parameters are within the ranges covered by the correlation:

$$2.1 \times 10^{-3} \leq u^2 = m_A V^2 L^2 / (EI) \leq 8 \times 10^{-1}$$

$$26.8 \leq \epsilon = L/D \leq 58.7$$

$$2.6 \times 10^4 \leq Re = VD/\nu \leq 7 \times 10^5$$

$$4.9 \times 10^{-4} \leq \beta = m_A/m_t \leq 6.2 \times 10^{-1}$$

$$2.10 \leq \alpha^2 = \Omega_1 [m_t L^4 / EI]^{1/2} \leq 20.8$$

$$1 \leq K_n \leq 5$$

where K_n is a noise factor representing a departure from quiet, steady axial flows of $K_n = 1$. Commercial systems are expected to be bounded by $K_n = 5$. E is the modulus of elasticity, I is the beam area moment of inertia, and ν is the fluid kinematic viscosity.

N-1400 DYNAMICS OF COUPLED FLUID-SHELLS

N-1410 INTRODUCTION

It is well known that the motion of a solid in a heavy liquid is different from that in a vacuum. In the case of a sphere or a cylinder moving in an infinite fluid medium, for example, the presence of the fluid can be accounted for by simply adding to the physical mass of the solid, the mass of fluid it displaces. Hence the term added mass, or hydrodynamic mass, has been used to describe this solid-fluid interaction phenomenon. When the fluid is viscous, then in addition to an added mass, there is an apparent added damping, or hydrodynamic damping, due to the viscosity of the fluid.

In the case of thin cylindrical shells vibrating with fluids entrapped in-between, the effect of fluid-structure interaction is far more complicated. Data from preoperational tests of nuclear plants showed that the natural frequencies of the thermal shields of light water nuclear reactors were much lower than their corresponding values measured in-air. Since then, theoretical studies by Fritz and Kiss (Ref. 143), Horvay and Bowers (Ref. 144), Au-Yang (Refs. 93 and 145), Chen (Refs. 90 and 146), Krajcinovic (Ref. 147), and Levin and Milan (Ref. 148) conclusively showed that the coupling effect of narrow fluid gaps on thin cylindrical shells is much stronger than that of infinite fluid media. Their conclusions are supported by

laboratory tests (Refs. 90 and 149). A few review papers on this topic were written by Chen (Ref. 90), Brown (Ref. 150), and Au-Yang (Ref. 151).

This guide describes a simple method to account for the effect of fluid-structure interaction on the response of cylindrical shells coupled by fluid gaps, using the structural priority approach (Ref. 155). In this approach, the effect of fluid-structure interaction is completely accounted for by the "added mass" and the "added damping" terms. The principal advantage of this method is its simplicity. Once the added mass and the added damping terms are computed, the structural response analysis can be carried out by standard methods without any need to revise the computer programs either for calculating the structural response or for calculating fluid forcing function. On the other hand this method is based on linear dynamic theory in which the principal interest is to estimate low-frequency structural responses. The vibration amplitude of the structure must be small compared with the width of the fluid gaps in order that linear dynamic theory holds. Internal structures of commercial nuclear reactors such as the core support structure and the thermal shield are usually restricted by limiter blocks so that their motions are small compared with the fluid annular gap width. In flow-induced vibration, seismic and loss-of-coolant analyses of these components, usually only the responses of the lower few modes are of interest, and the methods described in this guide can be applied. Structural analyses involving large displacements or in which responses to the high frequency components of the forcing function cannot be ignored, or analyses in which the principal interest is to estimate the hydraulic forcing function rather than the structural responses, should not follow the methods described in this guide.

N-1420 NOMENCLATURE

a	= radius of inner cylinder or (when used as a subscript or superscript) pertaining to the inner cylinder
b	= radius of outer cylinder or (when used as a subscript or superscript) pertaining to the outer cylinder
	Page 408
c	= velocity of sound
$C_{\alpha m}$	= Fourier coefficient of the m th cylinder axial mode onto the α th acoustic mode
$[C]$	= equivalent viscous damping coefficient matrix
f	= frequency in Hz
(f_o)	= externally applied force
(f)	= reaction force due to fluid shell coupling
$f_{m,n}$	= natural frequency of the (m,n) th mode
h	= Fourier component of the hydrodynamic mass matrix element
H	= hydrodynamic mass
$\bar{H}$	= generalized hydrodynamic mass
I	= modified Bessel function of first kind
J	= Bessel function of first kind
K	= modified Bessel function of second kind
$[K]$	= stiffness matrix
K_{ij}	= element of the stiffness matrix
$..$	= length of cylindrical shell

m	= axial modal index of the cylindrical shell
n	= circumferential modal index of the cylindrical shell
p	= pressure
q	= (u, v, w), displacement vector of the shell
r	= radial coordinate or (used in Fig. N-1451-1, a/b)
R	= radial function of acoustic mode
u	= displacement of the shell in the axial direction
v	= displacement of the shell in the tangential direction
w	= displacement of the shell in the normal direction
x	= axial coordinate
α	= axial mode number for the acoustic mode
β	= circumferential mode number for the acoustic mode

$$\delta_{33} = \begin{matrix} & \text{---} & \text{---} & \text{---} \\ \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} & \text{matrix in the } (u, v, w) \text{ space} \end{matrix}$$

MATRIX

ε	= α or $(2\alpha - 1)/2$ as defined in Eq. (108)
θ	= azimuthal coordinate
Θ	= mode shape function
λ	= defined in Eq. (115)
μ	= surface mass density of the shell
ν	= hysteretic damping factor; kinematic viscosity
ρ	= mass density of fluid
ϕ	= axial acoustic mode shape function
ψ	= axial cylinder mode shape function
ω	= angular frequency (rad/sec)

N-1430 FREE VIBRATION OF THIN CYLINDRICAL SHELL IN AIR

Figure N-1430-1 shows the vibration mode of a thin, finite cylindrical shell. Viewed from the ends, the vibration of the cylinder may consist of any number of waves distributed around the circumference. The number of circumferential waves is denoted by n , with $n = 1$ being the beam mode. Throughout this write-up, it is assumed that the circumferential mode shape is normalized to unity,

$$\int_0^{2\pi} \Theta^2(\theta) d\theta = 1 \quad (104)$$

(104)

When viewed from the side, the deformation of the cylinder consists of a number of waves distributed along the length of a generator. The number of half waves along a generator is denoted by $m, m = 1, 2, 3, \dots$ As shown in Fig. N-1430-1, the axial wave forms depend on the end conditions of the cylinder.

The equation of motion for the free vibration of the shell is,

$$(105) [\mu](\ddot{q}) + [K](q) = 0$$

Thus to determine the natural frequencies, one has first of all to calculate the modal stiffness matrix. In simple cases of cylinders with simply supported or clamped ends, simplified expressions for the stiffness matrix elements have been derived (Refs. 92 and 152), and the natural frequencies of the shell can be computed. There will be three roots for each set of K_{ip} corresponding to three natural frequencies for each set of m, n . Two of these frequencies are usually much higher than the third one. These are associated with vibrations predominantly in the axial and tangential directions. The lowest frequency, on the other hand, is associated with vibrations predominantly in the normal direction. This is the flexural mode and is usually the mode of interest in structural analysis.

N-1440 ACOUSTIC MODES OF A FLUID ANNULUS BONDED BY RIGID WALLS

The natural frequencies associated with the (α, β) th mode of the fluctuation pressure distribution

$$(106) p_{\alpha\beta} = R_{\alpha\beta}(r)\phi(x)\cos\beta\theta$$

inside the fluid annulus are given by the roots of the equation (Ref. 153),

Page 409

$$J'_\beta(x_\alpha a)Y'_\beta(x_\alpha b) = J'_\beta(x_\alpha b)Y'_\beta(x_\alpha a) \quad (107)$$

(107)

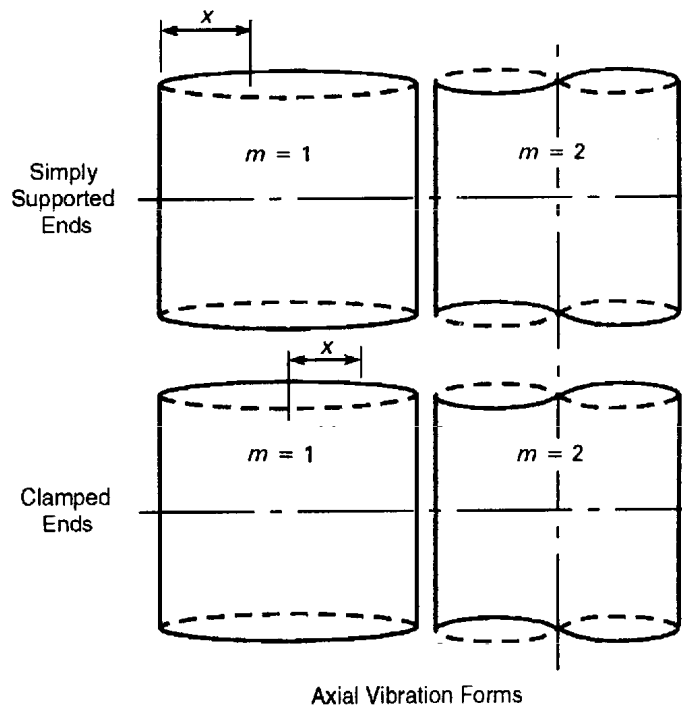
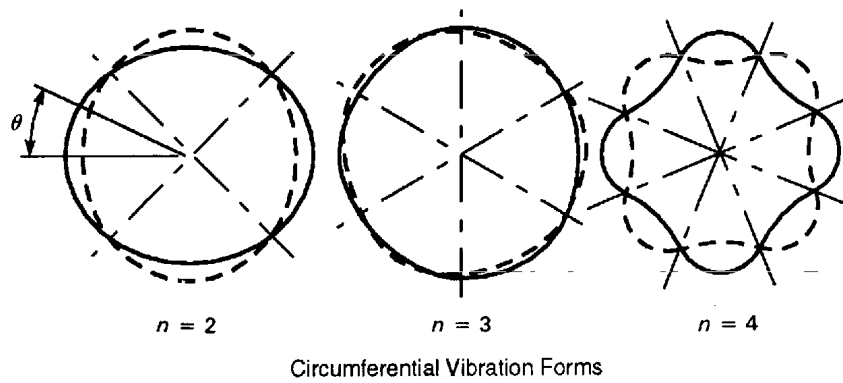


FIG. N-1430-1 VIBRATION FORMS FOR CIRCULAR CYLINDRICAL SHELLS

FIG. N-1430-1 VIBRATION FORMS FOR CIRCULAR CYLINDRICAL SHELLS

where J , Y are Bessel functions and,

$$x_\alpha^2 = (w/c)^2 - (\epsilon\pi/l)^2 > 0 \quad (108)$$

(108)

ϵ

= α if the fluid annulus has both pressure released ($p=0$) or both hard ($p=\max$) ends;

= $(2\alpha - 1)/2$ if one end is pressure released and the other end is hard.

Note that acoustic modes exist in the fluid annulus only if,

$$\omega/c < \epsilon\pi/l.$$

The frequency at which,

$$\omega/c < \epsilon\pi/l.$$

is known in acoustics as the coincidence frequency.

N-1441 Frequency Equation and Mode Shape for a Thin Fluid Annulus

For many applications, the fluid annulus is thin compared with its radius, so that the condition $(b - a)/a < 5$ is satisfied. Under this condition, the following approximate equation for the natural frequencies holds true for the plane wave mode (no radial node).

$$f_{\alpha\beta} (c/2\pi) [(\epsilon\pi/l)^2 + [2\beta/(a+b)]^2]^{1/2}$$

The second radial mode (with one radial node) usually has a lowest frequency much higher than that of the fundamental radial mode up to $\alpha = \beta = 5$. Thus, it can be ignored if only the lowest twenty or so acoustic modes are included in the analysis.

N-1450 FREE VIBRATION OF COUPLED FLUID-SHELL SYSTEMS

When the cylindrical shells bounding the fluid annulus are flexible, then not only are the motions of the shells coupled to the fluid, but they are coupled together by the fluid between them. It was shown that (Ref. 145) there is no cross circumferential model coupling between the fluid and a system of two coaxial, circular cylindrical shells. However, except in the rare case when both the cylinder and the fluid can be represented by the same mode shape function, as is the case of a simply supported cylinder vibrating in a fluid annulus with open ends, there will be coupling between the axial structural and acoustic modes (Refs. 93 and 145).

N-1451 The Hydrodynamic Mass Matrix

It was shown that for small motions of the shell, the pressure induced by the structure in the fluid is proportional to the normal component of the acceleration $\bar{w}$, of shell (Refs. 93, 145, and 155):

$$(109) \quad (p) = [H](\bar{W})$$

The "constant" of proportionality is commonly called the hydrodynamic mass or added mass matrix. In general, it is a full matrix, the element of which is dependent on the frequency. For two coaxial cylindrical shells coupled by a fluid gap, the hydrodynamic mass matrix elements are (Refs. 93 and 145),

$$\begin{aligned}
H_{mn}^{ab} &= \sum_{\alpha} C_{\alpha m}^a C_{\alpha n}^b h_{\alpha\alpha}^{ab}, & H_{mn}^a &= \sum_{\alpha} (C_{\alpha m}^a)^2 h_{\alpha\alpha}^a \\
H_{mn}^{ba} &= \sum_{\alpha} C_{\alpha m}^a C_{\alpha n}^b h_{\alpha\alpha}^{ba}, & H_{mn}^b &= \sum_{\alpha} (C_{\alpha m}^b)^2 h_{\alpha\alpha}^b \quad (110)
\end{aligned}$$

(110)

where $C_{\alpha m}^a$ for example, is the projection of the m th axial mode shape, ψ_m of cylinder a (the inner cylinder) onto the α th axial acoustic mode shape ϕ_{α} of the fluid annulus:

TEXT

$$C_{\alpha m}^a = \int_0^{\ell} \psi_m^a(x) \phi_{\alpha}(x) dx \quad (111)$$

(111)

C_{α}^b are similarly defined. h (and hence H) are in units of mass per unit area.

TEXT

The general expressions for the hydrodynamic mass which are valid for any boundary condition and any D/L ratio, are quite complicated, but still can easily be computed with the aid of a personal computer. In the following paragraphs, simplified expressions for computing h are given for several commonly encountered special cases.

N-1451.1

N-1451.1 Slender Cylinder Approximation.

When the conditions $|\varepsilon\pi a/c| \ll 1$ and $|\varepsilon\pi b/c| \ll 1$ are simultaneously satisfied, Ref. 145 shows that:

$$\begin{aligned} h_{\alpha n}^a &= (\rho a/n)(b^{2n} + a^{2n})/(b^{2n} - a^{2n}) \\ h_{\alpha n}^{ab} &= -(2\rho b/n)(a^n b^n)/(b^{2n} - a^{2n}) \\ h_{\alpha n}^b &= (\rho b/n)(b^{2n} + a^{2n})/(b^{2n} - a^{2n}) \\ h_{\alpha n}^{ba} &= -(2\rho a/n)(a^n b^n)/(b^{2n} - a^{2n}) \end{aligned} \quad (112)$$

(112)

Note that the h 's are independent of the axial acoustical wave number α in this case. From N-1452.1, the

Page 411

generalized hydrodynamic masses per unit length for the beam mode ($n = 1$) are,

$$\begin{aligned} \bar{H}^a &= \rho\pi a^2(b^2 + a^2)/(b^2 - a^2) \\ \bar{H}^{ab} &= \bar{H}^{ba} = -2\rho\pi a^2 b^2/(b^2 - a^2) \\ \bar{H}^b &= \rho\pi b^2(b^2 + a^2)/(b^2 - a^2) \end{aligned}$$

N-1451.2 The Ripple Approximation.

When the ratio $(b - a)/(b + a)$ is small, curvature effects become unimportant and the annular gap can be treated as a rectangular fluid region. In this case, the expressions for the hydrodynamic masses are greatly simplified to.

$$h_{an}^a = h_{an}^b = \rho[\lambda_{an} \tanh(\lambda_{an}d)]^{-1} \quad (113)$$

$$h_{an}^{ab} = h_{an}^{ba} = -\rho[\lambda_{an} \sinh(\lambda_{an}d)]^{-1} \quad (114)$$

(113 - 114)

where $d = b - a$ and,

$$\lambda_{an}^2 = (\epsilon\pi/\ell)^2 + [2n/(a + b)]^2 - (\omega/c)^2 \quad (115)$$

(115)

N-1451.3 Incompressible Fluid Assumption.

When $\omega \ll \epsilon\pi$, the term ω/c can be dropped from the argument of the Bessel function in Eq. (107), the resulting hydrodynamic masses are independent of frequency. Since this condition is satisfied when $c \rightarrow \infty$, it is called the incompressible fluid assumption. However, the incompressible fluid assumption must be used with caution for applications to large structures. For a structure 300 in. long, vibrating in water at 600°F (e.g., nuclear reactor internal components), the incompressible fluid assumption generally introduces errors in the hydrodynamic matrix elements of more than 10% for frequencies above 20 Hz. Thus, it should not be used in analyses involving rapid transients in which high frequency contributions to the response are significant.

N-1451.4 Single Beam ($n = 1$) in Narrow Annuli.

When a cylinder vibrates inside a stationary, rigid cylinder of slightly larger diameter, its added mass due to the water between the two cylinders can be estimated by a very simple equation (Ref. 143):

$$(116) M' = \rho a^2 / [(b - a)(1 + 12a^2/\ell^2)]$$

The above equation is valid only for the beam mode ($n = 1$) vibration. Figure N-1451-1 is a comparison between Eq. (116) and the exact solution and shows surprisingly good agreement between them as long as the fluid gap is small.

From N-1452.1, the generalized, or effective hydrodynamic mass per unit length of the cylinder is:

$$(117) \bar{H}^a = \rho \pi a^2 / [(b-a)(1 + 12a^2/\ell^2)]$$

N-1451.5 Single Cylinder Containing Fluid.

The case when there is only one cylinder containing a fluid is given by (Ref. 145):

$$\begin{aligned} h_{\alpha n} &= \rho I_n(x_\alpha a) / [x_\alpha I'_n(x_\alpha a)] \quad \text{for } f < c\epsilon/2\ell \\ &= \rho J_n(x_\alpha a) / [x_\alpha J'_n(x_\alpha a)] \quad \text{for } f > c\epsilon/2\ell \\ &= \rho a/n \quad \text{for } f = c\epsilon/2\ell \end{aligned} \quad (118)$$

(118)

where J_n, I_n are Bessel and modified Bessel functions of the first kind. From N-1452.1, for the beam mode ($n = 1$), the generalized hydrodynamic mass per unit length of the cylinder is,

$$\bar{H}_1 = \pi a h_{\alpha 1}$$

N-1451.6 Single Cylinder in Infinite Fluid.

The case where there is only one cylinder in an infinite fluid is given by

$$\begin{aligned} h_{\alpha n} &= -\rho K_n(x_\alpha a) / [x_\alpha K'_n(x_\alpha a)] \quad \text{for } f < c\epsilon/2\ell \\ &= -\rho Y_n(x_\alpha a) / [x_\alpha Y'_n(x_\alpha a)] \quad \text{for } f > c\epsilon/2\ell \\ &= \rho a/n \quad \text{for } f = c\epsilon/2\ell \end{aligned} \quad (119)$$

(119)

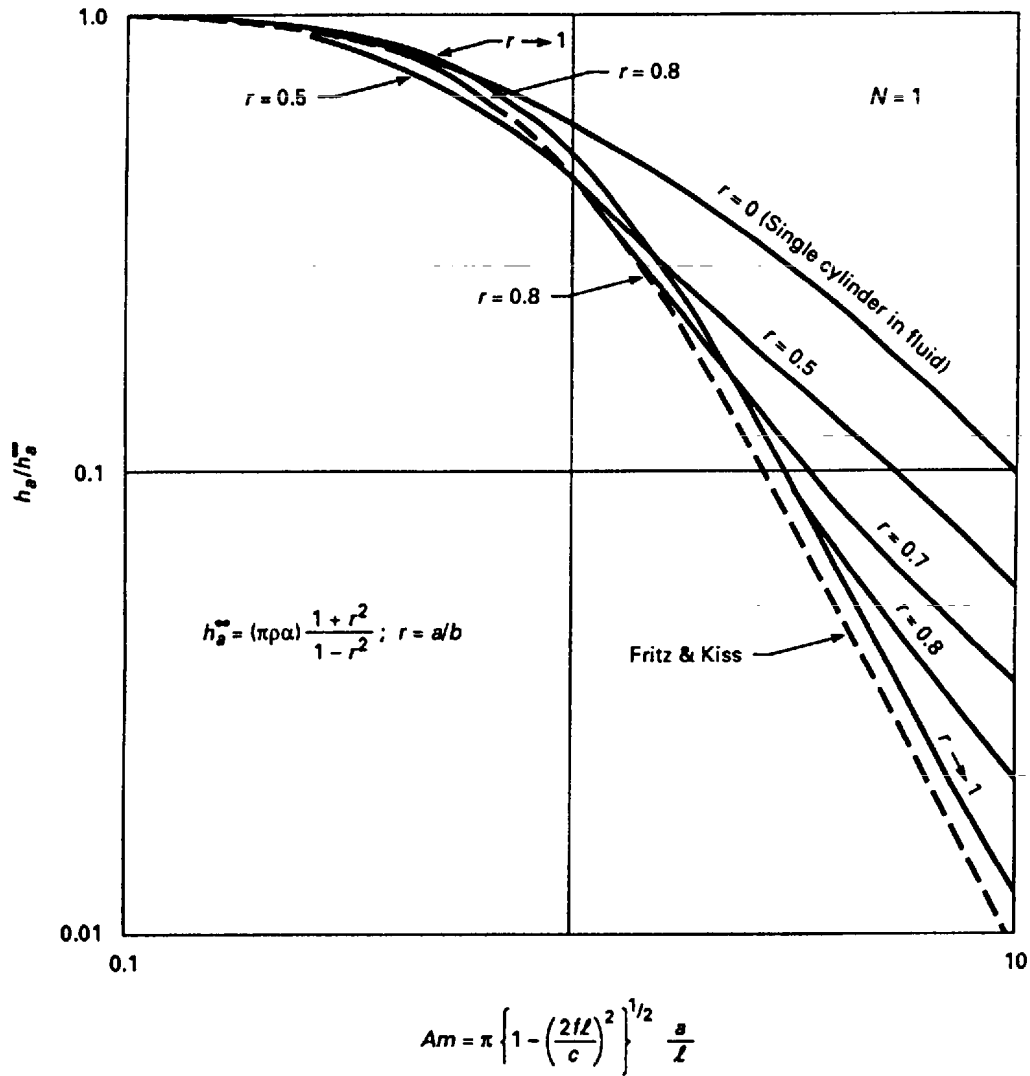
From N-1452.1, for the beam ($n = 1$) mode, the generalized hydrodynamic mass per unit length is,

$$\bar{H}_1 = \pi a h_{\alpha 1}$$

N-1452 Natural Frequencies of Coupled Fluid-Shells in Special Cases

Once the hydrodynamic mass matrix is computed, it can be input into finite element computer programs to calculate the natural frequencies of fluid coupled

shells. First, several special cases in which simplified method of analysis can be used will be considered.



GENERAL NOTE: h_s^∞ is the Fourier coefficient for the hydrodynamic mass surface mass density of an infinitely long cylinder.

FIG. N-1451-1 COMPARISON OF FRITZ AND KISS SOLUTION WITH EXACT SOLUTION

FIG. N-1451-1 COMPARISON OF FRITZ AND KISS SOLUTION WITH EXACT SOLUTION

N-1452.1 One-Axial Mode Approximation.

In many cases of practical importance, when the D/l ratio of the cylinders are not very small, only the first axial mode

is important in the dynamic analysis. Under these circumstances the frequencies of two coaxial cylindrical shells coupled by a fluid gap between them can be estimated by solving the following simplified coupled equations (Ref. 154)

$$\begin{aligned}
 (\mu^a + \bar{H}_{\text{ln}}^a)[(f_{\text{ln}}^a)^2 - f^2]w^a - f^2 \bar{H}_{\text{ln}}^{ab}w^b &= 0 \\
 -f^2 \bar{H}_{\text{ln}}^{ba}w^a + (\mu^b + \bar{H}_{\text{ln}}^b)[(f_{\text{ln}}^b)^2 - f^2]w^b &= 0 \quad (120)
 \end{aligned}$$

(120)

where $[\bar{H}]$ is the generalized hydrodynamic mass matrix with elements:

$$\begin{aligned}
 \bar{H}_{\text{ln}}^a &= (q^a)^T [H^a \delta_{33}] (q^a) [(q^a)^T (q^a)]^{-1} = H_{\text{ln}}^a / (1 + n^{-2}) \\
 \bar{H}_{\text{ln}}^b &= H_{\text{ln}}^b / (1 + n^{-2}) \\
 \bar{H}_{\text{ln}}^{ab} &= H_{\text{ln}}^{ab} / (1 + n^{-2}) \quad (121)
 \end{aligned}$$

(121)

$\bar{H}_{ln}^a$, for example, is the generalized hydrodynamic mass of the inner cylindrical shell, expressed in terms of the hydrodynamic mass defined in Eq. (110). From Eq. (121) it can be seen that, because the hydrodynamic mass effects exist only in the normal direction, the effectiveness of H in reducing the natural frequencies of the shell is decreased by the factor $1 + n^{-2}$. For the beam mode ($n = 1$), its effectiveness is reduced by a factor of $1/2$. For high shell modes ($n \gg 1$), it is as effective as the physical mass.

TEXT

For each n , two coupled frequencies and amplitude ratios for w_a/w_b can be obtained by solving the system of Eq. (120). The torsional and longitudinal modes of vibration are not affected and are not coupled by the fluid gap in the inviscid fluid assumption. Note that $[H]$ is dependent on f and Eq. (120) has to be solved by iteration except in the incompressible fluid limit.

The above equations can be generalized to a system of several coaxial cylindrical shells coupled by fluid gaps between them (Ref. 155). However, since the hydrodynamic mass is frequency dependent, many iterations may be necessary to obtain all the coupled frequencies. This procedure may become prohibitive when there are more than three cylinders.

N-1452.2 Cases When Only One Cylinder is Flexible (Ref. 156).

If only one cylinder is flexible, coupling between cylinders can be ignored. The only parameter of interest is the "in-water" frequency of the shell, which is also the natural frequency of the fluid-shell system. In this case, the natural frequencies can be obtained by a graphical method. If one plots the two functions:

$$(122) g_1 = f f_{mn}$$

$$(123) g_2 = [1 + \bar{H}_{mn}(f)/m g r_s]^{-1/2}$$

then where g_1 and g_2 intercept is a natural frequency of the coupled fluid-shell system. The lowest coupled frequency is usually referred to as the "in-water" frequency of the shell while the higher coupled frequencies are usually referred to as acoustic frequencies. This distinction, however, has no technical basis.

In the incompressible fluid limit, only the "in-fluid" natural frequency of the cylinder is of interest. This is given by,

$$(124) f_{mn} = f_{mn} [1 + \bar{H}_{mn}/\mu]^{-1/2}$$

N-1453 Use of Hydrodynamic Mass Matrix in Finite Element Structural Computer Programs

Closed form solutions are possible only in highly idealized cases of perfect circular cylindrical shells with classical boundary conditions coupled by perfectly uniform annular gaps. In many applications, even though the fluid gaps are annular and the uncoupled fluid dynamic problem is amenable to closed form solution, closed form solutions to the

coupled fluid shell problem are not possible because the cylindrical shells are not uniform, and the boundary conditions are not classically simply supported or clamped. Examples of this sort are common in the nuclear industry. In these cases, the structural problem is usually solved with the help of finite element computer programs.

The effect of fluid-structure interaction can be readily incorporated into the finite element computer program using closed form solutions for the hydrodynamic mass matrix, provided that the finite element computer program is designed to accept a full mass matrix. Many commercially available finite element computer programs have this capability.

It was shown in Ref. 155 that in finite element form, the hydrodynamic mass matrix can be written as:

Page 414

$$[M_H] = \begin{bmatrix} a^{-1} \sum_{\alpha} h_{\alpha}^a (\phi_{\alpha} \Delta A^a) (\phi_{\alpha} \Delta A^a)^T & b^{-1} \sum_{\alpha} h_{\alpha}^{ab} (\phi_{\alpha} \Delta A^a) (\phi_{\alpha} \Delta A^b)^T \\ a^{-1} \sum_{\alpha} h_{\alpha}^{ba} (\phi_{\alpha} \Delta A^a) (\phi_{\alpha} \Delta A^a)^T & b^{-1} \sum_{\alpha} h_{\alpha}^b (\phi_{\alpha} \Delta A_b) (\phi_{\alpha} \Delta A_b)^T \end{bmatrix} \quad (125)$$

(125)

where $\Delta A^a, \Delta A^b$ are element surface areas. These mass matrices can then be input into the finite element computer program just as the physical mass, with the exception that unlike the physical mass, the hydrodynamic mass, being a pressure, is effective only in the normal direction of the shell. Hence, the hydrodynamic mass should be associated only with the normal degree of freedom.

In the incompressible fluid approximation where the hydrodynamic mass matrix is independent of frequency, solution of the coupled fluid-shell dynamic problem is straightforward. In general, however, the hydrodynamic mass matrix is a full matrix with frequency dependent matrix elements. Solution of the coupled fluid-shell problem involves iteration between calculation of the mass matrix elements and the finite element computer program. When some of the coupled natural frequencies are near to the classical hard-walled acoustic modal frequencies, the hydrodynamic masses become extremely sensitive to the frequencies and solution to the coupled fluid-shell system can be difficult.

The method reported in Ref. 149 greatly simplifies the above computational procedure by reducing the size of the matrix, while still giving reasonable estimates of the coupled frequencies of the fluid shell system. It consists of calculating the 2×2 “generalized” hydrodynamic mass matrix, $\bar{H}_{mn}^a$, $\bar{H}_{mn}^b$, $\bar{H}_{mn}^{ab}$, and $\bar{H}_{mn}^{ba}$ of the cylindrical shells a and b , and uniformly distributing these hydrodynamic masses over the cylindrical surfaces. For the off diagonal elements, $\bar{H}_{mn}^{ab}$, $\bar{H}_{mn}^{ba}$, it is assumed that coupling exists only for elements of the cylinders that are directly opposite to each other. The resulting mass matrix is tri-diagonal instead of full, and greatly simplifies the computational procedure. The tri-diagonal hydrodynamic mass matrix approach yielded natural frequencies of a coupled fluid-shell system that agree quite well with those obtained from closed form solution.

TEXT

N-1460 FORCED RESPONSE OF COUPLED-SHELL SYSTEM

When the motion of the shells is small, the equation of motion for forced response of a coupled fluid-shell system can be written as:

$$[\mu](\ddot{q}) + [C](\dot{q}) + [K](q) = (f_o) + (f) \quad (126)$$

(126)

where ν is the equivalent hysteretic damping factor, f_o is the incident force acting on the shells, which is present irrespective of the motion of the shells. Examples of f_o are random pressure caused by turbulent boundary layers, or transient pulses caused by shock waves impinging on the shells. f is the reaction pressure induced on the shell as a consequence of its own motion: a result of the interaction (or coupling) between the fluid and the structure. From Eq. (109),

$$(127) \{f\} = (p \cdot \Delta A) = [M_H][\delta_{33}]\{\bar{q}\}$$

so that Eq. (126) becomes,

$$(128) ([\mu] + [M_H][\delta_{33}])\{\bar{q}\} + [C]\{q\} + [K]\{q\} = [f_o(t)]$$

Equation (128) is exactly the same as the equation of motion in-air with the forcing function f_o . The only difference is that added to the physical mass matrix $[\mu]$ is a hydrodynamic mass matrix M_H , which is effective only in the normal direction of the shells. Thus, once the hydrodynamic mass matrix is computed, the dynamic problem can be solved routinely, by finite element structural analysis computer programs or otherwise, as if there were no coupling between the fluid and the structure.

N-1470 HYDRODYNAMIC DAMPING

Just as the fluid mass adds to the effective mass of cylindrical shells, the viscosity of the entrapped fluid adds to the effective damping of the coupled fluid-shell system. This hydrodynamic damping, or added damping, due to coupling of a cylindrical structure and a viscous fluid, was studied by Chen (Refs. 90 and 146), Yeh and Chen (Ref. 157), and Mulcahy (Ref. 158). It was shown that the equivalent hydrodynamic modal damping ratio is dependent on a dimensionless parameter,

$$(129) S = \omega a^2 / \nu,$$

where ν is the kinematic viscosity of the entrapped fluid. The general expression for the hydrodynamic damping ratio, like that for the hydrodynamic mass, is quite complicated. Some insight, however, can be gained by studying the special case of the beam mode ($n = 1$) vibration of an infinitely long cylinder of radius a inside a stationary cylinder of radius b . In

Page 415

this case, the equivalent hydrodynamic modal damping ratio is given by

$$(130) \zeta_1 = - [0.5\pi a^2 / (M_H + \mu a^2)] \text{Im}(Z)$$

where Z is a fairly complicated function of modified Bessel functions and S . Figure N-1470-1, reproduced from Ref. 146, gives theoretical values of $-\text{Im}(Z)$ as a function of the radius ratio b/a , for different values of S , and shows that as $S \rightarrow \infty$, $-\text{Im}(Z)$ becomes infinitesimal even for small ratios of b/a , indicating that hydrodynamic damping is negligible for large values of S . As an example, for the vibration of the core support structure of a typical nuclear reactor inside the reactor vessel, $S \approx 10^9$. Thus, the hydrodynamic damping in this case is negligible. This conclusion, however, may not be true for the vibration of a thin rod inside a fluid-filled jacket of slightly larger diameter.

Although the above example is for the beam mode vibration of an infinitely long cylinder, the same conclusion holds true qualitatively for the shell mode vibration of finite cylindrical shells. This theoretical deduction is also supported by experimental observations. Damping ratios of thermal shields measured during pre-operational tests of pressurized water reactors show little difference from their corresponding values measured in-air. Thus, hydrodynamic damping in large cylindrical structures can be ignored.

N-1500 FLUID TRANSIENT DYNAMICS

In the course of preparation.

N-1600 MISCELLANEOUS IMPULSIVE AND IMPACTIVE LOADS

In the course of preparation.

N-1700 COMBINED RESPONSES

N-1710 DYNAMIC RESPONSE COMBINATION

In the design of nuclear power components it is necessary to consider the combined responses caused by two or more different sources of dynamic loading. There are two situations which arise: one in which the time phase relationship between

the two or more responses is known (deterministic); and a second, where the time phase relationship is said to be random. In the first situation, the response may be determined by the algebraic summation method of N-1720. In the second case where the time phase relationship is random, one of the three methods N-1721, N-1722, or N-1723 may be used depending upon satisfying the qualifying conditions contained in N-1721, N-1722, or N-1723. The owner, either directly or through his designee, may prescribe whether the time phase relationship of individual load responses is to be considered deterministic or random. Consideration may be given to the probability of occurrence of the associated events which cause the combined loading in arriving at detailed procedures for combining randomly phased responses (see discussion in N-1725).

N-1720 ALGEBRAIC SUMMATION

When the time phase relationship between two or more time history responses is known and the dynamic system is linear, the individual collinear responses may be algebraically added to determine the combined maximum and minimum structural response. If the dynamic system is nonlinear, then the combination loading should be input into the dynamic system analysis in order to determine the combination response.

N-1721 Peak Combined Response

In those cases where the dynamic system is linear and where two or more responses are to be combined, the peaks of the individual collinear responses can always be conservatively added to obtain the combined response irrespective of whether the phase relationship of the responses is undefined, deterministic, or random.

N-1722 SRSS (Square Root of Sum of Squares) Method

N-1722.1 For Responses With Nearly Equal Dominant Frequencies.

In those cases where the dynamic system is linear and where (a) the time phasing of the peak individual collinear responses is random and (b) all of the individual responses have nearly an equal dominant¹ frequency with arbitrary amplitude, the SRSS method may be used to determine the combined design response (Refs. 68, 69, and 70).

¹ An individual time history response may be considered to have dominant frequency if one-half or more of its total response can be identified with a single frequency.

N-1722.2 For Uncorrelated Dynamic Responses.

The intent of this method for combination of transient

Page 416

dynamic responses is to achieve a conditional nonexceedance probability of at least 50% for the peak combined response of the system, component, or element considered. That is, there is a 50% probability that the magnitude of the summed responses will not exceed the SRSS value, given that the combined events have occurred. This goal is achieved by compliance with the following criteria provided that the amplitude of loads or accelerations for each input are conservatively represented (approximately at the level of the 84th percentile or the mean plus one standard deviation of the input amplitude).

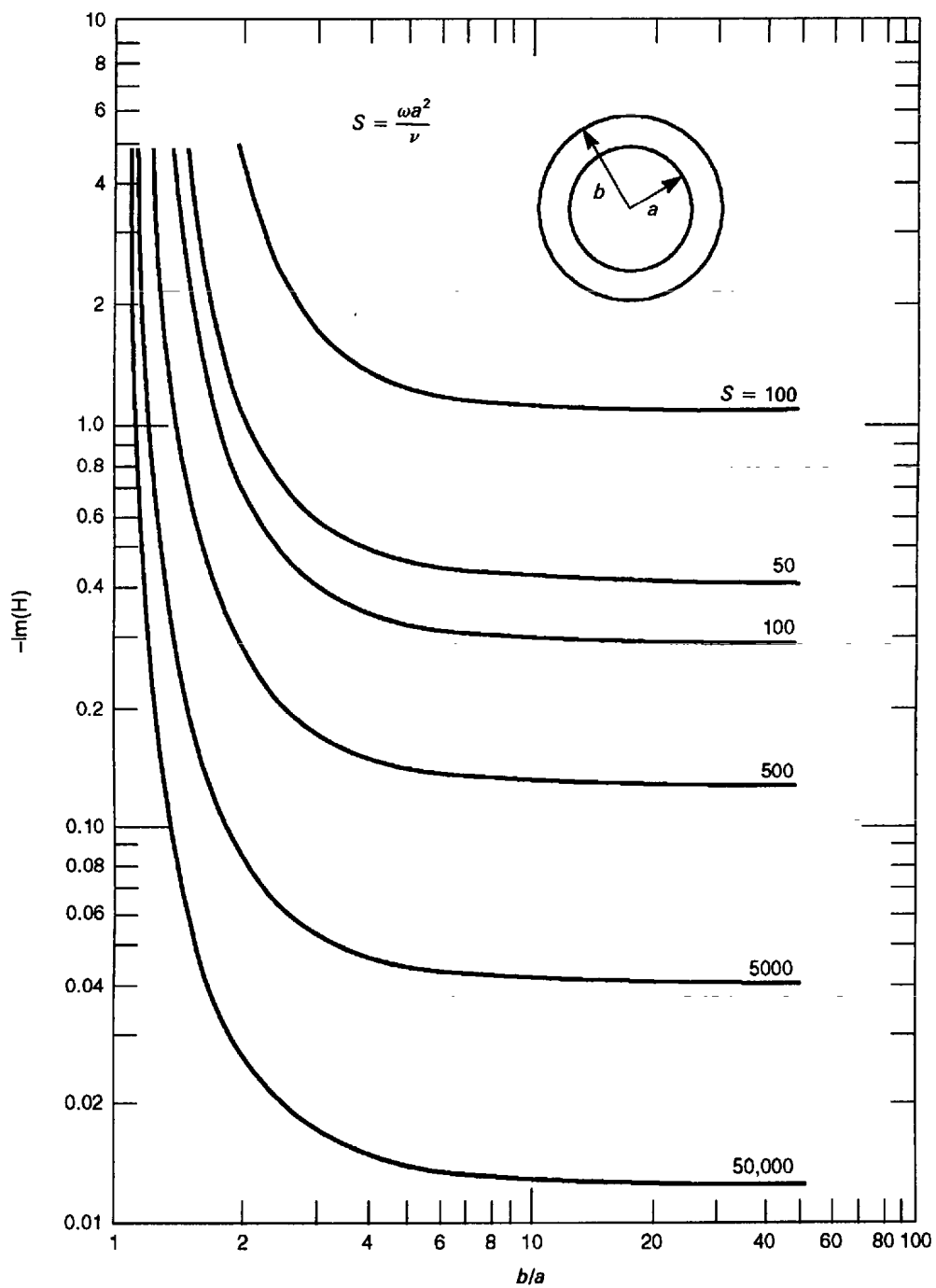
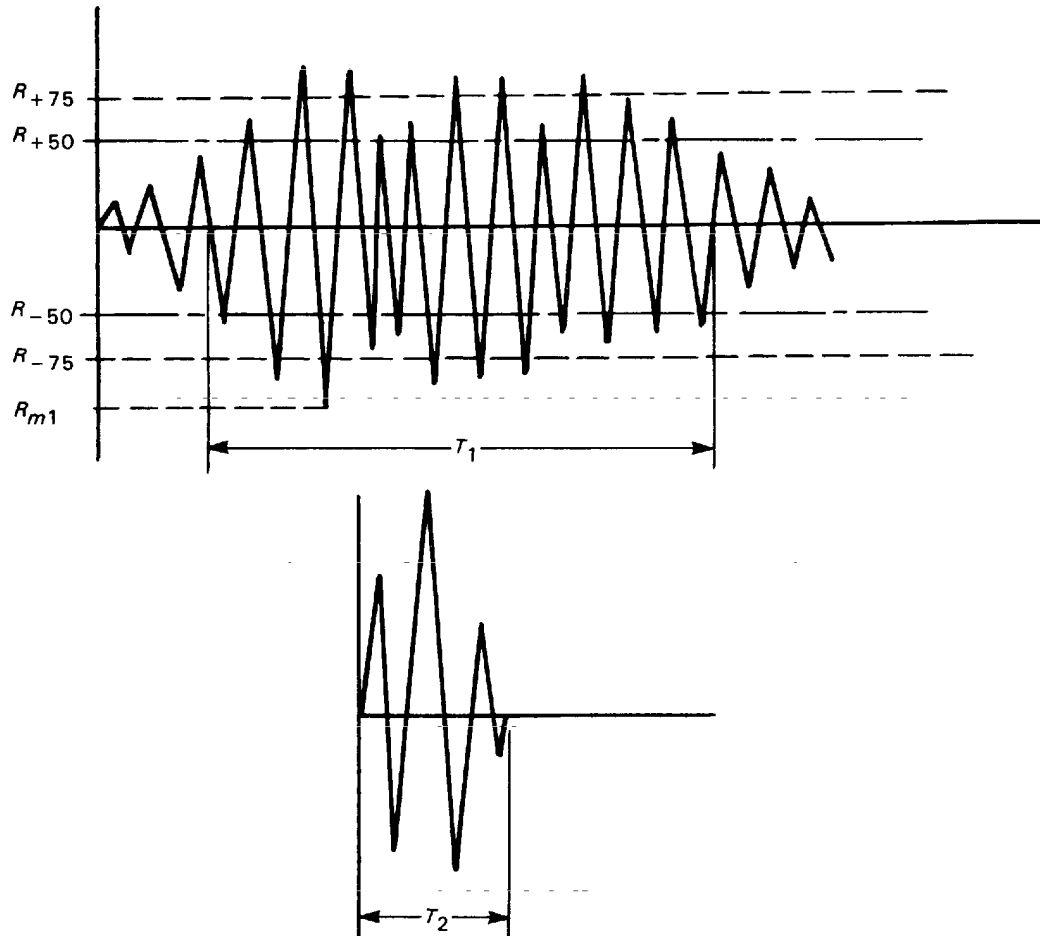


FIG. N-1470-1 IMAGINARY PART OF Z AS A FUNCTION OF b/a FOR SELECTED VALUE OF S (REF. 146)

FIG. N-1470-1 IMAGINARY PART OF Z AS A FUNCTION OF b/a FOR SELECTED VALUE OF S (REF. 146)



R_{m1} = absolute maximum response
 $R_{+75} = 0.75 |R_{m1}|$
 $R_{-75} = -0.75 |R_{m1}|$
 T_{+75} = summation of time intervals that response exceeds R_{+75}
 T_{-75} = summation of time intervals that response exceeds R_{-75}
 T_{75} = larger of T_{+75} or T_{-75}
 $\Delta T = T_1$, since $T_1 > T_2$

FIG. N-1722.2-1 DEFINITION OF NOTATION

FIG. N-1722.2-1 DEFINITION OF NOTATION

Criterion. Dynamic or transient responses of linear structures, components, and equipment arising from combinations of dynamic loading or motions may be combined by SRSS provided that each of the dynamic inputs or responses has a

limited number of peaks of force or acceleration and *approximately a zero mean*, and that the individual component inputs can be considered to be *relatively uncorrelated* (Refs. 75 to 78). Specific criteria for these three requirements are given below.

The requirement of a *limited number of peaks* is satisfied if any one of the following three criteria is met.

(a) For each response time history in the combination:

$$\frac{T_{75}}{\Delta T} \leq 0.02$$

and

$$\frac{T_{50}}{\Delta T} \leq 0.08$$

where T_{75} represents the summation of time intervals for all peaks over which the response exceeds 75% of either the maximum or minimum response (whichever is greater), T_{50} represents the time over which the response exceeds 50% of either the maximum or minimum response (whichever is greater), and ΔT represents the total time interval over which the maximum responses are expected to occur. For the case of random relative start times, ΔT represents the time interval during which the strong responses may overlap (generally taken as the time interval from the zero crossing time just preceding the first peak that exceeds 50% of the absolute maximum response to the zero crossing time just following the last peak that exceeds 50% of the absolute maximum response, of the longer time history). The strong motion of a seismic time history is discussed in N-1212.2(f). In determining the time T_{75} and T_{50} only the durations of peaks with the same sign (positive or negative) are additive. These definitions are illustrated in Fig. N-1722.2-1.

(b) For each input-time history in the combination:

$$\frac{T_{75}}{\Delta T} \leq 0.01$$

and

$$\frac{T_{50}}{\Delta T} \leq 0.04$$

where the definitions are the same as above, except for the substitution of input for response.

(c) If criteria (a) or (b) above are not met by each of the responses or inputs, respectively, in the combination, this requirement is still satisfied if the effective time ratios $(T_{75}/\Delta T)_e$ and $(T_{50}/\Delta T)_e$ for the response combination meet the requirements of (a) above. The effective time ratios for the response combination are given by:

$$\left(\frac{T_{75}}{\Delta T} \right)_e = \sqrt{\frac{\sum_{i=1}^N (R_m T_{75} / \Delta T)_i^2}{\sum_{i=1}^N (R_m)_i^2}}$$

where i represents each individual response in the combination and $(R_m)_i$ represents the maximum amplitude of that response component. The effective time ratio $(T_{50}/\Delta T)_e$ is obtained by substituting 50 for 75 in the above equation.

The requirement of *approximately a zero mean* is satisfied if, for the duration of strong input (or response), the ratio of the mean to maximum input (or response) is less than 0.20. The mean value is:

$$\mu = \frac{1}{N} \sum_{j=1}^n R_j$$

where μ is the mean value, R_j is the response at time increment j , and N is the total number of equally spaced time increments.

If this requirement is not met, responses can be divided into two parts (nonzero mean part and peak response relative to mean response) provided the response function is not skewed from the axis of the mean μ . The nonzero mean part of response can be combined algebraically (accounting for the sign of the mean response) and the peak responses relative to the mean responses can be combined SRSS if these relative responses meet the provisions of this section.

Page 419

The requirement of *relatively uncorrelated* inputs is met if either of the following is satisfied: (1) the individual dynamic inputs or responses are from events such that their relative start times are uncertain; (2) if the relative start times are known, then the coefficient of correlation must be less than 0.3.

N-1723 SRSSE (Equivalent SRSS) Method

(a) In those cases where individual linear system time history responses have randomly defined time phase relationships and condition (b) of N-1722 is not satisfied, the SRSSE method may be used to determine the combined design response. As an illustration, N-1723.1 and N-1723.2 describe a detailed numeric procedure for determining the combinations for the case where two individual time history responses have a uniform random time phase relationship.

(b) For the case when three or more linear time history responses are to be combined, the procedures of N-1724 may be used to determine the combined SRSSE design responses (Ref. 68).

N-1723.1 SRSSE Method for Two Time History Responses.

A method may be constructed to obtain the SRSSE response combinations as given in (a), (b), and (c) below.

(a) Determine one time history as a reference function. Bring the origin of the second function coincident with the origin of the reference function. Care should be taken to determine the reference function so that the time shift of the second function is consistent with the actual sequence of events expected. The origin of the second function could occur at, before, or after the origin of the reference function. The case where the origins are coincident will be discussed in (b) and (c) below. The procedure for the other two cases are similar.

(b) Shift the second function in small time steps relative to the reference function until the origin of the second function goes to the end of the reference function (see Fig. N-1723.1-1). For each time phase difference τ , a scan is made from the time zero to $t_{gr} + T_2$ if $(t_{gr} + T_2) \leq T_1$, or from the time zero to $(t_{gr} + T_2) < T_1$ to determine the largest amplitude (peak) of the sum of the two functions. T_1 and T_2 are the time duration of the reference function and second function, respectively. The algebraic maximum and minimum of these peaks, Maximum Combined Amplitude (FF), are plotted as functions of the time phase difference τ . The resulting function is called the Amplitude Phase Function (APF) which is shown in Fig. N-1723.1-3

(c) The functional relationship between the APF and the Probability Density Function (PDF) for the time shift (Fig. N-1723.1-2) is then used to compute the cumulative Distribution Functions (CDF) of the maximum and minimum combined amplitudes as detailed in N-1723.1.1 (Fig. N-1723.1-4). The choice of the appropriate PDF for τ should be developed on a case-by-case basis. The uniform PDF is frequently a reasonable assumption when there is a weakly known cause and effect between the initiation of the causative events.

N-1723.1.1 Cumulative Distribution Function (CDF).

Both the maximum and minimum Cumulative Distribution Functions need to be constructed.

(a) From Fig. N-1723.1-3, which illustrates the maximum APF function, it can be seen that any possible combined amplitude FF falls between two extreme limits $FF_{\max}$ and $FF_{\min}$. It is clear that the probability that the value of FF is less than $FF_{\max}$ is one, and the probability that the value of FF is less than $FF_{\min}$ is zero. Hence, in Fig. N-1723.1-4, we can immediately plot these two extreme points.

(b) The intermediate points on the CDF are found by integration of the distribution of the time shift τ between appropriate limits. Hence, at this point, the choice of the distribution for τ enters the calculations.

(c) Calculation of the intermediate points on the CDF requires the consideration of the functional relationship between the maximum combined amplitude FF and the time phase shift τ . For a given value of FF on Fig. N-1723.1-3 (in this case FF_1) there is an interval on the τ axis (τ_2, τ_3) in Fig. 1723.1-3. This same τ interval (τ_2, τ_3) can also be observed on the Probability Density Function for τ in Fig. N-1723.1-2. The shaded area of Fig. N-1723.1-2 represents the probability that τ falls in the interval (τ_2, τ_3). The event of τ falling in the interval (τ_2, τ_3) corresponds exactly to the event that FF is less than or equal to FF_1 . Therefore, the ordinate P of Fig. N-1723.1-4 corresponding to FF_1 can be computed as

$$P_1 = \int_{\tau_2}^{\tau_3} \text{PDF}(\tau) d\tau \quad (131)$$

(131)

and for the case where

$$(132) \text{PDF}(\tau) = 1/T_1$$

then

$$(133) P_1 = (\tau_3 - \tau_2)/\tau_1$$

(d) The same procedure is followed for other levels of FF. Note that care must be exercised when integrating

Page 420

multiple valued functions to avoid a loss of information. If the level of FF selected contains more than one interval of τ , all intervals must be integrated to obtain the associated probability. For example, in the case of FF, the integration limits in Eq. (131) would be from τ_1 to τ_4 and from τ_5 to τ_6 . The result of the integration is designated P_2 and plotted in Fig. N-1723.1-4.

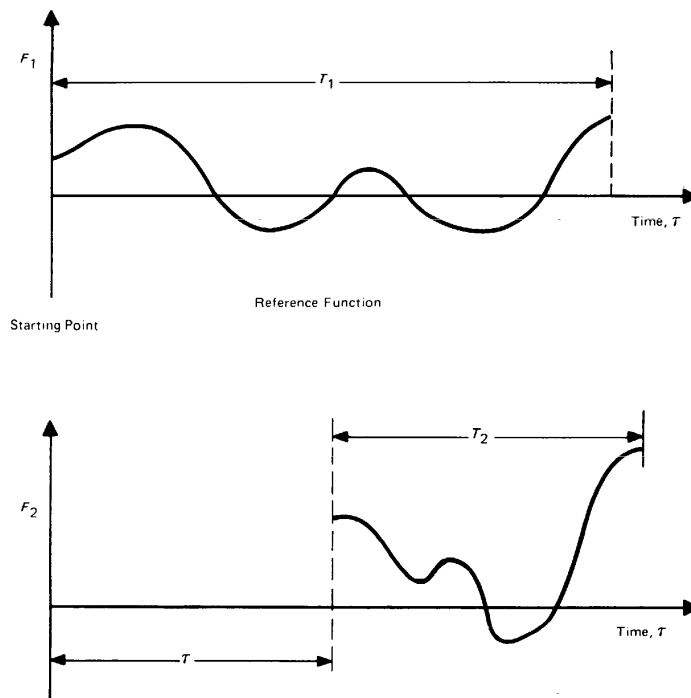


FIG. N-1723.1-1

FIG. N-1723.1-1

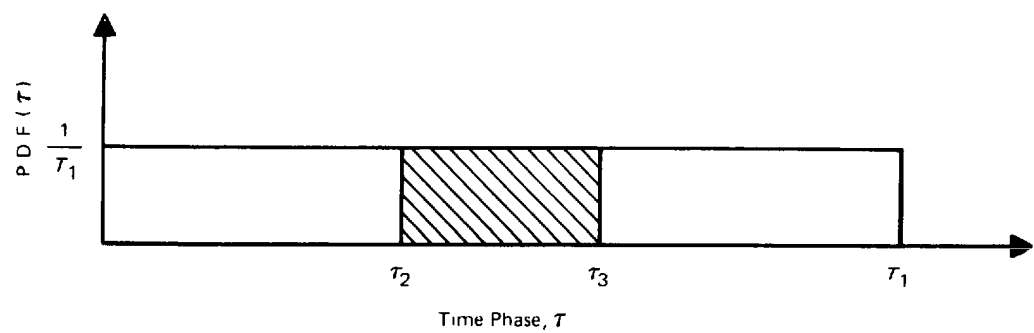


FIG. N-1723.1-2

FIG. N-1723.1-2

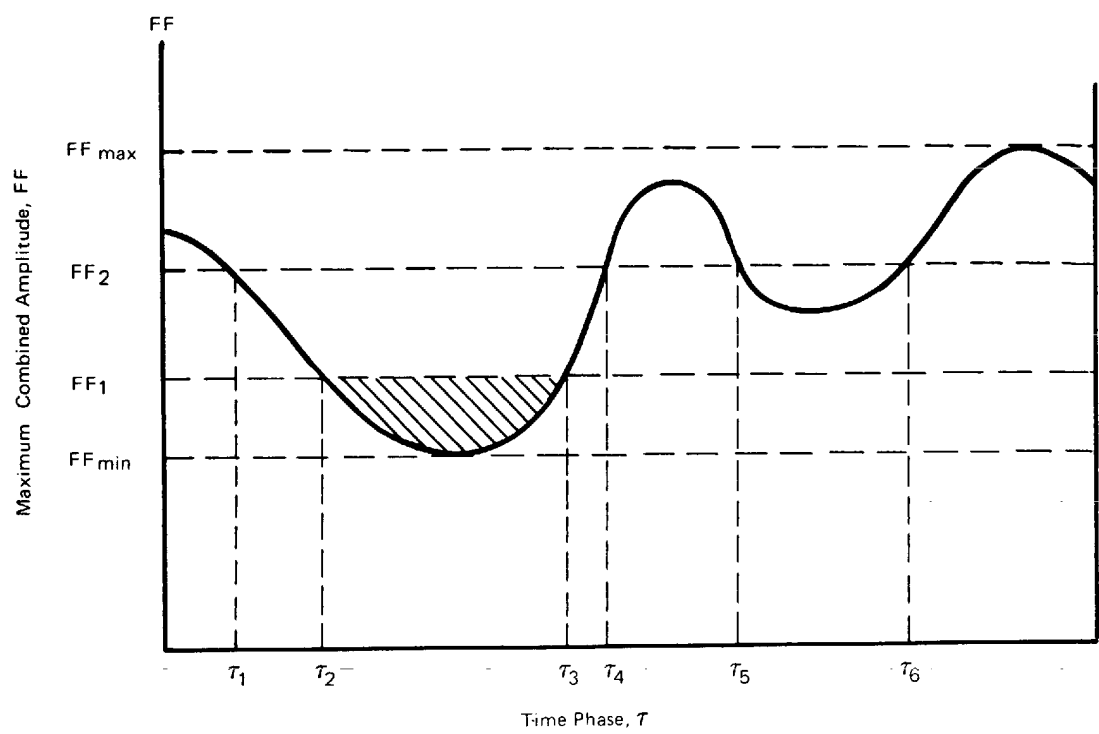


FIG. N-1723.1-3

FIG. N-1723.1-3

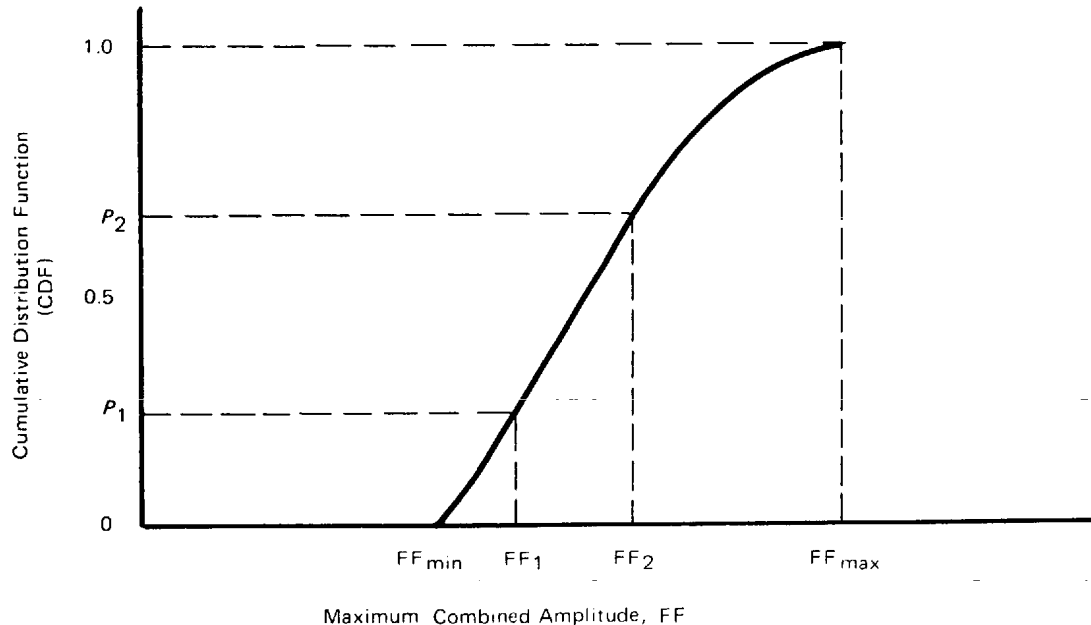


FIG. N-1723.1-4

FIG. N-1723.1-4

(e) Selecting different levels of FF and repeating the above procedure, the CDF function as shown in Fig. N-1723.1-4 can be constructed.

(f) This entire procedure is then repeated for the minimum APF function to find its corresponding CDF.

N-1723.1.2 Cumulative Distribution Function for the Absolute Maximum.

An alternative and more conservative procedure than that given in N-1723.1.1 may also be used to generate the CDF of combined responses. In this alternative procedure, instead of summing the positive and negative peaks of the response separately as in N-1723.1.1, the absolute value of the peak combined response is identified for each value of τ when generating the APF. In this alternative procedure, a single APF is generated which corresponds to a combination of both positive or negative combined responses, whichever is greater in absolute magnitude for each value of τ . The procedure to construct the absolute maximum CDF is the same as stated in N-1723.1.1, except that only one CDF is generated for each response combination instead of two.

N-1723.2 SRSSE Values.

From the maximum and minimum CDF determined in N-1723.1.1, select the values for SRSSE maximum and SRSSE minimum combinations corresponding to the 50% probability levels. It should be noted that these 50% levels are conditional probability levels given that the causative events have occurred. In order to determine total probability levels associated with the SRSSE values, it is necessary to multiply by the corresponding simultaneous combined event occurrence as illustrated in Ref. 70.

N-1724 SRSSE Method for Three or More Functions

A Monte Carlo simulation procedure (Refs. 69 and 70) will generally be required to generate the CDF if there are more than two time history response functions to be combined. The SRSSE maximum, minimum, or absolute maximum values are at the same 50% probability levels used in N-1723.2.

N-1725 Alternative CDF Values

The SRSSE values of N-1723.2 and N-1724 are at a conditional nonexceedance probability level of 50%. That is, there is a 50% probability that the magnitude of the summed responses will not exceed the SRSSE values, given that the combined events have occurred. When the peak combined response values of N-1721 are used, the 100% nonexceedance values result. Since the use of either of these levels (50%, 100%) must be specified through consideration of systems requirements and service levels, alternative nonexceedance probability levels between 50% and 100% may also be used.

Page 423

REFERENCES TO APPENDIX N

- (1) Newmark, N. M., Blume, J. A., and Kapus, K. K. Design Response Spectra for Nuclear Power Plants. *ASCE Structural Engineering Meeting*, San Francisco, CA, Apr. 1973.
- (2) N. M. Newmark Consulting Engineering Services. A Study of Vertical and Horizontal Earthquake Spectra. USAEC Contract No. AT(49-5)-2667, WASH-1255; Urbana, IL, Apr. 1973.
- (3) John A. Blume & Associates. Recommendations for Shape of Earthquake Response Spectra. USAEC Contract No. AT(49-5)3011, WASH-1254; San Francisco, CA, Feb. 1973.
- (4) Bendat, J. S., and Piersol, A. G. *Random Data: Analysis and Measurement Procedures*, Wiley-Interscience, 1971.
- (5) Penzien, J., and Watabe, M. Characteristic of 3-Dimensional Earthquake Ground Motions. *Earthquake Engineering and Structural Dynamics*, Vol. 3, 3-9, 1974.
- (6) Hadjian, A. H. On the Correlation of the Components of Strong Ground Motion - Part 2. *Bulletin of The Seismological Society of America*, Vol. 71, No. 4, pp. 1323-1331, Aug. 1987.
- (7) Kasawara, R. P., and Peck, D. A. Dynamic Analysis of Structural Systems Excited at Multiple Support Locations. *ASCE 2nd Specialty Conference on Structural Design of Nuclear Plant Facilities*, Chicago, IL, Dec. 1973.
- (8) Hurty, W. C., and Rubinstein, M. F. *Dynamics of Structures* Prentice-Hall, Englewood Cliffs, NJ, 1964.
- (9) Meek, J. W., and Veletsos, A. S. Dynamic Analysis by Extra Fast Fourier Transform. *Journal of Engineering Mechanics Division*, Vol. 98, No. EM2, pp. 367-384, ASCE, Apr. 1972.
- (10) Newmark, N. M. A Method of Computation for Structural Dynamics, *Journal of Engineering Mechanics Division*, Vol. 85, No. EM3, pp. 67-94, ASCE, July 1959.
- (11) Houbolt, J. C. A Recurrence-Matrix Solution of Dynamic Response of Elastic Aircraft. *Journal of Aeronautical Sciences*, Vol. 17, pp. 540-550, 1950.
- (12) Bathe, K. J., and Wilson, E. L. Stability and Accuracy Analysis of Direct Integration Methods. *Earthquake Engineering and Structural Dynamics*, Vol. 1, pp. 283-291, 1973.
- (13) Chan, S. P., Cox, H. L., and Benfield, W. A. Transient Analysis of Forced Vibrations of Complex Structural-Mechanical Systems. *Journal of the Royal Aeronautical Society*, Vol. 66, pp. 457-460, July 1962.
- (14) O'Hara, G. J., and Cunniff, P. F. Numerical Method for Structural Shock Response. EMD2, pp. 51-82, ASCE, 1964.
- (15) Riead, H. D. Nonlinear Response Using Normal Modes. *AIAA 12th Aerospace Sciences Meeting*, Paper No. 74-138, Jan. 1974.
- (16) Stricklin, J. A., and Haisler, W. E. Survey of Solution Procedures for Nonlinear Static and Dynamic Analysis. *SAE Conference on Vehicle Structural Mechanics*, pp. 1-17, Detroit, MI, Mar, 1974.

- (17) Lapidus, L., and Seinfeld, J. H. *Numerical Solution of Ordinary Differential Equations*, Academic Press, 1971.
- (18) Nordsieck, A. On Numerical Integration of Ordinary Differential Equations. *Journal of Mathematics and Computation*, p. 22, 1962.
- (19) Collatz, L. *The Numerical Treatment of Differential Equations*, Springer, 1960.
- (20) Garnet, H., and Armen, H. Evaluation of Numerical Time Integration Methods as Applied to Elastic-Plastic Dynamic Problems Involving Wave Propagation. Grumman Research Department Report, RE-475, Mar. 1974.
- (21) Nahavandi, A. N., and Bohm, G. J. A Solution of Nonlinear Vibration Problems in Reactor Components. *Nuclear Science and Engineering*, 26, pp. 80-89, 1966.
- (22) Wu, R. W. H., and Witmer, E. A. Nonlinear Transient Responses of Structures by the Spatial Finite-Element Method. Vol. 11, No. 8, pp. 1110-1117, AIAA, 1973.
- (23) Nickell, R. E. Direct Integration Methods in Structural Dynamics. EM2, Vol. 99, pp. 303-317, ASCE, 1973.
- (24) Cook, R. D. *Concepts and Applications of Finite Element Analysis*, pp. 252-254, Wiley-Interscience, 1974.
- (25) Wilson, E. L., Farhoomand, I., and Bathe, K. J. Nonlinear Dynamics Analysis of Complex Structure. *Earthquake Engineering and Structural Dynamics*, Vol. 1, pp. 241-252, 1973.
- (26) Macneal, R. H. Nastran Theoretical Manual. NASA SP-221(01), pp. 11.3-1-11.3-13, Dec. 1972.
- (27) Stricklin, J. A., Martinez, J. E., Tillerson, J. R., Hon, J. H., and Haisler, W. E. Nonlinear Dynamic Analysis of Shells of Revolution by Matrix Displacement Method. AIAA-7, Vol. 9, No. 4, pp. 629-636, 1971.
- (28) McNamara, J. F., and Marcal, P. V. Incremental Stiffness Method for the Finite Element Analysis of the Nonlinear Dynamic Problem *ONR Symposium: Numerical and Computer Methods in Structural Mechanics*, Urbana, IL, Sep. 1971.
- (29) Nagarajan, S., and Popov, E. P. Elastic-Plastic Dynamic Analysis of Axisymmetric Solids. NTIS, AD 764244, July 1973.
- (30) Hou, S. N. Earthquake Simulation Models and Their Applications. Ph.D. Thesis, MIT, 1968.
- (31) Lin, W. L., and Lin, T. H. A Discussion of Coupling and Resource Effects for Integrated Systems. *3rd SMIRT Conference*, Paper K5/2, London, 1975.
- (32) Hadjian, A. H. On the Decoupling of Secondary Systems for Seismic Analysis. *6th World Conference on Earthquake Engineering*, Vol. 12, pp. 12-13 - 12-18, New Delhi, Jan. 1977.
- (33) Pickle, T. W., Jr. Evaluation of Nuclear System Requirements for Accommodating Seismic Effects. *Nuclear Engineering and Design*, 20, 1972.
- (34) Fortune, H. J. Modeling Techniques and Procedures. *1st ASCE Specialty Conference on Structural Design of Nuclear Plant Facilities*, Pittsburgh, PA, Apr. 1972.
- (35) Hadjian, A. H. Earthquake Forces on Equipment in Nuclear Power Plants. *Journal of Power Division*, pp. 649-665, ASCE, July 1971.
- (36) Biggs, J. M. Seismic Response Spectra for Equipment Design in Nuclear Power Plants. *1st SMIRT Conference*, Paper K4/7, Berlin.
- (37) Kapur, K. K., and Shao, L. C. Generation of Seismic Floor Response Spectra for Equipment Design. *ASCE Specialty Conference*

on Structural Design of Nuclear Power Plant Facilities, Chicago, IL, Dec. 1973.

- (38) O'Hara, G. J. Effect Upon Shock Spectra of the Dynamic Reaction of Structures, NRL Report 5236, U.S. Naval Research Laboratory, Dec. 1958.
- (39) Newmark, N. M. Seismic Response of Reactor Facility Components, *ASME Symposium on Seismic Analysis of Pressure*

Vessels and Piping Components, San Francisco, CA, May 1971.

- (40) Hamilton C. W., and Hadjian, A. H. Probabilistic Frequency Variations of Structure-Soil Systems. *Nuclear Engineering and Design*: 38, pp. 303-322, 1976.
- (41) Amin, M., Hall, W. J., Newmark, N. M., and Kassawara, R. P. Earthquake Response of Multiple Connected Light Secondary Systems by Spectrum Methods. *ASME First National Congress on Pressure Vessel and Piping Technology*, San Francisco, CA, May 1971.
- (42) Tsai, N. C. Transformation of Time Axes of Accelerograms. *Journal of the Engineering Mechanics Division*, Vol. 95, No. EM3, Proceedings Paper 6584, PY807-812, ASCE, June 1969.
- (43) Vashi, K. M. Seismic Spectral Analysis of Structural Systems Subject to Nonuniform Excitation at Supports. *2nd ASCE Specialty Conference on Structural Design of Nuclear Power Plant Facilities*, Vol. 1-A, pp. 188-211, New Orleans, LA, Dec. 1975.
- (44) Shaw, D. E. Seismic Structural Response Analysis for Multiple Support Excitation. *Proceedings of the Third International Conference on Structural Mechanics in Reactor Technology*, Vol. 4, K7/3, London, 1975.
- (45) Thailer. Spectral Analysis of Complex Systems Supported at Several Elevations. *Journal of Pressure Vessel Technology*, pp. 162-165, May 1976.
- (46) Clough, R. W., and Pensien, J. *Dynamics of Structures*. Chapter 27-4, McGraw-Hill Book Co., New York, 1975.
- (47) Meirovitch, L. *Analytical Methods in Vibrations*. p. 403, MacMillan Co., New York, 1967.
- (48) Reid, T. J. Free Vibration and Hysteretic Damping. *Journal of the Royal Aeronautical Society*. Vol. 69, p. 283, 1956.
- (49) Bohm, G. J. Damping for Dynamic Analysis of Reactor Coolant Loop Systems. *ANS National Topic Meeting Water Reactor Safety*, CONF-730304 USAEC, Salt Lake City, UT, Mar. 1973.
- (50) Hart, G. C., and Ibanez, P. Experimental Determination of Damping in *Nuclear Power Plant Structures and Equipment*. *Nuclear Engineering and Design*: 25, pp. 112-125, 1973.
- (51) Newmark, N. M., and Rosenblueth, E. *Fundamentals of Earthquake Engineering*. pp. 321-363, Prentice-Hall, Englewood Cliffs, NJ, 1971.
- (52) Rayleigh, Lord, *The Theory of Sound* Vol. 1, p. 130, Dover, NY, 1945.
- (53) Caughey, T. K. Classical Normal Modes in Damped Linear Dynamic Systems. *Journal of Applied Mechanics*: 27, pp. 269-271, 1960.
- (54) Wilson, E. L., and Pensien, J. Evaluation of Orthogonal Damping Matrices. *Int. J. for Numerical Methods in Eng.*, Vol. 4, pp. 5-10, 1972.
- (55) Yeh, G. C. K. Determination of the Damping Matrix Dynamic Structural Analysis of Reactor Containment. *Proceedings of the First International Conference on Structural Mechanics in Reactor Technology*.
- (56) Hurry, W. C. Dynamic Analysis of Structural Systems Using Component Modes. *J. of AIAA*, Vol. 3, No. 4, Apr. 1965.
- (57) Koss, P. Element Associated Damping by Modal Synthesis. *ANS National Topic Meeting Water Reactor Safety*, Salt Lake City, LIT, Mar. 1973.
- (58) Olsen, B. E., Singleton, N. R., and Bohm, G. J. Indian Point Loop Vibration Test Program. SCAP 7920, Westinghouse Nuclear Energy Systems, 1972.
- (59) Whitman, R. V., Christian, J. T., and Biggs, J. M. Parametric Analysis of Soil-Structure Interaction for a Reactor Building. *Proceedings of the First International Conference on Structural Mechanics in Reactor Technology*, pp. 257-279, Berlin, Sep. 1971.
- (60) Johnson, T. E., and McCaffery, T. J. Current Techniques for Analyzing Structures and Equipment for Seismic Effects. *ASCE Conference*, New Orleans, LA, 1969.

- (61) Whitman, R. V. Soil Structure Interaction. *Seismic Designa for Nuclear Power Plants* (Hansen, R. J., ed.) pp. 241-269, MIT Press, Cambridge, MA, 1970.
- (62) Wiley, J. W., Schechter, K. M., Price, D. L. Koss, P. W. Seismic Analysis and Design of the San Onofre Nuclear Generation Station, Units 2 & 3 Containment. *Electric Power and the Civil Engineer*, ASCE, 1974.
- (63) Hurry, W. C., Collins, J. D., and Hass, G. C. Dynamic Analysis of Large Structures by Modal Synthesis Techniques. *Computer and Structures*, Vol. 1, 1971.
- (64) Pajuhesh, J., and Hadjian, A. H. Dynamic Interaction of Components, Structure and Foundation of Nuclear Power Facilities. *4th SMIRT Conference*, Paper K3/9, San Francisco, CA, Aug. 1977.
- (65) Ibrahim, A. M., and Hadjian, A. H. The Composite Damping Matrix for Three Dimensional Soil-Structure System. *2nd ASCE Specialty Conference on Structural Design of Nuclear Plant Facilities*, New Orleans, LA, Dec. 1975.
- (66) Roesset, J. M., Whitman, R. V., Dobry, R. Modal Analysis for Structures with Foundation Interaction. ST3, pp. 399-416, ASCE, Mar. 1973.
- (67) Caughey, T. K., and Vijayaraghavan, A. Free and Forced Oscillation of a Dynamic System with Linear Hysteretic Damping (Nonlinear Theory). *Int. J. Nonlinear Mechanics*, Vol. 5, pp. 533-555, 1970.
- (68) Papoulis, A. *Probability, Random Variables and Stochastic Processes*. McGraw-Hill, New York, 1965.
- (69) Shooman, M. L. *Probabilistic Reliability: An Engineering Approach*. McGraw-Hill, New York, 1968.
- (70) Tagart, S. W., Jr., and Vagliente, V. N. Probability Evaluation for Dynamic Response Combinations. *Proceedings of the Fourth International Conference on Structural Mechanics in Reactor Technology*, San Francisco, CA, Aug. 1977.
- (71) Tsai, N. C. Spectrum Compatible Motions for Design Purpose, *Journal of the Engineering Mechanics Division*, Vol. 98, No. 2, pp. 345-356, ASCE, 1972.
- (72) Lin, C. W. DEBLIN2 - A Computer Code to Synthesize Earthquake Acceleration Time Histories. WCAP 8867, Westinghouse Electric Corporation, Nov. 1976.
- (73) Housner, G. W., and Jennings, P. C. Generation of Artificial Earthquakes. 90, EMI, pp. 113-150, ASCE, 1964.
- (74) Amin, M., and Ang, A. H. S. A Nonstationary Stochastic Model of Earthquake Motions, University of Illinois, Civil Engineering Studies. Urbana, IL, 1966.
- (75) Kennedy, R. P., and Newmark, N. M. Bases for Criteria for Combination of Earthquake and Other Transient Response by the Square-root-sum-of-the-squares Method. NEDO-24010-2, General Electric Company, San Jose, CA, Dec. 1978.
- (76) Singh, A. K., and Subramanian, C. V. SRSS Application Criteria as Applied to Mark 11 Load Combination Cases. NEDO-24010-1, General Electric Company, San Jose, CA, Oct. 1978.

Page 425

- (77) Kennedy, R. P., Tong, W. H., and Newmark, N. M. Study to Demonstrate the SRSS Combined Response Has Greater Than 84 Percent Nonexceedance Probability When the Newmark-Kennedy Acceptance Criteria Are Satisfied. NEDO-24010-03, General Electric Company, San Jose, CA, Aug. 1979.
- (78) Review of Methods and Criteria for Dynamic Combinations in Piping Systems. NURE 6/CR-1330, Brookhaven National Laboratory, Apr. 1980.
- (79) Chen, P. Y. (ed.) *Flow-Induced Vibration Design Guidelines*, ASME, Vol. pp. 1-52, New York, 1981.
- (80) Paidoussis, M. P. A Review of Flow-Induced Vibrations in Reactors and Reactor Components. *Nuclear Science and Engineering*: 74, pp. 31-60, 1983.
- (81) Chen, S. S. *Flow-Induced Vibration of Circular Cylindrical Structures*, Hemisphere Publishing Corporation, Washington, DC, 1987.
- (82) Blevins, R. D. *Flow-Induced Vibration*, 2nd Ed., Van Nostrand Reinhold, New York, 1990.

- (83) Mulcahy, T. M., and Wambsganss, M. W. Flow-Induced Vibration of Nuclear Reactor System Components, *Shock Vib. Dig.* 8(7), pp. 33-45 1976.
- (84) Naudascher, E., and Rockwell, D. (eds.) *Practical Experiences with Flow Induced Vibrations*, Springer-Verlag, New York, 1980.
- (85) Mulcahy, T. M. Flow-Induced Vibration Testing Scale Modeling Relations. *Flow-Induced Vibration Design Guidelines*, pp. 111-126.
- (86) Bohm, G. J., and Tagart, S. W., Jr. Flow-Induced Vibration in the Design of Nuclear Components. *Flow-Induced Vibration Design Guidelines*, pp. 1-10.
- (87) Sarpkaya, T. Vortex-Induced Oscillations - A Selective Review. *Journal of Applied Mechanics*, 6, pp. 241-258 1979.
- (88) Chen, S. S. Vibration of a Group of Circular Cylinders Subjected to a Fluid Flow. *Flow-Induced Vibration Design Guidelines*, pp. 75-88.
- (89) Connors, H. J., Jr. Vortex Shedding Excitation and the Vibration of Circular Cylinders. *Flow-Induced Vibration Design Guidelines*, pp. 47-74.
- (90) Chen, S. S. Fluid Damping for Circular Cylindrical Structures. *Nucl. Eng. Des.* 63(1), pp. 81-109, 1981.
- (91) Mulcahy, T. M. Fluid Forces on Rods Vibrating in Finite Length Annular Regions. *Journal of Applied Mechanics* 102(2), pp. 234-240, 1980.
- (92) Blevins, R. D. *Formulas for Natural Frequency and Mode Shape*, Van Nostrand Reinhold Company, New York, 1979. Reprinted Robert E. Krieger Publishing Co., Malabar, FL.
- (93) Au-Yang, M. K. Generalized Hydrodynamic Mass for Beam Mode Vibration of Cylinders Coupled by Fluid Gap. *Journal of Applied Mechanics* 44, pp. 172-173, 1977.
- (94) King, R. A Review of Vortex Shedding Research and Its Application. *Ocean Engineering* 4, pp. 141-171, 1977.
- (95) Blevins, R. D. Review of Sound Induced by Vortex Shedding from Cylinders. *J. Sound Vib.* 92, pp. 455-470, 1984.
- (96) Den Hartog, J. P. *Mechanical Vibrations*, 4th Ed., McGraw-Hill, New York, p. 305, 1956.
- (97) Keefe, R. T. An Investigation of the Fluctuating Forces Acting on a Stationary Circular Cylinder in a Subsonic Stream and of the Associated Sound Field. University of Toronto, UTIA Report No. 76, 112, 1961.
- (98) Ramberg, S. E. The Influence of Yaw Angle Upon the Vortex Wakes of Stationary and Vibrating Cylinders. Naval Research Laboratory Memorandum Report 3822, Washington, DC, 1978.
- (99) Paidoussis, M. P. Fluid-elastic Vibration of Cylinder Arrays in Axial and Cross-Flow State of the Art. *Flow-Induced Vibration Design Guidelines*, pp. 11-46.
- (100) Pettigrew, M. J., and Gorman, D. J. Vibration of Heat Exchanger Tube Bundles in Liquid and Two-Phase Cross-Flow. *Flow-Induced Vibration Design Guidelines*, pp. 89-110.
- (101) Zdravkovich, M. M. Review of Flow Interference between Two Circular Cylinders in Various Arrangements. *Journal of Fluids Engineering* 99, pp. 618-633, 1977.
- (102) Owen, P. R. Buffeting Excitation of Boiler Tube Vibration. *J. Mech. Eng. Sci.* 7, p. 437, 1965.
- (103) Chen, Y. N. Flow-Induced Vibration and Noise in Tube Bank Heat Exchangers Due to von Karman Streets. *Journal of Engineering for Industry* 90(1), pp. 135-146, 1968.
- (104) Fitz-Hugh, J. S. Flow-Induced Vibration in Heat Exchangers. *International Symposium on Vibration Problems in Industry*, Keswick, England, Paper 427, 1973.
- (105) Chen, Y. N. Fluctuating Lift Forces of the Karman Vortex Streets on Single Circular Cylinders and in Tube Bundles, Part 3 - Lift Forces in Tube Bundles. *Journal Engineering for Industry* 94, pp. 603-628, 1972.
- (106) Scruton, C. On the Wind Excited Oscillations of Stacks, Towers, and Masts. *National Physical Laboratory Symposium on*

- Wind Effects on Buildings and Structures*, Paper 16, pp. 798-832, 1963.
- (107) Bishop, R. E. D., and Hassan, Y. A. The Lift and Drag Forces on a Circular Cylinder in a Flowing Field. *Proc. Royal Soc.*, London, A 227, pp. 51-75, 1964.
- (108) King, R. On Vortex Excitation of Model Piles in Water. *J. Sound Vib.* 29(2), pp. 169-188, 1973.
- (109) Mulcahy, T. M. Avoidance of the Lock-in Phenomenon in Partial Cross Flow. *J. Sound Vib.* 112(3), pp. 570-574, 1987.
- (110) Sarpkaya, T. Fluid Forces on Oscillating Cylinders. *J. Water Way Port Coastal and Ocean Division* 104, pp. 275-290, ASCE, 1978.
- (111) Griffin, O. M., Skop, R. A., and Ramberg, E. The Resonant, Vortex-Excited Vibrations of Structures and Cable Systems. *Offshore Technology Conference*, Houston, TX, Paper No. OTC-2319, 1975.
- (112) Au-Yang, M. K. Flow-Induced Vibration - Guidelines for Design, Diagnosis, and Trouble Shooting of Common Power Plant Components. *Joint Flow-Induced Vibration Symposium*, ASME Winter Annual Meeting, New Orleans, LA, 1984; and *Journal of Pressure Vessel Technology* 107, pp.326-334, 1985.
- (113) Connors, H. J. Fluid-elastic Vibration of Tube Arrays Excited by Cross Flow. *Symposium on Flow-Induced Vibration in Heat Exchangers*, ASME Winter Annual Meeting, Dec. 1970.
- (114) Roberts, B. W. Low Frequency, Aero-elastic Vibrations in a Cascade of Circular Cylinders. *Mechanical Engineering Science Monograph No. 4*, 1966.
- (115) Chen, S. S., Jendrzejczyk, J. A., and Lin, W. H. Experiments on Fluid-elastic Instability in Tube Banks Subject to Liquid Cross Flow, Part 1: Rectangular Arrays. Argonne National Laboratory Report ANL-CT-78-44, July 1978.
- (116) Weaver, D. S., and Grover, L. K. Cross Flow Induced Vibrations in a Tube Bank. *Journal of Pressure Vessel Technology* 101, 1979.
- (117) Guerrero, H. N., et al. Flow Induced Vibrations of a PWR Upper Guide Structure Tube Bank Model. Paper presented at *Topical Meeting on Nuclear Reactor Thermal Hydraulics*, Saratoga, NY, Oct. 1980; Combustion Engineering Technical Paper, Windsor, TIS-6297.

Page 426

- (118) Southworth, D. J., and Zdravkovich, M. M. Cross Flow Induced Vibrations of Finite Tube Banks with In-Line Arrangements. *J. Mech. Eng. Sci.* 17, pp. 190-198, 1975.
- (119) Paidoussis, M. P. Flow-Induced Vibrations in Nuclear Reactors and Heat Exchangers. In *Practical Experience with Flow Induced Vibrations* (E. Naudascher and D. Rockwell, eds.), Springer-Verlag, New York, pp. 1-81, 1980.
- (120) Chen, S. S. Guidelines for the Instability Flow Velocity of Tube Arrays in Cross Flow. *J. Sound Vib.* 93(1), pp. 439-455, 1984.
- (121) Blevins, R. D. Discussion of Guidelines for the Instability Flow Velocity of Tube Arrays in Cross Flow. *J. Sound Vib.* 97, pp. 641--644, 1984.
- (122) Au-Yang, M. K., and Connelly, W. H. A Computerized Method for Flow-induced Random Vibration Analysis of Nuclear Reactor Internals. *Nucl. Eng. Des.* 42, pp. 257-263, 1977.
- (123) Lin, Y. K. *Probabilistic Theory of Structural Dynamics*, McGraw Hill, New York, 1967.
- (124) Wambsganss, M. W., and Boers, B. L. Parallel-Flow-Induced Vibration of a Cylindrical Rod. ASME Paper No. 68-WA/NE-15, Dec. 1968.
- (125) Crandall, S. H., and Marks, W. D. *Random Vibration in Mechanical Systems*, Academic Press, New York, 1963.
- (126) Corcos, G. M. The Structure of the Turbulent Pressure Field in Boundary Layer Flow. *J. Fluid Mech.* 13, 1964.
- (127) Au-Yang, M. K. Turbulent Buffeting of a Multi-Span Tube Bundle. *Journal of Vibration, Stress and Reliability in Design*, 108, pp. 150-154 1986.

- (128) Blevins, R. D., Gibert, R. J., and Villard, B. Experiments on Vibration of Heat Exchanger Tubes in Cross Flow. *Sixth International Conference on Structural Mechanics in Reactor Technology*, Paris, France, Paper 136/9, 1981.
- (129) Mulcahy, T. M. Fluid Forces on a Rigid Cylinder in Turbulent Cross Flow. *Symposium on Flow-Induced Vibrations, Vol. I - Excitation and Vibration of Bluff Bodies in Cross Flow*, pp. 5-28, ASME, New York, 1984.
- (130) Chen, S. S. A Review of Flow-Induced Vibration of Two-Circular Cylinders in Cross Flow. *Journal of Pressure Vessel Technology* 108, pp. 382-393, 1986.
- (131) Chen, S. S., and Wambsganss, M. W. Parallel-Flow-Induced Vibration of Fuel Rods. *Nucl. Eng. Des.* 18, pp. 253-278, 1972.
- (132) Mulcahy, T. M., Wambsganss, M. W., Lin, W. H., Yeh, T. T., and Lawrence, W. P. Measurements of Wall Pressure Fluctuations on a Cylinder in Annular Water Flow with Upstream Disturbances. *Sixth International Conference on Structural Mechanics in Reactor Technology*, Paris, France, Paper B6/5*, 1981.
- (133) Gibert, R. S. Etude des fluctuations of pression dans les circuits para courus par des fluides - Sources de fluctuations engendrees par les singularites d'Scoulement. Note CEA-N 1925, 1976.
- (134) Mulcahy, T. M., Yeh, T. T., and Miskevics, A. J. Turbulence and Rod Vibrations in an Annular Region with Upstream Disturbances. *J. Sound Vib.* 69(1), pp. 59-69, 1980.
- (135) Lin, W. H., Wambsganss, M. W., and Jendrzejczyk, J. A. Wall Pressure Fluctuations Within a Seven Rod Array. General Electric Report GEAP-24375 (DOE/ET/34209-20), San Jose, CA, Nov. 1981.
- (136) Kadlec, J., and Ohlmer, E. On the Reproducibility of the Parallel-Flow Induced Vibration of Fuel Pins. *Nucl. Eng. Des.* 17, pp. 355-360, 1971.
- (137) Wambsganss, M. W., and Mulcahy, T. M. Flow-Induced Vibration of Nuclear Reactor Fuel. *Shock Vib. Dig.* 11(11), pp. 11-22, and 11(12), pp. 11-13, 1979.
- (138) Weaver, D. S., and Yeung, H. C. The Effect of Tube Mass on the Flow Induced Response of Various Tube Arrays in Water. *J. Sound Vib.* 93(3), pp. 409-425, 1984.
- (139) Weaver, D. S., and Fitzpatrick, J. A. A Review of Flow Induced Vibrations in Heat Exchangers. *International Conference on Flow Induced Vibrations*, Bowness-on-Windermere, England, Paper A1, pp. 1-17, May 1987.
- (140) Weaver, D. S., Fitzpatrick, J. A., and ElKashlan, M. Strouhal Numbers for Heat Exchanger Tube Arrays in Cross Flow. *Journal of Pressure Vessel Technology* 109, pp. 219-223, 1987.
- (141) Chen, S. S., and Jendrzejczyk, J. A. Fluid Excitation Forces Acting on a Square Tube Array. *Journal of Fluids Engineering* 109, pp. 415-423, 1987.
- (142) Axisa, F., Antunes, J., Villard, B., and Wullschleger, M. Random Excitation of Heat Exchanger Tubes by Cross Flow. *1988 International Symposium on Flow-Induced Vibration and Noise*, ASME, Chicago, IL, Vol. 2 - *Flow-Induced Vibration of Cylinder Arrays in Cross Flow*, pp. 2347, 1988.
- (143) Fritz, R. I., and Kiss, E. The Vibration of a Cantilevered Cylinder Surrounded by An Annular Fluid. Knolls Atomic Power Laboratory Report KAPL-M-6539.
- (144) Horvay, G., and Bowers, G. Influence of Entrained Water Mass on the Vibration Mode of a Shell. *Journal of Fluids Engineering*, 1975.
- (145) Au-Yang, M. K. Free Vibration of Fluid Covered Coaxial Cylindrical Shells of Different Lengths. *Journal of Applied Mechanics*: 43, pp. 480-484, 1976.
- (146) Chen, S. S., Wambsganss, M. W., and Jendrzejczyk, J. A. Added Mass and Damping of a Vibrating Rod in Confined Viscous Fluid. *Journal of Applied Mechanics*: 98(2), pp. 325-329, 1976.
- (147) Krajcinovic, D. Vibration of Two Coaxial Cylindrical Shells Containing Fluid. *Nuclear Engineering and Design*: 30, pp. 242-248, 1974.

- (148) Levin, L., and Milan, D. Coupled Breathing Vibration of Two Thin Cylindrical Shells in a Fluid. *Proceedings of Vibration Problems in Industry*, Keswick, England, Paper 616, 1973.
- (149) Au-Yang, M. K., and Skinner, D. A. Effect of Hydrodynamic Mass Coupling on the Response of a Nuclear Reactor to Ground Acceleration. *Proceedings of the 4th International Conference on Structural Mechanics in Reactor Technology*, Paper K5/5.
- (150) Brown, S. J. A Survey of Studies into the Hydrodynamic Response of Fluid-Coupled Cylinders. *Journal of Pressure Vessel Technology*: 104, pp. 2-19, 1982.
- (151) Au-Yang, M. K. Dynamics of Coupled Fluid-Cylindrical Shells. *Journal of Vibration, Stress and Reliability in Design*: 108, pp. 339-347, 1986.
- (152) Arnold, R. H., and Warburton, G. B. 1949 *Proceeding Royal Society A*: 197, p. 238.
- (153) Au-Yang, M. K. Pump-Induced Acoustic Pressure Distribution in An Annular Cavity Bounded by Rigid Walls. *Journal of Sound and Vibration*: 62, pp. 577-591, 1979.
- (154) Au-Yang, M. K. Response of Fluid-Elastically Coupled Coaxial Cylindrical Shells to External Flow. *Journal of Fluids Engineering*: 99, pp. 319-324, 1977.
- (155) Au-Yang, M. K., and Galford, J. E. A Structural Priority Approach to Fluid-Structure Interaction Problems. *Journal of Pressure Vessel Technology*: 103, pp. 142-150, 1981.
- (156) Au-Yang, M. K. The Hydrodynamic Mass at Frequencies above Coincidence. *Journal of Sound Vibration*: 86, pp. 288-292, 1983.

Page 427

- (157) Yeh, T. T., and Chin, S. S. Dynamics of a Cylindrical Shell System Coupled by Viscous Fluid, *Journal of Acoustical Society of America*: 62, pp. 262-270, 1977.
- (158) Mulcahy, T. M. Fluid Forces on Rods Vibrating in Finite Length Annular Regions. *Journal of Applied Mechanics*: 47, pp. 59-69, 1980.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP O

APPENDIX O RULES FOR DESIGN OF SAFETY VALVE INSTALLATIONS

Page 429

ARTICLE O-1000 RULES FOR DESIGN OF SAFETY VALVE INSTALLATIONS

O-1100 SCOPE AND DEFINITION

O-1110 SCOPE

(a) The scope of Appendix O is confined to the design of the safety valve installations as defined in O-1120. The loads acting at the safety valve station will affect the bending moments and stresses in the complete piping system, out to its anchors and/or extremities, and it is the designer's responsibility to consider these loads. This Appendix, however, deals primarily with the safety valve installation and not the complete piping system.

(b) The design of the safety valve installation requires that careful attention be paid to all loads acting on the system, the forces and bending moments in the piping and piping components resulting from the loads, the loading and stress criteria, and general design practices. All components in the safety valve installation must be given consideration, including the complete piping system, the connection to the main header, the safety valve, valve and pipe flanges, the downstream

discharge or vent piping, and the system supports. The scope of this Appendix is intended to cover all loads on all components.

(c) This Appendix has application to either safety, relief, or safety relief valve installations. For convenience, however, the overpressure protection device is generally referred to as a safety valve. The loads associated with relief or safety relief valve operation may differ significantly from those of safety valve operation, but otherwise the rules contained herein are equally applicable to each type of valve installation.

(d) Pressure relief safety valve stations require detailed analysis. In performing its design function the station is subject to dynamic loading from the structural response to both thermal and hydraulic forces and, in some instances, significant impact loading from the valve mechanism. The resultant loading is a mechanical load.

(e) This Appendix provides guidance for design and analysis of the piping components of a safety valve station. The guidance is presented by discussing four areas of consideration:

- (1) load computation - open discharge system;
- (2) stress evaluation - open discharge system;
- (3) closed discharge system;
- (4) general design considerations.

O-1120 DEFINITIONS

(a) *Safety Valve*. An automatic pressure relieving device actuated by the static pressure upstream of the valve and characterized by full opening pop action. It is used for gas or vapor service.

(b) *Relief Valve*. An automatic pressure relieving device actuated by the static pressure upstream of the valve which opens further with the increase in pressure over the opening pressure. It is used primarily for liquid service.

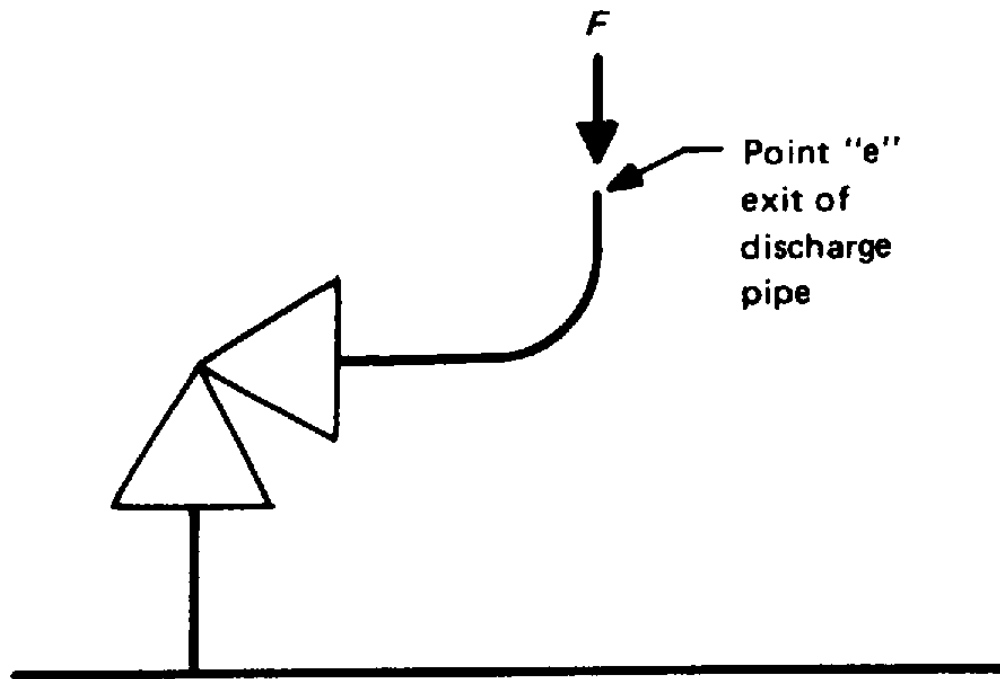
(c) *Safety Relief Valve*. An automatic pressure actuated relieving device suitable for use either as a safety valve or relief valve, depending on application.

(d) *Power-Actuated Pressure Relieving Valve*. A relieving device whose movements to open or close are fully controlled by a source of power (electricity, air, steam, or hydraulic). The valve may discharge to atmosphere or to a container at lower pressure. The conditions, and such effects, shall be taken into account. If the power-actuated pressure relieving valves are also positioned in response to other control signals, the control impulse to prevent overpressure shall be responsive only to pressure and shall override any other control function.

(e) *Open Discharge Installation*. An installation where the fluid is discharged directly to atmosphere or to a vent pipe that is uncoupled from the safety valve. Figure O-1120(e)-1 shows a typical open discharge

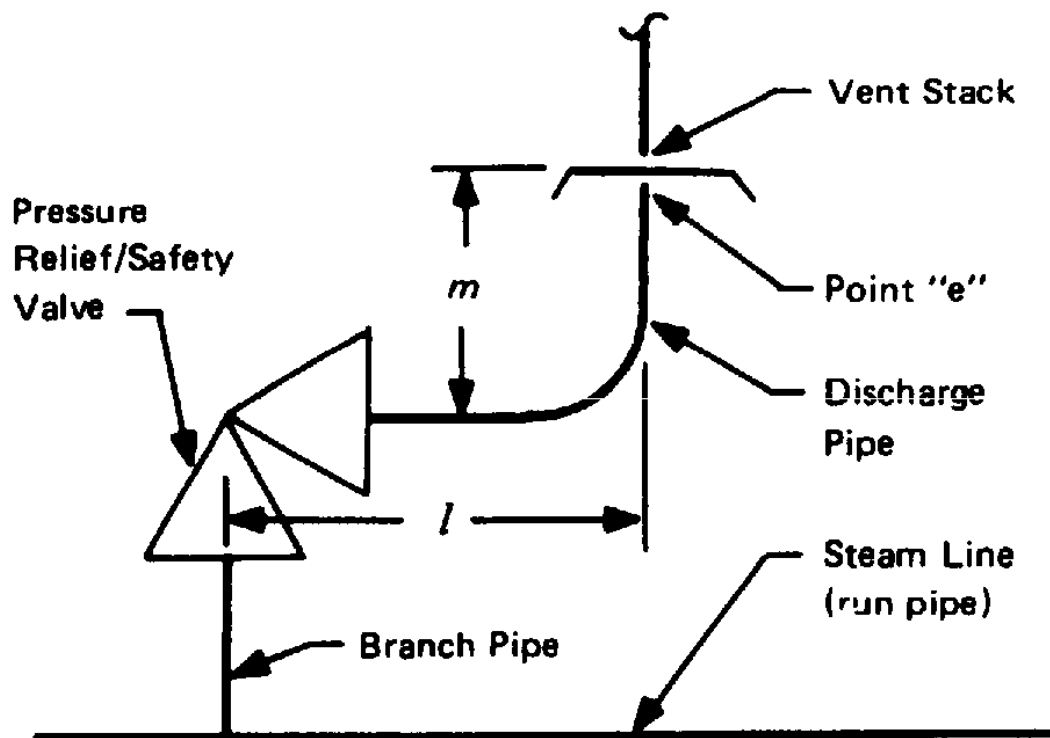
Page 432

installation with an elbow installed at the valve discharge to control direction of flow. Figure O-1120(e)-2 shows a typical open discharge system discharging into a vent pipe. The values for l and m in Fig. O-1120(e)-2 are upper limits for which the rules for open discharge systems may be used.



**FIG. 0-1120(e)-1 APPLICATION POINT OF VENTING
FORCE F**

FIG. 0-1120(e)-1 APPLICATION POINT OF VENTING FORCE F



$$l \leq 4.0 \times \text{discharge pipe diameter}$$

$$m \leq 6.0 \times \text{discharge pipe diameter}$$

FIG. O-1120(e)-2 LIMITING SAFETY VALVE ARRANGEMENTS AND DIMENSIONS

FIG. O-1120(e)-2 LIMITING SAFETY VALVE ARRANGEMENTS AND DIMENSIONS

(f) *Closed Discharge Installation.* An installation where the effluent is carried to a distant spot by a discharge pipe which is connected directly to the safety valve.

(g) *Safety Valve Installation.* The safety valve installation is defined as that portion of the system shown on Figs. O-1120(e)-1 and O-1120(e)-2. It includes the run pipe, the branch connection, the inlet pipe, the valve, the discharge piping,

and the vent pipe. Also included are the components used to support the system for all static and dynamic loads.

O-1200 METHOD OF AND PROCEDURE FOR LOAD COMPUTATION

O-1210 BASIC CONSIDERATIONS

(a) The load computation includes two thermodynamic computations: evaluation of momentum effects and evaluation of pressure effects. The response computation of the piping system includes consideration of transient, dynamic loading effects of the sudden opening and closing valve action. The loads computation is combined with other specified loads and translated to a stress computation which is then compared to the Code allowable stress for acceptability.

(b) The basic principles of analysis of a pressure relief valve station are generally applicable to both open and closed discharge systems. The application of these basic principles may be quite different.

O-1220 OPEN SYSTEM - DISCHARGE THRUST

(a) The limiting dimensions for safety valve arrangements are shown by Fig. O-1120(e)-2. The determination of the reaction force F value(s) is the responsibility of the piping system designer.

(b) The steady-state load due to steam reaction force from the opening and subsequent venting of the safety valve shall include consideration of both momentum and pressure effects and may be computed by the formula:

$$F = (W/g) V_e + (P_e)A$$

where

F	= reaction force, lbf
W	= mass flow rate (relieving capacity stamped on the valve × 1.11 - adjust for units to be compatible, if necessary), lbm/sec
g	= gravitational constant, 32.2 lbm-ft/lbf-sec ²
V_e	= exit velocity at point e , ft/sec
P_e	= static gage pressure at point e , lbf/in. ²
A	= exit flow area at point e , in. ²

The reaction force F is a design mechanical load that requires structural equilibrium for system stability and is applied as shown in Fig. O-1120(e)-1.

(c) To ensure consideration of the effects of the suddenly applied load F , a dynamic load factor DLF, based on the relief/safety valve opening time and system dynamic characteristics, shall be applied to the forces and moments due to the reaction force F .

(d) Instead of a simplified dynamic analysis with the application of the DLF a dynamic hydraulic/structural system analysis may be performed.

O-1230 OTHER MECHANICAL LOADS

Other mechanical loads to be considered should include, as a minimum:

- (a) interaction loads on the run pipe when more than one valve releases; and
- (b) the transient impacting of the valve mechanism opening and closing, if applicable.

O-1300 STRESS EVALUATION OPEN SYSTEM

Evaluation of stresses due to the design mechanical loads may be made by using the rules for Class 1 piping, O-1310 and for

Class 2 or Class 3 piping, O-1320.

O-1310 CLASS 1 PIPING

(a) Whenever any of the equations of NB-3650 are used in the analysis of Class 1 piping systems, the value of M_i shall include the reaction force moment. The contribution from the reaction force F to the branch moment M_b , as defined in Note (5) of Table NB-3682.2-1, shall be no less than the product $F \times \text{nominal discharge pipe size} \times \text{DLF}$.

(b) Note that the use of the equations of NB-3650 for branch connections requires a nozzle spacing as defined by NB-3686.1(c).

(c) When Eq. (9) of NB-3650 is used in the analysis, the value of M_i shall be defined as:

M_i	= resultant moment due to a combination of primary loads. Loads to be considered include: weight; earthquake, considering only one-half the range of the earthquake and excluding the effects of anchor displacement due to earthquake; thrusts from relief and safety valve loads from pressure and flow transients; and other sustained mechanical loads.
-------	---

(d) The combination of loads shall be specified in the Design Specification. In the combination of loads, all directional moment components in the same direction shall be combined before determining the resultant moment; i.e., resultant moments of loads shall not be combined.

(e) When Eq. (10) is used in the analysis, the value of M_i shall be defined as:

M_i	= resultant range of moment due to a combination of primary plus secondary loads. Loads to be considered include: thermal expansion; anchor movement from any cause; earthquake effects; thrusts from relief and safety valve loads from pressure and flow transients; and other mechanical loads.
-------	--

(f) The combination of loads shall be specified in the Design Specification. The earthquake loading shall be considered in conjunction with the operating conditions. Weight effects need not be considered in the range loading because they are noncyclic in character. In the combination of loads, all directional moment components in the same direction shall be combined before determining the resultant moment; i.e., resultant moments of loads shall not be combined. If a combination includes earthquake effects, M_i shall be the greater of the resultant range of moment due to the combination of all loads considering one-half the range of the earthquake or the resultant range of moment due to the full range of the earthquake.

O-1320 CLASS 2 OR CLASS 3 PIPING

(a) For Class 2 or Class 3 piping, Eq. (9) of NC-3652 or ND-3652 is to be used with M_b to include the reaction force moment. The contribution from the reaction force F to the branch moment, as defined in NC-3652.4 or ND-3652.4, shall be no less than the product, $F \times \text{nominal discharge pipe size} \times \text{DLF}$.

(b) Note that the use of Eq. (9) of NC-3652 or ND-3652 for branch connections requires a nozzle spacing, as defined by NC-3643.3(c)(6) or ND-3643.3(c)(6).

O-1400 CLOSED DISCHARGE SYSTEMS - OPEN DISCHARGE SYSTEMS WITH LONG DISCHARGE PIPES - SYSTEMS WITH SLUG FLOW

(a) For closed discharge systems, open discharge systems with long discharge pipes, and systems with slug flow, the state of the art does not lend itself to

Page 434

a well defined method of load computation. For these systems the dynamic interaction forces of the total system including the attached discharge piping must be considered.

(b) When a safety valve discharge is connected to a relatively long run of pipe and is suddenly opened, there is a period of transient flow until the steady-state discharge condition is reached. During this transient period, the pressure and flow will not be uniform. When the safety valve is initially opened, the discharge pipe may be filled with air. If the safety valve is on a steam system, the steam discharge from the valve must purge the air from the pipe before steady state steam flow is established and, as the pressure builds up at the valve outlet flange and waves start to travel down the discharge pipe, the pressure wave initially emanating from the valve will steepen as it propagates, and it may steepen into a shock wave before it reaches the exit.

(c) Relief valves discharging into an enclosed piping system create momentary unbalanced forces which act on the piping system during the first few milliseconds following relief valve lift. The pressure waves traveling through the piping system following the rapid opening of the safety valve will cause bending moments in the safety valve discharge piping and throughout the remainder of the piping system. In such a case, the designer must compute the magnitude of the loads and perform appropriate evaluation of their effects.

(d) Particular attention should be given to the large forcing functions acting on the pipe if it contains water seals, two phase flow, or if there is a water column in the discharge piping.

(e) The reaction force effects are dynamic in nature. A time history dynamic solution, incorporating a multi-degree-of-freedom model solved for the transient hydraulic forces is considered to be a preferred method of analysis.

O-1500 DESIGN CONSIDERATIONS

Reference should be made to NB/NC/ND-7000.

It is recommended that the following be included as part of the total design consideration.

(a) Where not required by the Code, it is recommended that the header penetrations for relief valves be in accordance with the nozzle spacing recommendation of NB-3686.1(c).

(b) No more than one penetration should be made around the circumference of the run pipe (i.e., no two penetrations in the same transverse plane), the spacing to be in accordance with (a) above.

(c) The stress analysis of the pipe could require additional thickness for membrane protection above that required by the thickness equation for pressure load only.

(d) Detail design should preclude sharp notches that may be generated by the use of saddles, gussets, ribs, etc.

(e) Contoured outlets are often advantageous.

(f) The direction of discharge of several pressure relief valves on the same run pipe should be such as to tend to balance one another for all modes of operation specified in the piping design specification.

(g) Supports may require a detailed analysis to determine their role in restraint as well as support. Considerations should be given to the possibility that, under load, snubbing devices may permit significant deflections.

(h) The reaction force moment arm on the outlet piping should be minimized in accordance with the valve manufacturer's recommendation.

(i) The relief valve outlet piping stack clearance should be checked for interference from thermal expansion, earthquake displacements, etc. The vent stack and valve discharge piping system should be arranged such that pull out of the valve discharge pipe does not occur.

(j) Thermal expansion effects are to be considered as they presently are defined in the Code.

(k) The force due to venting should be included in the evaluation of the stack forces. The effects of back pressure in the discharge stack can be significant.

(l) The station should be arranged such that the discharge piping is void of collected water. The discharge piping from each valve or device should be at least of the same size as the valve outlet.

(m) Drains shall be provided so that condensed leakage, rain, or other water sources will not collect on the discharge side of

the valve and adversely affect the reaction force. Safety valves are generally provided with drain plugs that can be used for a drain connection. Discharge piping shall be sloped and provided with adequate drains if low points are unavoidable in the layout.

(n) Where water seals are used ahead of the safety valve, the total water volume in the seals should be minimized. To minimize forces due to slug flow or water seal excursion, the number of changes of direction and the lengths of straight runs of piping should be limited.

(o) Often safety valves are full lift, pop-type valves and are essentially full flow devices with no capability for flow modulation. In actual pressure transients, the steam flow required to prevent overpressure is a varying quantity, from zero to the full rated capacity of the

Page 435

safety valves. As a result, the valves may be required to open and close a number of times during the transient. Since each opening and closing produces a reaction force, consideration should be given to the effects of multiple valve operations on the piping system, including supports.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP P

APPENDIX P CONTENTS OF CERTIFIED MATERIAL TEST REPORTS

Page 437

ARTICLE P-1000 CERTIFIED MATERIAL TEST REPORTS

P-1100 INTRODUCTION

The requirements for a Certified Material Test Report (CMTR) are stated in NCA-3860. However, the material requirements vary with the class of construction, the product form of material, the requirements of the material specification, and the manufacturer's procedures. Since changes in any of these requirements may be made by Addenda or new editions of the Code, it is important for the purchaser and the supplier to know the requirements of the applicable edition and Addenda, so that the reported results can be compared with the requirements to determine whether or not the material is in compliance with the Code.

P-1200 GENERAL REQUIRED INFORMATION

The items of information given in (a) through (i) below are required in the CMTRs for metallic material (as defined by NCA-1220 and NB/NC/ND/NE/NF/NG-2100) used in Section III, Division 1, construction.

- (a) Name of certifying organization [P-1200(j)].
- (b) Number and expiration date of the organization's Certificate of Authorization or Quality System Certificate (Materials). Alternatively, if the organization was qualified by a party other than the Society, the revision and date of the written program under which the material is being certified.
- (c) Purchaser's order or contract number.
- (d) Description of the material, including specification number, grade, class, type, and nominal size, as applicable. For pipe made to specifications which include both seamless and welded pipe, the report shall designate which type it is.
- (e) Description of material identification marking.
- (f) Actual results of chemical analyses, tests, and examinations required by the Material Specification and this Section.
- (g) Reports of weld repairs performed, if any, as required by NB/NC/ND/NE/NF/NG-2500, including radiographic films, when radiography is required.

(h) Charpy V-notch and drop-weight test results required by NB/NC/ND/NE/NF/NG-2320, when this testing is required by NB/NC/ND/NE/NF/NG-2311. When Charpy V-notch impact tests are required, the report shall include the test temperature; the absorbed energy when required; the lateral expansion; and the location and orientation of the specimens used. When drop-weight tests are required, the report shall include the test temperature; the type, location, and orientation of the specimens used; and the results of the tests (break or no break).

(i) Nondestructive examinations performed and accepted as required by NB/NC/ND/NE/NF/NG-2500.

P-1300 INFORMATION REQUIRED UNDER SPECIFIC CIRCUMSTANCES

The information given in (a) through (f) below is required under specific circumstances.

(a) Heat treatment data, as follows:

(1) temperatures (or temperature ranges) and times at temperature used when the material specification requires specific temperatures and times;

(2) heat treatment conditions when no specific temperatures (or temperature ranges) or times are required by the material specification;

(3) the minimum solution annealing temperature used for austenitic stainless steels and high nickel alloys;

(4) recorded temperature ranges and actual times at temperature, and heating and cooling rates, for postweld heat treatment of materials that are repaired by welding, when postweld heat treatment is required by NB/NC/ND/NE/NF/NG-2500;

Page 440

(5) recorded temperatures and actual times at temperature for test coupons when required by NB/NC/ND/NE/NF/NG-2500, when those paragraphs are applicable.

(b) Hydrostatic test pressure, when a hydrostatic test is required by the material specification, or notation that the hydrostatic test has not been performed, if it is deferred.

(c) Ferrite Number for all A-No. 8 welding material except type 16-8-2, as required by NB/NC/ND/NE/NF/NG-2500.

(d) The grain size, reported in accordance with ASTM E 112, when a fine grain size is specified for metallic materials.

(e) For welding materials, in addition to applicable paragraphs above, the process, the preheat and interpass temperature, the type of chemical analysis (filler metal/undiluted deposit), the shielding gas composition, and the Ferrite Number shall be reported as required by NB/NC/ND/NE/NF/NG-2500 and as applicable.

(f) A list of chemical analyses, tests, examinations, and heat treatments required by the Material Specification that were not performed.

P-1400 EXECUTION

(a) All requirements of the material specification and this Section need not be performed by the same organization. In that case the certifying organization shall ensure that each organization, providing material or services, is identified on the CMTR along with the activities for which it is responsible. Alternatively, the CMTR's furnished by the other organizations may be referenced on and attached to the CMTR of the organization which supplies the material.

(b) The CMTR shall include a dated statement affirming that the contents of the report are correct and accurate.

(c) Signing or notarization of the CMTR is not required.

July 1, 1998
American Society Of Mechanical Engineers
SEC III D1 NMA APP Q

APPENDIX Q DESIGN RULES FOR CLAMP CONNECTIONS

Page 441

ARTICLE Q-1000 DESIGN RULES FOR CLAMP CONNECTIONS

Q-1100 INTRODUCTION

Q-1110 SCOPE

(a) The rules in Appendix Q apply specifically to the design of clamp connections for pressure vessels and vessel parts and may be used in conjunction with the applicable requirements in Subsections NC, ND, and NE. These rules are not to be used for the determination of the thickness of supported or unsupported tube sheets integral with a hub nor for the thickness of covers. These rules provide only for hydrostatic end loads and gasket seating and do not consider external loads or thermal effects.

(b) The design of a clamp connection involves the selection of the gasket, bolting, hub, and clamp geometry (see Fig. Q-1130-1). Bolting shall be selected to satisfy the requirements of Q-1140. Connection dimensions shall be such that the stresses in the clamp and hub, calculated in accordance with this Appendix, do not exceed the allowable stresses specified in Q-1180. All calculations shall be made on dimensions in the corroded condition. Calculations for both assembly and operating conditions are required.

(c) It is recommended that either a pressure energized or a low seating load gasket, or both, be used to compensate for possible nonuniformity in the gasket seating force distribution. Hub faces shall be designed so as to have metal-to-metal contact outside the gasket seal diameter. This may be provided by recessing the hub faces or by use of a metal spacer (see Fig. Q-1130-1). The contact area shall be of sufficient cross-sectional area to prevent yielding of either the hub face or spacer under both operating and assembly axial loads.

(d) It is recognized that there are clamp designs which utilize no wedging action during assembly since clamping surfaces are parallel to the hub faces. These designs should satisfy the bolting and corresponding clamp and hub requirements of a clamp connection design with a total included clamping angle of 10 deg. This will provide some safety against loads imposed by angular deflections of the connection faces during operation and also provide some compensation against mechanical and thermal ratcheting.

(e) The rules of this Appendix should not be construed to prohibit the use of other types of clamp connections provided that they are designed in accordance with good engineering practice and the method of design is acceptable to the Inspector. These rules shall apply only to new construction.

(f) Clamps designed to the rules of this Section shall be provided with a bolt retainer. The retainer shall be designed to hold the clamps together independently in case of failure of the primary bolting. An appropriate external yoke or multiple bolting is considered satisfactory for this requirement. Clamp-hub friction shall not be considered as a retainer method.

Q-1120 MATERIALS

(a) Materials used in the construction of clamp connections shall comply with the requirements given in NC, ND, or NE-2000, as applicable.

(b) Hubs and clamps shall not be machined from plate.

Q-1130 NOTATION

The symbols defined below are used in the formulas for the design of clamp-type connections (see also Figs. Q-1130-1 and Q-1130-2).

A	= outside diameter of hub, in.
A_b	= total cross-sectional area of bolts per clamp lug using the root diameter of the thread or least diameter of unthreaded portion, whichever is less, sq in. Cross-sectional area of bolt retainer shall not be included in calculation of this area.

A_c

= total effective clamp cross-sectional area, sq in.

$$= A_1 + A_2 + A_3$$

Page 444

Page 445

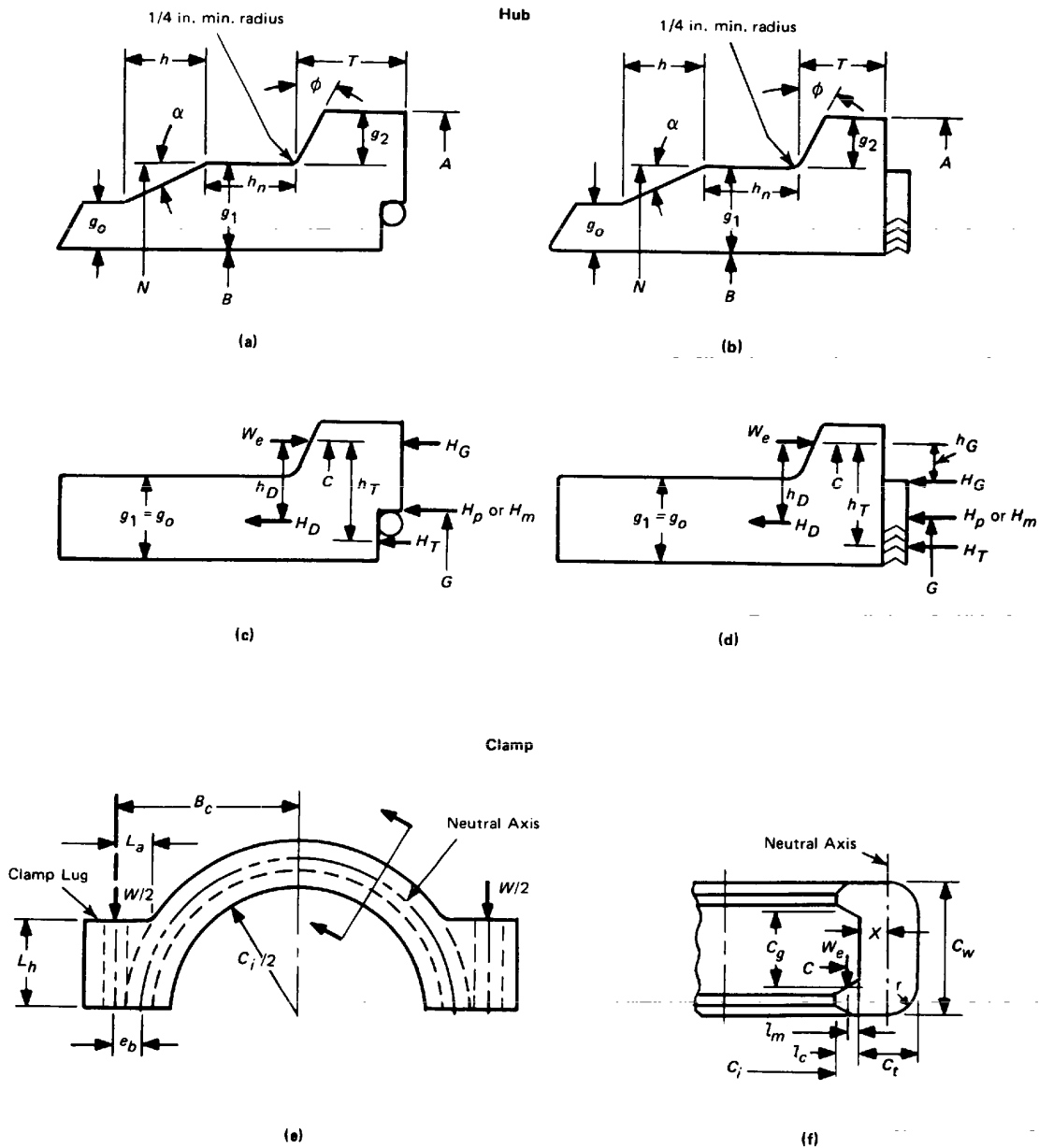


FIG. Q-1130-1 TYPICAL HUB AND CLAMP

A_1	= partial clamp area, sq in. = $(C_w - 2C_t)(C_t)$
A_2	= partial clamp area, sq in. = $1.571C_t^2$
A_3	= partial clamp area, sq in. = $(C_w - C_g)l_c$
A_{m1}	= total cross-sectional area of bolts per clamp lug at root of thread or section of least diameter under stress, required for the operating conditions, sq in. = $W_{m1}/2S_b$
A_{m2}	= total cross-sectional area of bolts per clamp lug at root of thread or section of least diameter under stress, required for gasket seating, sq in. = $W_{m2}/2S_a$
A_{m3}	= total cross-sectional area of bolts per clamp lug at root of thread or section of least diameter under stress, required for assembly conditions, sq in. = $W_{m3}/2S_a$
A_m	= total required cross-sectional area of bolts per clamp lug taken as the greater of A_{m1} , A_{m2} , or A_{m3} , sq in.
b	= effective gasket or joint-contact surface seating width, in. (see Table XI-3221.1-2)
b_o	= basic gasket or joint-contact surface seating width, in. (see Table XI-3221.1-2)
B	= inside diameter of hub, in.
B_c	= radial distance from connection center line to effective center of bolts, in.
C	= diameter of effective clamp-hub reaction load, in. = $(A + C_i)/2$
C_i	= inside diameter of clamp, in.
C_g	= effective clamp gap taken at clamp-hub contact center (C), in.

C_t	= effective clamp thickness, in.
C_w	= effective clamp width, in.
e_b	= radial distance from effective center of the bolts to the centroid of the clamp body, in.
	$= B_c - (C_t/2) - l_c - X$
f	= hub stress correction factor from Fig. XI-3240-6. (This is the ratio of the stress in the small end of the hub to the stress in the large end.) (For values below limit of the Figure, use $f=1.0$.)
g_o	= thickness of hub neck at small end, in.
g_1	= thickness of hub neck at intersection with hub shoulder, in.
g_2	= height of hub shoulder, in. (g_2 shall not be larger than T)
$\bar{g}$	= radial distance from the hub inside diameter to the hub shoulder ring centroid, in.
	=

$$\frac{Tg_1^2 + h_2g_2(2g_1 + g_2)}{2(Tg_1 + h_2g_2)}$$

G	= diameter at location of gasket load reaction. Except as noted in Fig. Q-1130-1, G is defined as follows (see Table XI-3221.1-2): (a) when $b_o \leq \frac{1}{4}$ in., G = mean diameter of gasket or joint contact face, in. (b) when $b_o > \frac{1}{4}$ in., G = outside diameter of gasket contact face less $2b$, in.
h	= hub taper length, in.
h_D	= radial distance from effective clamp-hub reaction load to the circle on which H_D acts, in. $= [C - (B + g_1)]/2$
h_G	= radial distance from effective clamp-hub reaction load to the circle on which H_G acts, in. (for full face contact geometries $h_G = 0$)
h_n	= hub neck length, in. (minimum length of h_n is $0.5g_1$ or $\frac{1}{4}$ in., whichever is larger)
h_o	= $\sqrt{Bg_o}$ in.

h_T	= radial distance from effective clamp-hub reaction load to the circle on which H_T acts, in. = $[C - (B + G)/2]/2$
h_2	= average thickness of hub shoulder, in. = $T - (g_2 \tan \phi)/2$
$\bar{h}$	= axial distance from the hub face to the hub shoulder ring centroid, in.

$$\frac{T^2 g_1 + h_2^2 g_2}{2 (T g_1 + h_2 g_2)}$$

H	= total hydrostatic end force, lb = $0.785 G^2 P$
H_D	= hydrostatic end force on bore area, lb = $0.785 B^2 P$
H_G	= difference between total effective axial clamping preload and the sum of total hydrostatic end force and total joint contact surface compression, lb = $[1.571 W / \tan(\phi + \mu)] - (H + H_p)$
H_m	= total axial gasket seating requirements for makeup, lb (3.14 bGy or the axial seating load for self-energizing gaskets, if significant)
H_p	= total joint-contact surface compression load, lb = $2b \times 3.14 GmP$ (for self-energized gaskets, use $H_p = 0$ or actual retaining load if significant)
H	

T	hydrostatic end force on bore area, lb
	$= H - H_D$
I_c	= effective moment of inertia of clamp relative to axis of entire section, in. ⁴
	$=$
	$\left(\frac{A_1}{3} + \frac{A_2}{4} \right) C_t^2 + \frac{A_3 l_c^2}{3} - A_c X^2$
I_h	= effective moment of inertia of hub shoulder ring relative to its neutral axis, in. ⁴
	$=$
	$(T^2 g_1 + h_2^2 g_2) \frac{\bar{h}}{6} + \frac{Th_2 g_1 g_2 (T - h_2)^2}{3(Tg_1 + h_2 g_2)}$
L_a	= distance from W to the point where the clamp lug joins the clamp body, in.
L_h	= clamp lug height, in.
L_w	= clamp lug width, in.
l_c	= effective clamp lip length, in.
l_m	= effective clamp lip moment arm, in.
	$= l_c - (C - C_i)/2$
m	= gasket factor from Table XI-3221.1-1
M_D	= component of moment due to H_D , in.-lb
	$= H_D h_D$
M_F	= offset moment, in.-lb
	$= H_D (g_1 - g_o)/2$

M_G

= component of moment due to H_G in.-lb

$$= H_G h_G$$

M_H

= reaction moment at hub neck, in.-lb

=

$$M_O / \left\{ 1 + \frac{1.818}{\sqrt{B g_1}} \left[T - \bar{h} + \frac{3.305 I_h}{g_1^2 (B/2 + \bar{g})} \right] \right\}$$

M_O

= total rotational moment on hub, in.-lb (see Q-1150)

M_P

= pressure moment, in.-lb

$$= 3.14 \times PBT(T/2 - \bar{h})$$

M_R

= radial clamp equilibrating moment, in.-lb

$$= 1.571 W \{ \bar{h} - T + [(C - N) \tan \phi] / 2 \}$$

M_T

= component of moment due to H_T in.-lb

$$= H_T h_T$$

N

= outside diameter of hub neck, in.

P

= Design Pressure, psi

Q

= reaction shear force at hub neck, lb

=

$$1.818 \frac{M_H}{\sqrt{B g_1}}$$

r	= clamp body radius, in. (shall be less than or equal to C_l)
S_a	= allowable bolt stress at atmospheric temperature, psi (see Section II, Part D, Subpart 1, Table 3)
S_b	= allowable bolt stress at Design Temperature, psi (see Section II, Part D, Subpart 1, Table 3)
S_{OH}	= allowable design stress for hub material at (service condition) Design Temperature, psi (see Section II, Part D, Subpart 1, Tables 1A and 1B)
S_{AH}	= allowable design stress for hub material at (assembly condition) atmospheric temperature, psi (see Section II, Part D, Subpart 1, Tables 1A and 1B)
S_{OC}	= allowable design stress for clamp material at (service condition) Design Temperature, psi (see Section II, Part D, Subpart 1, Tables 1A and 1B)
S_{AC}	= allowable design stress for clamp material at (assembly condition) atmospheric temperature,

Page 448

	psi (see Section II, Part D, Subpart 1, Tables 1A and 1B)
S_1	= hub longitudinal stress on outside at hub neck, psi
S_2	= maximum Lame hoop stress at bore for hub neck section, psi
S_3	= hub axial shear stress (maximum) across the hub shoulder, psi
S_4	= hub radial shear stress (maximum) across the hub neck, psi
S_5	= clamp longitudinal stress at clamp body inner diameter, psi
S_6	= clamp tangential stress at clamp body outer diameter, psi
S_7	= shear stress (maximum) across clamp lips, psi
S_8	= clamp lug bending stress, psi
S_9	= effective bearing stress between clamp and hub, psi
T	= thickness of hub shoulder for design purposes, in. The hub shoulder ring is the ring with cross-sectional dimensions T by $(A - B)/2$.
W	= total design bolt load required for service or assembly, as may apply, lb
W_e	= total effective axial clamping preload on one clamp lip and hub shoulder (gasket seating or assembly), lb
	$= 1.571W/\tan(\phi + \mu)$
W_{m1}	= minimum required total bolt load for the service conditions, lb [see Q-1140(b)(1)]
W_{m2}	= minimum required total bolt load for gasket seating, lb [see Q-1140(b)(2)]

W_{m3}

= minimum required total bolt load for assembly, lb [see Q-1140(b)(3)]

X

= radial distance from inside surface of clamp body to the centroid of the clamp body, in.

=

$$\left[\left(\frac{C_w}{2} - \frac{C_t}{3} \right) C_t^2 - \frac{(C_w - C_g)}{2} l_c^2 \right] / A_c$$

y

= gasket or joint-contact surface unit seating load, psi (see Table XI-3221.1-1)

Z

= effective clamp-hub taper angle, deg. (for gasket seating and preload, $Z=\phi+\mu$; for operating, $Z=\phi-\mu$) [see Q-1140(b)(4)]

α

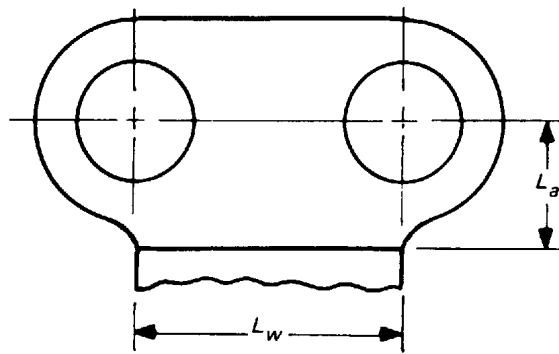
= hub-neck pipe transition taper, deg. (α shall not be greater than 45 deg.)

μ

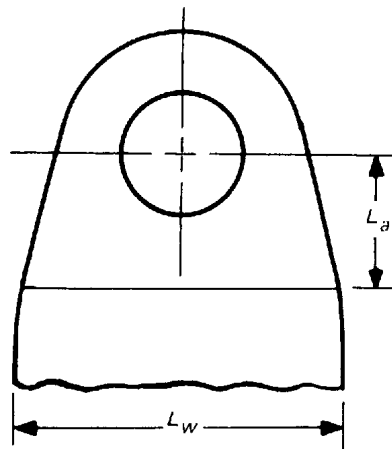
= effective friction angle, deg.

ϕ

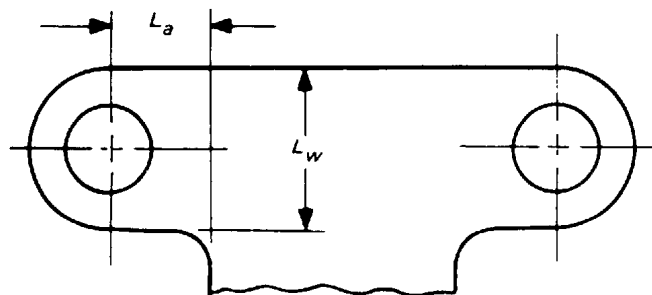
= clamp-hub taper angle, deg. (ϕ shall not exceed 35 deg.)



(a)



(b)



(c)

FIG. Q-1130-2 TYPICAL CLAMP LUG CONFIGURATIONS

FIG. Q-1130-2 TYPICAL CLAMP LUG CONFIGURATIONS

Q-1140 BOLT LOADS

(a) *General.* During assembly of the clamp connection, the design bolt load W is transferred via the clamp-hub taper angle to an axial load (effective clamp preload W_e). In addition, the effect of friction will cause W_e to be reduced for a given W . Friction effects can be reduced by lubrication or by jarring the clamps during assembly. An appropriate friction angle shall be established for both assembly and operating conditions.

(b) *Calculations.* In the design of the bolting for a clamp connection, complete calculations shall be made for three separate and independent sets of conditions which are defined as follows.

(1) The required bolt load for the service conditions W_{m1} shall be sufficient to:

(a) resist the hydrostatic end force H exerted by the maximum allowable working pressure on the area bounded by the diameter of gasket reaction; and

(b) maintain on the gasket or joint-contact surface, a compression load H_p which experience has shown to be sufficient to ensure a tight joint.

The minimum operating bolt load W_{m1} shall be determined in accordance with Eq. (1).

$$W_{m1} = 0.637 (H + H_p) \tan (\phi - \mu) \quad (1)$$

(1)

(2) Before a tight joint can be obtained, it is necessary to seat the gasket or joint-contact surface properly by applying a minimum initial load (under atmospheric temperature conditions without the presence of internal pressure), which is a function of the gasket material and the effective gasket area to be seated. The minimum initial bolt load required for gasket seating W_{m2} shall be determined in accordance with Eq. (2).

$$W_{m2} = 0.637 H_m \tan (\phi + \mu) \quad (2)$$

(2)

(3) To ensure proper preloading of the clamp connection against service conditions, an assembly bolt load W_{m3} shall be determined in accordance with Eq. (3).

$$W_{m3} = 0.637 (H + H_p) \tan (\phi + \mu) \quad (3)$$

(3)

(4) In Eq. (1) credit for friction is allowed based on clamp connection geometry and experience, but shall be limited to a value in which $(\phi + \mu)$ is equal to or greater than 5 deg. In Eqs. (2) and (3), friction shall be considered and be such that μ is equal to or greater than 5 deg. This will then satisfy the requirements of Q-1110(d).

Page 449

(5) The need for providing sufficient bolt load for either gasket seating in accordance with Eq. (2) or assembly in accordance with Eq. (3) will prevail on many low pressure designs and with facings and materials that require a high seating load where the service bolt load computed by Eq. (1) is insufficient to properly preload the connection.

(c) *Required Bolt Area.* The total cross-sectional area of bolting A_m required shall be the greater of the values for service conditions A_{m1} , gasket seating conditions A_{m2} , or assembly condition A_{m3} . Bending of the bolting due to nonparallel nut bearing surfaces shall be compensated for by use of a stress correction factor in bolt area calculations or by use of spherically seated nuts and/or washers.

(d) *Clamp Connection Design Bolt Load W .* The bolt load used in the design of the clamp connection shall be the values obtained from Eqs. (4) and (5).

For service conditions:

$$W = W_{m1} \quad (4)$$

(4)

For assembly conditions:

$$W = (A_m + A_b)S_a \quad (5)$$

(5)

Q-1150 HUB MOMENTS

In the calculation of hub stresses, the moment of a load acting on the hub is the product of the load and its moment arm. The moment arm is determined by the relative position of the effective hub-clamp reaction diameter with respect to that of the load producing the moment [see Fig. Q-1130-1, sketches (c) and (d)]. In addition to the load moments, additional reaction moments with relation to the hub shoulder ring centroid are considered to compensate for hub-to-pipe transition, radial pressure, and clamp radial equilibrating effects.

For the service conditions, the rotational hub moment M_O is the sum of six individual moments M_D, M_G, M_T, M_P, M_P , and M_R based on the design bolt load of Eq. (4) with moment arms as given in Fig. Q-1130-1.

For assembly, the rotational hub moment M_O is based on the design bolt load of Eq. (5) in which case

$$M_O = \frac{0.785 W(C - G)}{\tan(\phi + \mu)} \quad (6)$$

(6)

Q-1160 CALCULATION OF HUB STRESSES

The stresses in the hub shall be determined for both the service and the assembly conditions.

(a) The reaction moment M_H and reaction shear Q as defined in Q-1130 shall be calculated at the hub neck for rotational moment M_O

(b) Hub stresses are to be calculated from the following formulas:

Hub longitudinal stress

$$S_1 = f \left[\frac{PB^2}{4g_1(B + g_1)} + \frac{1.91 M_H}{g_1^2(B + g_1)} \right] \quad (7)$$

(7)

Hub hoop stress

$$S_2 = P \left(\frac{N^2 + B^2}{N^2 - B^2} \right) \quad (8)$$

(8)

Hub axial shear stress

$$S_3 = \frac{0.75 W}{T(B + 2g_1) \tan Z} \quad (9)$$

(9)

Hub radial shear stress

$$S_4 = \frac{0.477 Q}{g_1 (B + g_1)} \quad (10)$$

(10)

Q-1170 CALCULATION OF CLAMP STRESSES

The stresses in the clamp shall be determined for both the service and the assembly conditions. Clamp stresses are to be calculated from the following equations:

Page 450

Clamp longitudinal stress

$$S_5 = \frac{W}{2C(\tan Z)} \left[\frac{1}{C_t} + \frac{3(C_t + 2l_m)}{C_t^2} \right] \quad (11)$$

(11)

Clamp tangential stress

$$S_6 = \frac{W}{2} \left[\frac{1}{A_c} + \frac{|e_b|(C_t - X)}{I_c} \right] \quad (12)$$

(12)

Clamp lip shear stress

$$S_7 = \frac{1.5 W}{(C_w - C_g) C \tan Z} \quad (13)$$

(13)

Clamp lug bending stress

$$S_8 = 3 W \frac{L_a}{L_w L_h^2} \quad (14)$$

(14)

In addition, a bearing stress calculation is to be made from Eq. (15) for either the clamp or hub.

$$S_9 = \frac{W}{(A - C_i) C \tan Z} \quad (15)$$

(15)

**TABLE Q-1180-1
ALLOWABLE DESIGN STRESS FOR CLAMP
CONNECTIONS**

Stress Category	Allowable Stress
S_1	$1.5 S_{OH}$ or $1.5 S_{AH}$
S_2	S_{OH}
S_3	$0.8 S_{OH}$ or $0.8 S_{AH}$
S_4	$0.8 S_{OH}$ or $0.8 S_{AH}$
S_5	$1.5 S_{OC}$ or $1.5 S_{AC}$
S_6	$1.5 S_{OC}$ or $1.5 S_{AC}$
S_7	$0.8 S_{OC}$ or $0.8 S_{AC}$
S_8	S_{OC} or S_{AC}
S_9	(1)

NOTE:

(1) 1.6 times the lower of the allowable stresses for hub material (S_{OH} , S_{AH}) and clamp material (S_{OC} , S_{AC}).

Q-1180 ALLOWABLE DESIGN STRESS FOR CLAMP CONNECTIONS

Table Q-1180-1 gives the allowable stresses that are to be used with the equations of Q-1160 and Q-1170.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP R

APPENDIX R DETERMINATION OF PERMISSIBLE LOWEST SERVICE METAL TEMPERATURE FROM T_{NDT} FOR CLASSES 2 AND MC CONSTRUCTION

Page 451

ARTICLE R-1000 DETERMINATION OF PERMISSIBLE LOWEST SERVICE METAL TEMPERATURE FROM T_{NDT} FOR CLASSES 2 AND MC CONSTRUCTION

R-1100 INTRODUCTION

R-1110 Scope

These rules provide the method for determining the permissible lowest service metal temperatures for materials having nil-ductility transition temperatures (T_{NDT}) determined in accordance with NC- or NE-2311(a)(8) or NC- or NE-2331(a)(2).

R-1200 DETERMINATION OF PERMISSIBLE LOWEST SERVICE METAL TEMPERATURE

The permissible lowest service metal temperature is defined as:

$$T_{NDT} + A$$

where T_{NDT} is determined in accordance with NC- or NE-2311(a)(8) or NC- or NE-2331(a)(2), and A is determined from Fig. R-1200-1 for the thickness of the material.

R-1210 Material Acceptability

For the material to be acceptable, the permissible lowest service metal temperature shall not be higher than the specified lowest service metal temperature.

Page 454

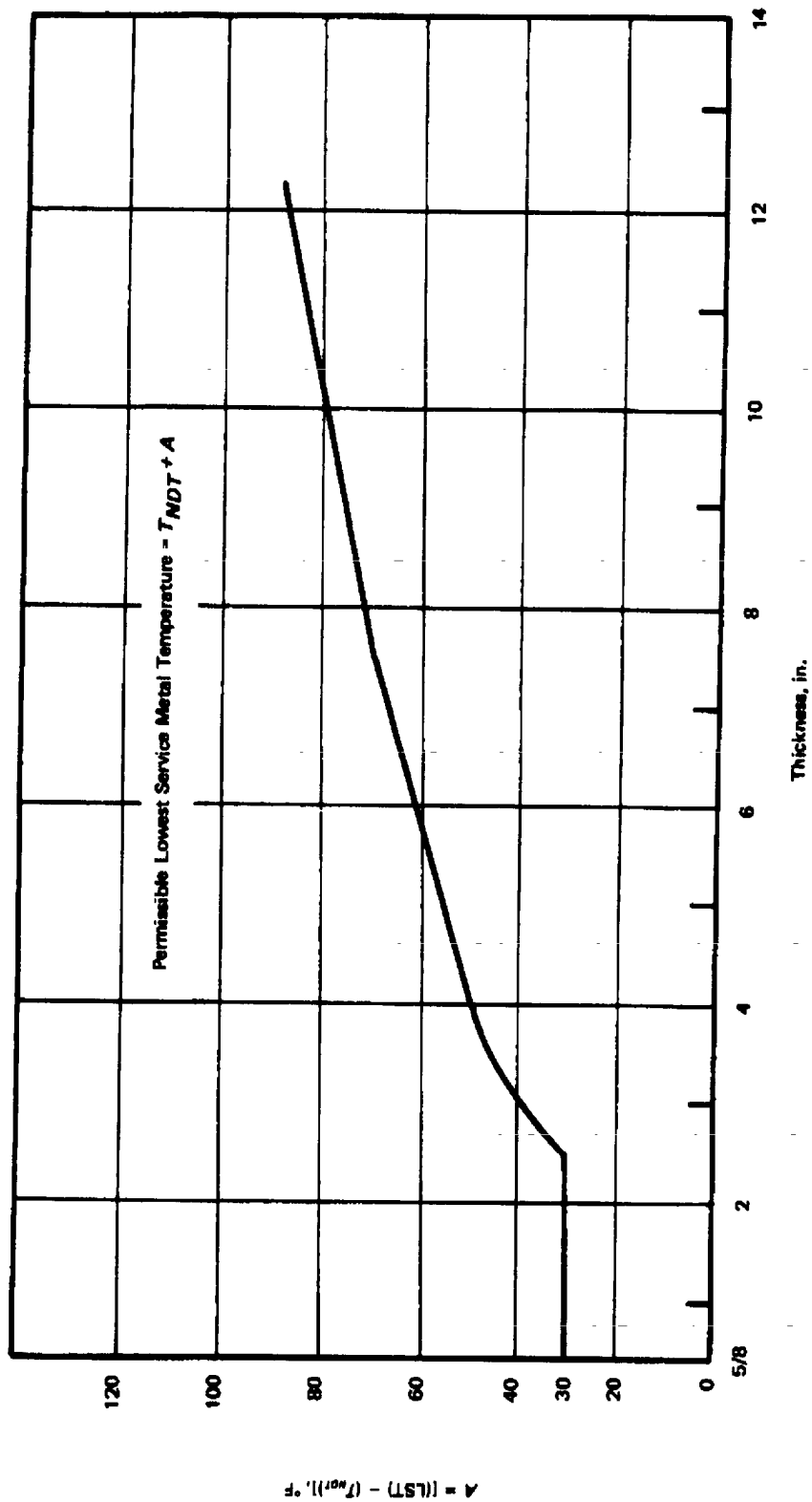


FIG. R-1200-1 DETERMINATION OF PERMISSIBLE LOWEST SERVICE METAL TEMPERATURE

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP S

APPENDIX S PUMP SHAFT DESIGN METHODS

Page 455

ARTICLE S-1000 PUMP SHAFT DESIGN METHODS

S-1100 INTRODUCTION

(a) This Appendix provides guidelines for the design and evaluation of shafts for Section III nuclear pumps. They include suggestions for the loads to be considered and the method for arriving at a design that will sustain these loads for the life of the pump.

(b) The method presented is not intended to exclude other methods which may be equally satisfactory. Experience and expertise will be factors in determining the best method. In the final analysis the skill and judgement of the designer determine the quality of the design.

S-1200 SCOPE

The guidelines presented are intended to cover the design of pump shafts, including rigid couplings, up to, but not including, separable parts which attach the shaft to the driver.

S-1300 DESIGN REQUIREMENTS

S-1310 DESIGN METHODS

The design rules presented in this section are provided as guidance to the designer of pump shafts. Alternative design methods may be used based on the pump manufacturer's experience with pumps in similar service.

S-1320 OPERATING CONDITIONS

Pump shaft assemblies are subject to combinations of steady state and variable or transient loads. These loads include torsional, lateral, bending, axial, and thermal components. They may occur as a result of power input, hydraulically imposed forces, static or dynamic unbalance, rotating element runout, internal misalignment, thermal distortion, system and component vibration, and resonance. External system applied loads, such as seismic and other loads associated with A, B, C, and D Service Level Loadings must also be considered.

S-1400 RESPONSIBILITY

(a) *Owner's Responsibility.* It shall be the responsibility of the Owner or his designee to include in the Design Specification all external forces and operating conditions that may have an effect on the operability of the pump shaft.

(b) *Pump Designer Responsibility.* It is the responsibility of the pump Designer to include in the evaluation the specified pump loads and identify the type and magnitude of the internal operating loads on the shaft assembly.

S-1500 OPERATING LOADS

S-1501

In establishing maximum shaft operating loads, the design should take into account plant service that the pump will experience and external loads associated with these conditions. Other forms of off-normal operating loadings may include inservice testing, inadvertent starting and stopping, loss of coolant accident, etc.

S-1502

Thermal loads shall be considered as one of the internal operating loads.

S-1503 Off-Normal Operating Loads

The maximum steady state and transient loads will usually occur in the pump when it is operating away from its best efficiency point. Typically it will be the combination of loads producing stresses at regions of high stress concentration that may result in high cycle

Page 458

fatigue failures of shafts. The very nature of these loads makes it difficult to quantify them and in some cases a bounding estimate must be made. Examples of load sources include low flow recirculation, flow separation, and other hydraulic instabilities which cause radial and axial alternating or transient loads on the shaft. Lacking a thorough understanding of these loads, conservative design practices based on years of operating experience must be used to insure successful design of pump shafts.

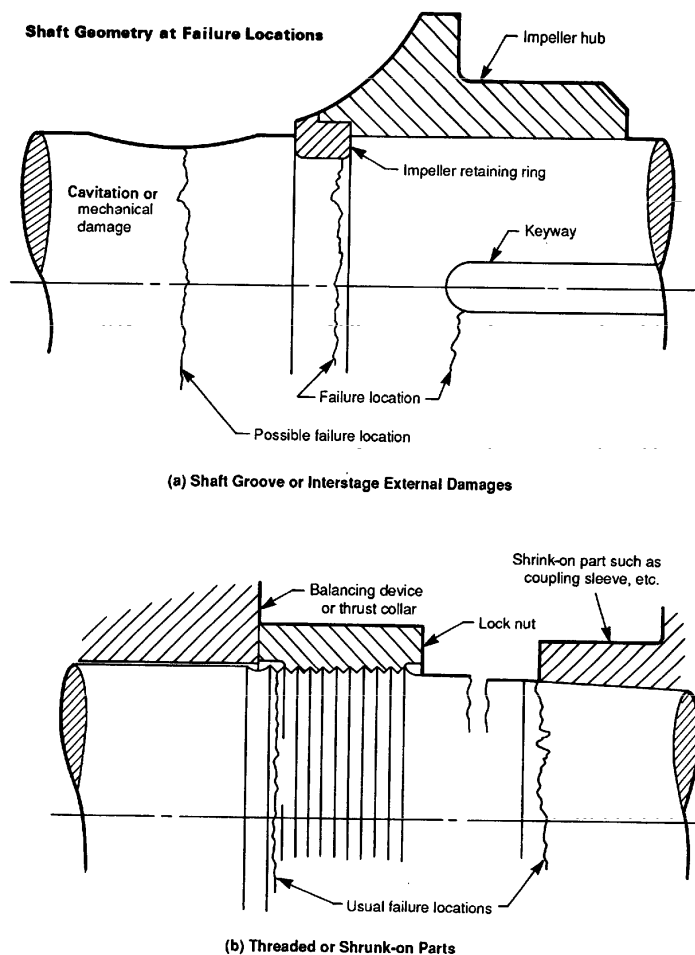


FIG. S-1600-1 TYPICAL CENTRIFUGAL PUMP SHAFT FAILURE LOCATIONS

S-1600 SHAFT FAILURE MODES

Shaft failures usually occur at points of high stress concentration or structural discontinuities. The most common locations of shaft failures are threaded regions, shaft grooves, shoulders, keyways, couplings, and collars (see Fig. S-1600-1). Areas susceptible to erosion/corrosion, stress corrosion cracking, thermal transients, and steep temperature gradients are also possible locations for shaft failure.

Page 460

ARTICLE S-2000 DESIGN PROCEDURE

Any method of evaluation (analytical or experimental) which can be substantiated by data from pumps in service, experiencing conditions similar to the specified operating limits, may be used.

S-2100 CRITICAL SPEEDS

The evaluation shall address both torsional and lateral, and where applicable, axial critical speeds, shaft deflections, and stresses. Critical speeds and shaft deflections shall be such as to avoid any difficulties for the specified range of the design and operating conditions. The actual percentage difference between critical and operating speeds shall take account of the method of determination of critical speed. The percentage difference between stress allowed and calculated shall also take account of the accuracy of the design and the analysis method.

S-2200 MAXIMUM TORSIONAL LOAD

The maximum torsional load shall be defined. The maximum torsional shear stress for this load (stress resulting from this load without application of concentration factors) shall be based on design experience or experimental evidence for the particular class of pump involved. The maximum driver horsepower may determine the maximum torsional loading for units with short shafts (typical of pump types A, B, and C). The motor startup torque may determine the maximum torsional load for pumps with relatively long shafts (typical of type L pumps). Torsional alternating or transient loads shall be considered if applicable.

S-2300 SHAFT EVALUATION

The flow chart, Fig. S-2300-1, outlines a procedure for evaluation of pump shafts to meet load requirements. This procedure establishes a basic sizing criterion as well as a detailed fatigue evaluation method.

The basic shaft sizing criterion is based on maximum shear stress and conservative cyclic loading factors. These fatigue factors include an evaluation of the endurance limit of the unnotched and polished test specimen reverse bending test data in air (S_e), which in the absence of specified data can be approximated as:

$$S_e = 0.5S_u$$

This polished specimen test endurance limit is then factored for the product of reduction factors that account for such items as environment, reliability, size, finish, duty cycles, etc., which is conservatively estimated as $1/3$. Consequently, this corrected material endurance limit stress can be represented as:

$$S'_e = \frac{1}{K_{\text{total}}} \cdot \frac{S_e}{3}$$

where the terms used on the chart, Fig. S-2300-1, are as follows:

K_{total}	= stress concentration factors. An initial value of 6.0 is suggested where reasonable stress riser control is exercised. Higher values may be required for designs with severe discontinuities (eg., small fillet radii relative to shaft diameter). Lower values may be used if justified by design methods and/or testing that accounts for the specific shaft discontinuities under consideration. Notch sensitivity values, when available, may be used. For additional information, see ANSI/ASME B106.1M-1985.
S_a	= alternating axial stress
S_b	= alternating component of the shaft bending stress
S_e	= material endurance limit
S'_e	= design endurance limit
S_s	= maximum shear stress
S_{ss}	= material allowable shear stress

Page 461

Page 462

	= $S_y/3$ unless higher values are justified through specified shear test data
S_u	= material ultimate strength at design temperature
S_y	= material yield stress at design temperature
U_t	= summation of usage cycles. Each usage cycle shall be determined as the ratio of the maximum alternating stress in

determined as the ratio of the maximum alternating stress in the shaft divided by the design fatigue stress of the material for that number of cycles. U_T will be determined by summing all of the above ratios.

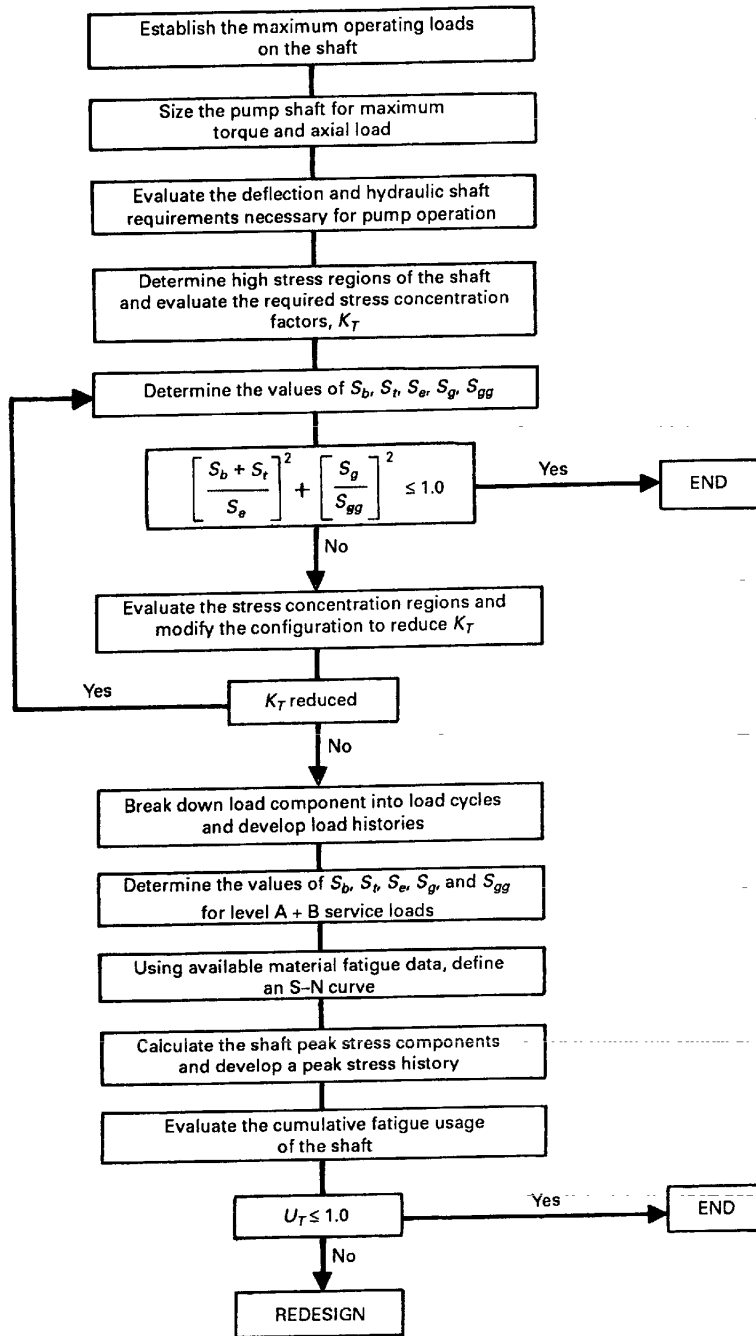


FIG. S-2300-1 STEPS IN THE DESIGN OF A PUMP SHAFT

S-2400 OTHER CONSIDERATIONS

The fatigue life of a shaft is not always the limiting factor in its design. The effect of misalignment and deflection of a shaft on the performance of support bearings, seals, and couplings as well as on other key power transmission components must also be taken into account. Shafts can be strong enough to meet fatigue life requirements, yet not stiff enough to satisfy natural frequency and operational requirements.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP T

APPENDIX T RECOMMENDED TOLERANCES FOR RECONCILIATION OF PIPING SYSTEMS

Page 463

ARTICLE T-1000 RECOMMENDED TOLERANCES FOR RECONCILIATION OF PIPING SYSTEMS

T-1100 INTRODUCTION

The building structure and major components of a power plant are constructed according to rules that permit varied tolerances. Since piping system installation follows construction of the building and installation of the major components, the piping systems must be permitted to vary within the space allotted to them. In addition, a large number of systems are often installed in a limited space. Interferences often occur and changes within Installation Tolerances may be used to eliminate the interference. The tolerances provided in this Appendix bridge the gap between the exactness associated with a design by analysis, and a practical and acceptable installation.

The basis for the tolerances and guidance in this Appendix was developed by the PVRC Technical Committee on Piping Systems.¹ Additional guidance on implementation of these tolerances has been published by EPRI.²

T-1110 SCOPE

This Appendix provides recommended tolerances and methods for satisfying the requirements of NCA-3554, "Modification of Documents and Reconciliation With Design Report" for piping systems designed to the rules of NB-, NC-, or ND-3600. This Appendix provides:

- (a) identification of dimensions and weights significant to the piping stress analysis; and
- (b) acceptable tolerances for these dimensions and weights such that if piping is installed within these tolerances, the reconciliation is accomplished.

¹ "Technical Position on Piping Installation Tolerances," *Welding Research Council Bulletin* 316, July 1986.

² "Guidelines for Piping System Reconciliation" (NCIG-05, Revision 1), *Electric Power Research Institute, EPRI-5639*, May 1988.

These tolerances have been established such that their effect on the accuracy of analysis results is minimal and is consistent with accepted practices and the use of tolerances in the Code. These tolerances are applicable to most situations; however, specific situations where more restrictive tolerances may be needed are identified.

The tolerances in this Appendix are applicable to piping systems where conventional seismic analysis methods were used for the original design, i.e., modal response spectrum analysis methods. For piping systems where seismic analysis methods that are significantly more sensitive to the tolerances were used in the original design (i.e., seismic time history analysis methods), the Designer shall review the applicability of these tolerances and establish more stringent guidelines if necessary. Further, this Appendix shall be restricted to piping systems analyzed using linear elastic methods.

This Appendix does not relieve the Designer of responsibility for consideration of other unique situations where more restrictive tolerances may be required to satisfy the intent of the design bases or the Code.

Installation Tolerances more restrictive than the Total Tolerances recommended in this Appendix may be specified. Less restrictive tolerances may be specified when engineering justification is provided to demonstrate that the design requirements have been satisfied.

Tolerances for complete, installed piping are addressed. Tolerances provided for manufacturing or fabricating the individual items or subassemblies that make up piping systems are not addressed, but the effect of these tolerances on the as-installed condition shall be within the Total Tolerance. Other design and construction areas which may be included in reconciliation such as design or operating conditions, support details, and gaps are not addressed.

Tolerances for support erection, including length and orientation of individual members and pipe location on the support, are specified in Appendix K.

Page 466

T-1120 TERMS RELATED TO RECONCILIATION

Definitions of terms used in this Appendix are given in the following paragraphs.

T-1121 Nominal Dimension

This is the dimension which provides configuration and/or spatial information on piping drawings within specified tolerances.

T-1122 As-Analyzed Configuration

This is the configuration of piping components and supports, defined by nominal sizes, weights, cross section properties, and dimensions, which forms the basis for the piping stress analysis. In the case of piping systems which are qualified by simplified rules, the design drawings for the systems are considered as the As-Analyzed Configuration.

T-1123 Critical-to-Design (CTD) Dimension

A dimension that must be satisfied, within a specified tolerance, in order for the piping stress analysis to remain valid. These dimensions define the relative configuration of the piping. They may also include dimensions which define the global or spatial position of the piping.

Examples of CTD dimensions are: the location of a pipe support relative to in-line pipe components such as valves, anchors, and other supports; the orientation of the pipe support center line relative to the pipe center line; length of pipe runs; and spacing between supports.

T-1124 Fit/Clearance (F/C) Dimension

This is a dimension that is specified to provide reasonable assurance that the piping fits into the allocated building space. These dimensions define the global position of the piping in three-dimensional space and deviations from these dimensions do not have a significant effect on the validity of the piping stress analysis. Examples of F/C dimensions are the locating dimensions of pipe center lines from column lines, walls, and floors. However, dimensions defining clearance required to allow thermal expansion or to protect critical components from adverse interaction due to dynamic (earthquake) loads are CTD dimensions.

T-1125 As-Built Documents

These are the drawings, sketches, or other documents which define the as-installed piping configuration (nominal dimensions and tolerances) and which have been reconciled with the stress analysis.

T-1126 Installation Tolerance

This is the specified acceptable departure from nominal piping dimensions, support locations and orientations, and

component weights to be used during installation to provide for practical installation limitations. Installation Tolerances for CTD dimensions shall be less than or equal to the corresponding Total Tolerances.

T-1127 Total Tolerance

This is the maximum allowable departure between corresponding as-built and as-analyzed CTD piping dimensions, support locations and orientations, and component weights for the piping stress analysis to be applicable. The Total Tolerance is applicable only to CTD dimensions since F/C dimensions are not critical to the stress analysis. Acceptable Total Tolerances are provided in T-1200.

T-1130 MEASUREMENT ACCURACY

Measurements of the as-built configuration for use in reconciliation shall be made using methods capable of producing accuracy to the nearest inch for linear dimensions and to the nearest 2 deg. for angular dimensions (Fig. T-1213-1 shows examples of angular dimensions).

T-1140 EVALUATION OF OUT-OF-TOTAL TOLERANCE CONDITIONS

CTD values that exceed Total Tolerances shall be recorded and evaluated to assure the design bases, including the applicable design code, have been satisfied. This evaluation may be made using engineering judgment, simplified models, or by reanalyzing the complete original model. The objective should be to determine if the condition being evaluated had any significant effect on the response of the piping systems to the design loadings. The use of engineering judgment shall be documented with the technical reasoning described so that a technically qualified third party reviewer will understand how the evaluation was justified. The documentation requirements for evaluation based on

Page 467

Page 468

engineering judgment shall be consistent with other engineering calculations.

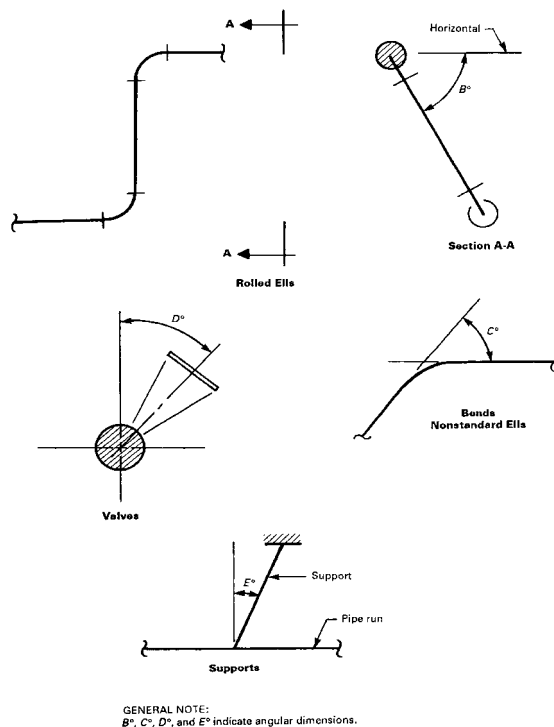


FIG. T-1213-1 ILLUSTRATIONS OF ANGULAR DIMENSIONS — PIPE LEGS, VALVES, SUPPORTS, BENDS

FIG. T-1213-1 ILLUSTRATIONS OF ANGULAR DIMENSIONS - PIPE LEGS, VALVES, SUPPORTS, BENDS

If it is determined that there is no significant effect, then the original analysis remains valid and the results (stress summaries, support design loads, etc.) need not be revised. If changes are found to be significant, then the affected results shall be revised.

T-1200 TOTAL TOLERANCES

T-1210 GENERAL

The Total Tolerances are given for the reconciliation of the piping stress analysis in terms of the maximum allowable plus or minus departure between the as-analyzed (nominal) value and the as-built value. These tolerances should not be used to circumvent specific requirements established by the Design or Installation Specification nor other applicable material or fabrication standards.

As-built piping systems that conform with the piping stress analysis within the Total Tolerances are acceptable and evaluation of the as-built condition is not required.

T-1211 Altering Relative Position

Tolerances shall not be applied in such a manner that would result in alteration of the relative position of piping components and supports. For example, supports shall not be moved across valves, tees, elbows, etc. In no case shall the permissible location change the directions of a support or its function.

T-1212 Independence

The tolerances given are independent of each other and are not interrelated to position of adjacent items except as noted in T-1211. Each tolerance may be applied independently of any other.

T-1213 Methods of Dimensioning

Examples of angular dimensions are shown in Fig. T-1213-1. Two common methods of dimensioning piping installation are shown in Fig. T-1213-2. Either method or some combination of these methods are usually used on the Design Drawings. The chain method references a dimension to the adjacent dimensions. The common point method references a number of dimensions to a common base. All measurements should be rounded off to the nearest inch for linear dimensions and the nearest 2 deg. for angular dimensions.

T-1220 PIPING CONFIGURATION TOLERANCES

T-1221 Center Line Lengths

Center line length to fittings, flanges, valves, and piping specialties including branch line piping shall be within the tolerance specified below. (Locations of branch connections on the run pipe are not included. See T-1222.)

Specified Nominal Dimension (Feet)	± Total Tolerance (Inches)
0 to <5	3
5 to <10	6
10 to <15	9
15 to <20	12
20 to <25	15
25 to <30	18
30 to <35	21
35 and over	24

NOTE: The 3 in. tolerance for nominal dimensions of 0 to less than 5 ft may not be applicable in all cases. For example,

cantilevered vents and drains, relief valve inlet and outlet piping, and instrument piping near the connection to the process piping are cases where more restrictive tolerances may be needed. If so, they shall be specified on the design documents.

When common point dimensions (see Fig. T-1213-2) are used, the tolerances along the pipe center line are to be applied to each pipe leg, i.e., piping between changes in direction. There may be cases where the nominal dimensions must be determined from the difference in common point dimensions for the ends of the pipe leg.

T-1222 Center Line Location of Branch Connections (Relative to Run)

(a) This section applies to branch connections independent of the connection detail or type of fitting used.

(b) The location of branches for branch/run size combinations indicated by an asterisk (*) in Table T-1222-1 have no design related tolerance restrictions except when the stress intensification factor (SIF) on the run pipe exceeds 1.0, in which case the maximum tolerance is ± 2 ft 0 in. (610 mm) and the requirements of (d) shall be satisfied.

(c) The location of branches for the branch/run size combinations without an asterisk (*) in Table T-1222-1 (including sizes not listed in the table) have the same tolerance as in T-1221.

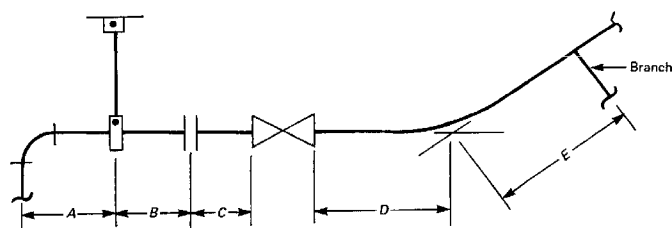
(d) For all branch/run size combinations, changes in location of the branch connection that exceed 2 ft (610 mm) shall be approved by the Designer and should not

(1) change the flow path defined on the piping system diagram;

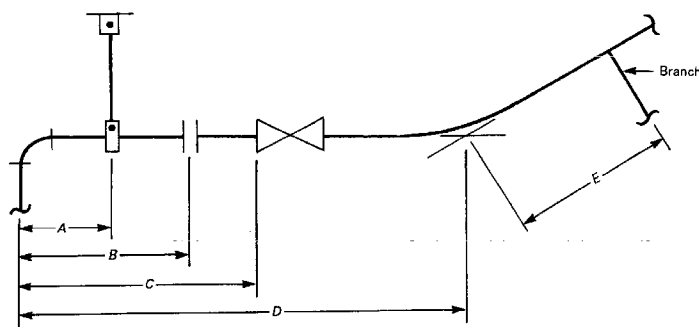
(2) affect system functional flow and pressure characteristics, such as branch connections used for differential

Page 469

Page 470



Method 1 — Chain Dimensions



Method 2 — Common Point Dimensions

FIG. T-1213-2 ILLUSTRATIONS OF LINEAR DIMENSIONS

FIG. T-1213-2 ILLUSTRATIONS OF LINEAR DIMENSIONS

pressure and flow measurement, for safety and relief valves, and for core safety injection;

**TABLE T-1222-1
BRANCH/RUN SIZE COMBINATIONS**

Run Size — NPS	3/4						
	1						
	1½						
	2						
	2½	*					
	3	*	*				
	4	*	*				
	6	*	*	*	*		
	8	*	*	*	*	*	
	10	*	*	*	*	*	*
	12	*	*	*	*	*	*
	14	*	*	*	*	*	*
	16	*	*	*	*	*	*
	18	*	*	*	*	*	*
	20	*	*	*	*	*	*
	24	*	*	*	*	*	*
	3/4	1	1½	2	2½	3	4
Branch Size — NPS							

TABLE T-1222-1 BRANCH/RUN SIZE COMBINATIONS

(3) be allowed without considering the effect of run pipe movement on the branch pipe. (Not significant if the tolerances of T-1221 are satisfied.)

T-1223 Angular Deviation of Pipe Center Line

Angular deviation of pipe center line from theoretical center line is limited to ± 10 deg. See Fig. T-1213-1, Rolled Ells ("B°") and Bends; Nonstandard Ells ("C°").

T-1224 Angular Tolerance on Power Operated Valves

Angular tolerance on power operated valves over NPS 2 (Nominal Pipe Size) is limited to ± 15 deg. See Fig. T-1213-1, Valves ("D°"). For power operated valves NPS 2 and smaller, the angular tolerance of ± 15 deg. applies only when the weight of the valve operator equals or is less than the valve analyzed weight. When the weight of the valve operator exceeds the valve's analyzed weight for an NPS 2 (DN 50) or smaller valve, the angular tolerance is not provided in this Appendix. There are no CTD restrictions on angular orientation of manually operated valves.

T-1230 PIPING SUPPORT LOCATION/ORIENTATION TOLERANCES

The tolerance provided as piping support tolerances assume the support is the specified type and rating. The support type shall not be changed without approval of the Designer.

These tolerances are applicable to the reconciliation of the piping stress analysis. They are not applicable for the reconciliation of the pipe support design.

T-1231 Location of Supports

Tolerances on the location of supports, anchors, and restraints along the pipe center line of the horizontal or vertical straight runs that do not contain significant concentrated weight are:

Pipe Size	Tolerance
NPS 2 and smaller	6 in.
NPS 2½ and larger	One pipe diameter or 12 in., whichever is greater

T-1232 Location of the First Support on Either Side of Spans That Contain Concentrated Weights

Tolerances on the location of the first support or restraint on either side of spans that contain concentrated weights such as valves, flanges, risers, fittings, bends, or other concentrated loads are:

Pipe Size	Tolerance
NPS 12 and smaller	Smaller of 3 pipe diameters or 12 in.
Larger than NPS 12	One pipe diameter

These tolerances may not be applicable to the first restraint adjacent to a bend, which is oriented in the plane of the bend, when the piping is subjected to waterhammer, steamhammer, or relief valve discharge loading. In these cases, if more restrictive tolerances are needed they must be specified on the design documents.

T-1233 Location of the First Support From Rotating Equipment Nozzles

Tolerances for the location of the first support or restraint in each direction from rotating equipment nozzles are:

Pipe Size	Tolerance
NPS 2 and smaller	3 in.

NPS 2½ and larger

One-half pipe diameter or 6 in., whichever is greater

T-1234 Snubbers

The location of snubbers with axis coincident to the pipe leg center line is not a critical dimension. However, snubbers with tolerances greater than those of T-1231 should be approved by the Designer who must assure they are not affected by the anticipated thermal movements.

T-1235 Angular Orientation of Supports

The tolerance for the angular orientation of supports is ± 5 deg. [See Fig. T-1213-1, Supports ("E").] The angular tolerance may be increased to ± 10 deg. if this value plus the angularity change from thermal expansion of the system does not exceed functional limitations established by the support manufacturer and the Designer assures that any increased loadings on the connection are compatible with the design.

T-1240 WEIGHT TOLERANCES

T-1241 General

Tolerances on both uniformly distributed weights and concentrated weights are included in this Appendix. These tolerances do not imply that components should be weighed, but provide for reconciliation of weight changes identified in the design process. As a practical matter, the concentrated weight of items is a concern primarily for valves and other in-line components of significant weight, but particularly power operated valves. Changes to the distributed weight of insulation systems and other piping items should also be considered.

T-1242 Uniformly Distributed Weight

The uniformly distributed weight for the piping system may vary by $\pm 20\%$ from the as-analyzed weight.

This weight tolerance may need to be reduced for piping primarily supported by constant force supports or springs.

T-1243 Concentrated Weight

Concentrated weights of in-line items such as valves may vary by the greater of $\pm 20\%$ of the analyzed weight or 20 lb (9 kg).

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP U

APPENDIX U RULES FOR PUMP INTERNALS

Page 473

U-1000 RULES FOR PUMP INTERNALS

U-1100 INTRODUCTION

U-1110 SCOPE

These rules apply to materials, fabrication and examination of internal items for Classes 1, 2 and 3 pumps. Pump internal items are those parts other than pump cases, inlets and outlets, covers clamping rings, seal housings, related bolting and other items as covered in Subsections NB, NC, and ND.

U-1120 CATEGORIES

Category as set forth in Table U-1600-1 is the grouping of various pump internal items for the purpose of applying the rules of this Appendix. Categories for typical pump types are shown in Figs. U-1500-1 through U-1500-7. The figures are not to scale, and are not intended to convey any preference for pump type or design, but are provided as a guide to the manufacturer to identify the various internal items of a pump for categorization. In determining categories for items of pump types not specifically illustrated, a pump or pump detail which is most nearly representative shall apply. Categories 1 and 2 are pressure retaining items presently covered by Subsections NB, NC and ND. Categories 3 through 6 are pump internal items which may be constructed in accordance with this Appendix except that Material Manufacturers and/or Material Suppliers for Category 3 through 6 items are not required to comply with NCA-3800. Material which forms an integral welded extension to Category 1 material in Fig. U-1500-1, items 1-5, may be classified as Category 4 or 5 material when it serves a nonpressure-retaining function and its structural effect is considered in the design of the Category 1 material. For use in Class 1, 2, and 3 pumps the extension material shall satisfy the requirements of NB-2300 NC-2300, or ND-2300.

U-1200 GENERAL REQUIREMENTS

U-1210 RESPONSIBILITIES AND DUTIES

It is the responsibility of the Certificate Holder manufacturing pumps to assign each item of a pump to the proper category and to indicate the categories in a report or on a drawing.

U-1220 CODE STAMPING

Code symbol stamping is not required for pump internal items.

U-1300 MATERIALS

U-1310 GENERAL REQUIREMENTS FOR MATERIAL

U-1311 Scope of Principal Terms Employed

The term *materials* as used in this Appendix applies to those items produced to material specifications permitted by Section III, Division 1, and/or other material permitted by this Appendix.

U-1312 Permitted Material Specifications

(a) Materials used for Category 3 and 4 items shall conform to the requirements of one of the specifications for materials given in Table U-1610-1 of this Appendix for Class 1, 2 and 3 pumps; materials listed in Section II, Part D, Table 2A for Class 1 and 2 pumps; materials listed in Table 2A for Class 2 pumps; or materials listed in Table 1A for Class 3 pumps; and to the special requirements of this Appendix which apply to the item for which the material is used.

(b) Category 5 and 6 items may be made from any material suitable for the intended service.

(c) The Certificate Holder manufacturing pumps shall provide a list which identifies the material used for

Page 476

each Category 3, 4, 5 or 6 item. This list may be a bill of materials or a separate list.

(d) Where the tensile strength, yield strength, tempering temperature or aging temperature listed in Table U-1610-1 differ from the requirements of the material specification, the minimum requirements listed in Table U-1610-1 shall apply.

U-1313 Special Requirements Conflicting With Permitted Material Specifications

(a) Special requirements stipulated in this Appendix shall apply in lieu of the requirements of the material specifications wherever the special requirements conflict with the material specification requirements. Where the special requirements include an examination, test, or treatment which is also required by the material specification, the examination, test, or treatment need be performed only once. Any required nondestructive examinations shall be performed as specified in para. U-1430 Any examination, repair, test, or treatment required by the material specification or this Appendix may be performed by the Material Manufacturer, Material Supplier, or the Certificate Holder manufacturing pumps. The Material Manufacturer or Material Supplier shall obtain approval from the Certificate Holder manufacturing pumps for the weld

repair of materials (see para. U-1440).

(b) For materials listed in Table U-1610-1 for Category 3 and 4 items, the tensile test requirements of the material specification may be performed on representative samples of each heat of material used, for each specified heat treatment. The tensile strength and yield strength results shall satisfy the specified values *and be below the maximum specified values listed in Table U-1610-1*. Where the material will be used to fabricate various item sizes in different heat treated thicknesses, the manufacturer shall assure himself that the heat treatment specified will be effective for the entire size range.

U-1314 Certification of Materials

(a) *Certification by Material Manufacturer.* The Material Manufacturer shall provide a Certified Material Test Report for Category 3 items and Category 4, Class 1 impellers, including all welding and brazing materials used on these items. The Material Manufacturer shall certify that the contents of the report are correct and accurate, and that all operations performed by him or his subcontractors are in compliance with the requirements of the material specification and this Appendix. Alternatively, the Material Manufacturer shall provide a Certified Material Test Report for operations he performed and at least one Certified Material Test Report from each of his subcontractors for operations they performed. Chemical analysis, tests, examinations, and heat treatments required by the material specification that were not performed shall be listed on the Certified Material Test Report. A Material Manufacturer's Certificate of Compliance with the material specification, grade, class, and heat treated condition, as applicable, may be provided in lieu of a Certified Material Test Report for material used for pumps with inlet connections 2 in. nominal pipe size and less, and bolting 1 in. nominal diameter and less. Material identification including any marking code (see para. U-1316) shall be described in the Certified Material Test Report or Certificate of Compliance as applicable.

(b) *Certification by Material Supplier.* The Material Supplier who completes any operation not performed by the Material Manufacturer shall provide a Certified Material Test Report for all operations performed by him. This certification affirms that the contents of the report are correct and accurate, and that all test results and operations performed by him or his subcontractors are in compliance with the material specification and the applicable material requirements of this Section as designated by the purchaser.

(c) Certified Material Test Reports or Material Manufacturer or Material Supplier Certificates of Compliance are not required for Category 5 and 6 items.

U-1315 Welding and Brazing Materials

All welding and brazing materials used on Category 3 and 4 items shall meet the requirements of NB-2400, NC-2400, or ND-2400, as applicable.

U-1316 Material Identification

U-1316.1 Class 1 and 2 Pump Items

(a) The identification of Materials for Category 3 items used for Class 1 and 2 pumps shall consist of marking or tagging the material with the applicable specification number, grade, heat number or heat code, and any additional marking required to facilitate traceability of the reports of the results of all tests and examinations performed on the material, except that heat number identification is not required for pumps with inlet connections 2 in. nominal pipe size (DN 50) and less. Alternatively, a marking symbol and/or code may be used which identifies the material with the Materials Certification and such symbol and/or code shall be explained in the certificate (see para. U-1314).

Page 477

For identification and marking during fabrication by the Pump Manufacturer, see para. U-1420.

(b) The identification of Materials for Category 4 items used for Class 1 and 2 pumps shall consist of marking or tagging the material or its container in accordance with the marking requirements of the applicable material specification. Category 5 items shall be identified as set forth in the Manufacturer's Quality System Program.

(c) Materials may be marked by any method which will not result in any harmful contamination or sharp discontinuities. Stamping, when used, shall be done with blunt-nosed-continuous or blunt-nosed-interrupted-dot die

stamps.

U-1316.2 Class 3 Pump Items.

The identification of materials for Category 3 through 5 items used for Class 3 pumps shall consist of marking the material or its container in accordance with the requirements of the Manufacturer's Quality System Program.

U-1316.3 Welding and Brazing Material Identification.

Welding and brazing materials shall be clearly identified by legible marking on the package or container *so that they are identifiable as acceptable material until the material is actually consumed in the process.*

U-1320 FRACTURE TOUGHNESS REQUIREMENTS FOR CATEGORY 3 MATERIALS

U-1321 Materials to Be Impact Tested

Impact tested specimens shall be representative of the final heat treatment of the finished part.

U-1321.1 Materials for Which Impact Testing Is Required.

Materials for Category 3 items for Class 1 pumps, and for Class 2 and 3 pumps when required by the Design Specification, shall be impact tested in accordance with the requirements of para. U-1320 except that the following materials do not require impact testing:

- (a) all thickness of materials for pumps with a nominal inlet pipe size 6 in. (152 mm) diameter and smaller;
- (b) materials for pumps with all pipe connections of $\frac{5}{8}$ in. (16 mm) nominal pipe wall thickness and less;
- (c) materials with a nominal section thickness of $\frac{5}{8}$ in. (16 mm) and less;
- (d) bars with a nominal cross-sectional area of 1 sq in. (645 mm²) and less;
- (e) austenitic stainless steels;
- (f) nonferrous materials.

U-1321.2 Impact Test Procedure

U-1321.2.1 Charpy V-Notch Tests.

The Charpy V-Notch Test shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Fig. 11, Type A. A test shall consist of a set of 3 full-size 10 × 10 mm specimens. The test temperature and lateral expansion shall be reported in the Certified Material Test Report.

U-1321.2.2 Location and Orientation of Test Specimens.

Impact test specimens shall be removed from the locations and orientations specified by the material specification for tensile test specimens in each product form.

U-1321.2.3 Test Requirements and Acceptance Standards.

Three Charpy V-Notch specimens shall be tested at a temperature equal to or lower than the lowest service temperature. All three specimens shall meet or exceed 15 mils lateral expansion (0.015 in.) (0.38 mm). Lowest service temperature is the minimum temperature of the fluid retained by the pump. The lowest service temperature shall be specified in the Design Specification.

U-1321.2.4 Retests.

One retest at the same temperature may be conducted provided:

- (a) not more than one specimen per test is below the minimum requirements; and
- (b) the specimen not meeting the minimum requirements is not lower than 5 mils (0.13 mm) below the specified requirements.

U-1400 FABRICATION REQUIREMENTS

Category 3 through 5 items shall be fabricated in accordance with the requirements of para. U-1400 and shall be manufactured from materials which meet the requirements of para. U-1300.

U-1410 CERTIFICATION OF MATERIALS AND FABRICATION BY PUMP MANUFACTURER

The pump manufacturer shall provide certification that all treatments, tests, repairs, or examinations performed on pump items are in compliance with the requirements of this Appendix. Reports of all required treatments and the results of all required tests, repairs, and examinations performed shall be maintained in accordance with NCA-3867.4 or NCA-4134.17.

Page 478

U-1420 MATERIAL IDENTIFICATION

Material for Category 3 and 4 items for Class 1 and 2 pumps shall carry identification markings, *including heat treatment grade either* directly on the item or on a separate tag that accompanies the item, which will be *maintained during and after assembly*.

U-1430 EXAMINATION OF MATERIALS

Bars and forgings for Category 3 pump shafting for Class 1 pumps, shall be ultrasonically examined in accordance with NB-2542 and NB-2547. Materials for Class 1 pumps, Category 3 items and Category 4 impellers for Class 1 pumps shall be examined on all external and accessible internal surfaces by the magnetic particle or liquid penetrant method in accordance with Section V. The examination may be performed by the Material Manufacturer, Material Supplier, or the pump manufacturer (see para. U-1313). Acceptance standards for magnetic particle and/or liquid penetrant examination shall be as follows.

- (a) Only indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant.
- (b) The following relevant indications are unacceptable:
 - (1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for materials less than $\frac{5}{8}$ in. (16 mm) thick; greater than $\frac{1}{8}$ in. (3.2 mm) long for materials from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick; and $\frac{3}{16}$ in. (4.8 mm) long for materials 2 in. (51 mm) thick and greater;
 - (2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;
 - (3) four or more indications greater than $\frac{1}{16}$ in. (1.6 mm) in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;
 - (4) ten or more indications greater than $\frac{1}{16}$ in. (1.6 mm) in any 6 sq in. (3871 mm²) of area whose major dimension is no more than 6 in. (152 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated;
 - (5) linear nonaxial indications.

Materials for Category 4 and 5 items for Class 1 pumps and for Category 3, 4, and 5 items for Class 2 and 3 pumps shall be examined in accordance with the material specification. When Category 4 or 5 material forms an integral or welded extensions to Category 1 material (see para. U-1120), the examination required for the Category 4 or 5 portion shall be in accordance with this Appendix. In addition, the requirements for the examination of the Category 1 portion shall be applied for a distance of at least $2t$ (t is thickness of the Category 4 or 5 material) from the Category 1 boundary as defined by the pump designer.

U-1431

U-1431 Time of Examination

Magnetic particle or liquid penetrant examination shall be performed in the finished conditions, *after all heat treatment operations and postweld heat treatment*, except that threaded items may be examined prior to threading. Examinations shall be performed prior to any coating or plating. Lapping of seating surfaces to reduce leakage or lapping of bearing surfaces shall not require reexamination.

U-1432 Elimination of Surface Defects

(a) Unacceptable surface defects shall be removed by grinding or machining, provided:

- (1) the remaining thickness of the section is not reduced below the minimum required by the design;
 - (2) the depression, after grinding or machining, is blended uniformly into the surrounding surface and the depression does not affect the function of the item;
 - (3) after grinding or machining, the area is examined by the method which originally disclosed the defect to assure that the defect has been removed or the indication reduced to an acceptable size.
- (b) If grinding or machining reduces the thickness of the section below the minimum required by the design, the item may be repaired and returned to an acceptable size.

U-1440 REPAIR BY WELDING OF CATEGORY 3, 4, AND 5 PUMP ITEMS

(a) Category 3, 4 and 5 items for Class 1, 2 and 3 pumps may be repaired by welding using the provisions of Section IX for materials in Table U-1610-1 with assigned P-numbers provided the requirements of the following subparagraphs are met.

(b) Until such time as P-numbers are assigned, welding of those materials without P-numbers shall be separately qualified as required by Section IX.

(c) Bolts, studs, nuts, and material for which welding is prohibited by Note 2 of Table U-1610-1 shall not be repair welded.

Page 479

U-1441 Defect Removal

The defect shall be removed or reduced to an acceptable size by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair.

U-1442 Qualification of Welding Procedures and Welders

(a) When impact tests of Category 3 items are required, the impact testing requirements of para. U-1321.2.3 shall be met in the heat affected zone regardless of filler metal used and in the weld metal for all material except austenitic and nonferrous filler metal.

(b) Except as permitted in (c) below, the welding procedure and welders or welding operators shall be qualified in accordance with Section IX.

(c) Heat-treated materials listed in Table U-1610-1 which are not capable of passing bend tests required by Section IX for procedure or performance qualification may be qualified by a Fillet Weld Test in accordance with QW-180. In addition, a minimum of two cross sections of the qualification test plate (assembly) shall be ground and etched with a suitable etchant and visually examined at 10× magnification. The weld metal and adjacent base material of the ground and etched cross sections shall be free of cracks.

U-1443 Blending of Repaired Areas

After repair, the surface shall be blended into the surrounding surface.

U-1444 Examination of Repair Welds

Each repair weld of materials for Category 3 items for Class 1 pumps shall be examined by the method that originally disclosed the defect. The finished surface shall be examined by either the magnetic particle or liquid penetrant method in

accordance with Section V. The acceptance standards shall be those specified in paras. U-1430(a) and U-1430(b). Repair welds of materials for the other categories shall be in accordance with the material specification.

U-1445 Heat Treatment After Repair

(a) Materials listed in Table U-1610-1 which are repaired by welding shall be heat treated in accordance with the requirements of NB-4600, NC-4600 and ND-4600 as applicable, or as allowed by (c) below.

(b) Materials listed in Table U-1610-1 which are repaired by welding shall be heat treated and tempered or aged after repair, except as allowed by (c) below. The minimum tempering or aging temperature shall be as specified in Table U-1610-1 for the finished item.

(c) Repair weld procedures for welds not exceeding the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness shall be qualified by test weld specimens meeting the tensile and bend test requirements of Section IX, without PWHT, for the material repaired.

U-1446 Repair Weld Report

A record shall be made of each defect repair of Category 3 items for Class 1 pumps in which the depth of the repair cavity exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness. The record shall include the location and size of the repaired cavity, the welding material, the welding procedure, the heat treatment, and the examination results.

U-1450 WELDING REQUIREMENTS

Except as permitted in paras. U-1442 and U-1451, all welds shall be made using qualified welding procedures and welders or welding operators in accordance with Section IX.

U-1451 Special Fabrication Welds

Fillet welds and partial penetration welds $\frac{1}{4}$ in. (6 mm) and less in size may be made in the fabrication of pump items or between pump items where either of the items is a material listed in Table U-1610-1 provided welding is not prohibited by Note 2 in Table U-1610-1, and the procedures and welders are qualified as follows:

(a) a test assembly shall be made for each combination of materials to be welded;

(b) the test assembly shall be a duplicate of the production weld joint or a groove butt weld $\frac{1}{4}$ in. (6 mm) minimum thickness;

(c) the test assembly shall be sectioned (a minimum of four cross sections), ground, etched with a suitable etchant, and visually examined at $10\times$ magnification. All surfaces of the weld and adjacent base material(s) shall be free of cracks.

U-1452 Examination of Welds

All welds shall be examined by the magnetic particle or liquid penetrant method in accordance with Section V. The time of examination shall be in accordance

Page 480

with NB-5120, NC-5120 and ND-5120. Acceptance standards shall be as follows.

U-1453 Acceptance Standards

(a) Only indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant.

(b) The following relevant indications are unacceptable:

(1) any cracks or linear indications;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);

(3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 sq in. (3871 mm²) of surface with the major dimensions of this area not to exceed 6 in. (152 mm), with the area taken in the most unfavorable location relative to the indications being evaluated.

U-1454 Heat Treatment of Welds

(a) Postweld heat treatment of welds which join materials listed in Table U-1610-1 shall be in accordance with the postweld heat treatment requirements of NB-4620, NC-4620 or ND-4620, as applicable.

(b) Postweld heat treatment of welds which join materials listed in Table U-1610-1 shall be in accordance with the postweld heat treatment requirements of NB-4620, NC-4620, or ND-4620, as applicable. Special techniques, such as local postweld heat treatment, may be necessary to avoid changing the base material properties of the item in location not adjacent to the weld. A change in the specified postweld heat treatment temperature will require requalification of the WPS in accordance with Section IX, para. QW-407.1.

(c) Postweld heat treatment of welds which join materials listed in Table U-1610-1 to materials listed in Section II, Part D, Table 1A shall be in accordance with the postweld heat treatment requirements of NB-4620, NC-4620 or ND-4620, as applicable. Special techniques, such as local postweld heat treatment, may be necessary to avoid changing the base material properties of the item in location not adjacent to the weld. A change in the specified postweld heat treatment temperature will require requalification of the WPS in accordance with Section IX, para. QW-407.1.

(d) Postweld heat treatment of welds for joining materials listed in Table U-1610-1 shall be in accordance with the heat treatment specified for the material of the finished item, i.e., the heat treatment required to obtain the tensile strength and/or yield strength listed in Table U-1610-1.

(e) Materials listed in Table U-1610-1 subject to material specification heat treatment after repair welding shall be welded to a procedure which shall demonstrate that the required strength can be met in the weld without affecting the properties of the base material.

(f) For fillet welds and partial penetration welds $\frac{1}{4}$ in. (6 mm) and less in size, postweld heat treatment is neither required nor prohibited, provided the requirements of para. U-1451 are met.

Page 481

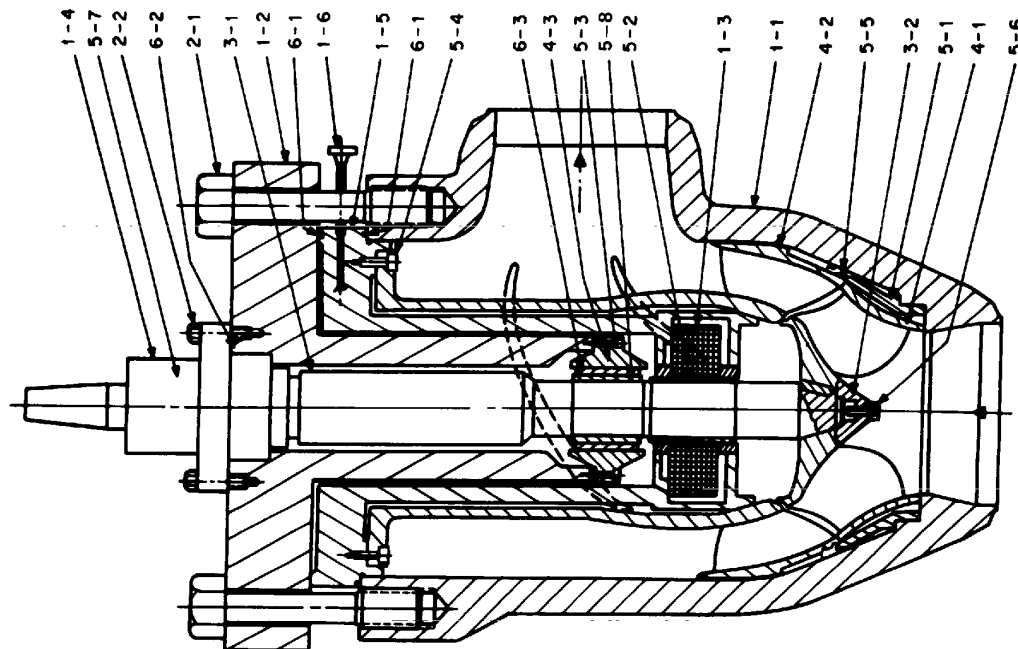
Page 482

**TABLE U-1600-1
SUMMARY OF REQUIREMENTS**

Typical Items	Category No. & Pump Class	Stress Report	Certified Material Test Report	Non-destructive Examination	Impact Testing	Material Identif.
Pressure Retaining Items	Category 1 Class (All)	Subsection NB, NC, ND				
Pressure Retaining Bolting	Category 2 Class (All)	Subsection NB, NC, ND				
Shafting	Category 3					
Line Shaft Couplings	Class 1	—	X	(5)(7)	X	X
Impeller Nuts or	Class 2	—	X	—	(4)	X
Impeller Locking	Class 3	—	X	—	(4)	(1)
Screw						
Impellers	Category 4					
Bearing Support	Class 1	—	(2)(3)	(6)See para. U-1120	—See para. U-1120	X
Bearings	Class 2	—	(2)	—See para. U-1120	—See para. U-1120	X
Journals	Class 3	—	(2)	—See para. U-1120	—See para. U-1120	(1)
Im./Case Rings	Category 5					
Keys	Class 1	—	(2)	—See para. U-1120	—See para. U-1120	(1)
Mech. Seal (Met.)	Class 2	—	—	—See para. U-1120	—See para. U-1120	(1)
Parts	Class 3	—	—	—See para. U-1120	—See para. U-1120	(1)
Bolting (Internal)						
Bearings						
Journals						
Packing	Category 6					
Gaskets	Class 1	—	—	—	—	—
"O" Rings	Class 2	—	—	—	—	—
Carbon	Class 3	—	—	—	—	—

- (1) Quality control system.
(2) Materials Manufacturer's Certificate of Compliance.
(3) Certified Material Test Reports required for impellers.
(4) When required for the pump per Design Specification.
(5) Ultrasonic Examination required for Class 1 shafting.
(6) Magnetic Particle or Liquid Penetrant Examination required for Class 1 impellers.
(7) Magnetic Particle or Liquid Penetrant Examination required for all Class 1, Category 3 items.

TABLE U-1600-1 SUMMARY OF REQUIREMENTS



Key to Fig. U-1500-1

Cat.	Pump Item	Name (Typical)
1	1-1	Casing
	1-2	Main Flange
	1-3	Heat Exchanger
	1-4	Seal Housing
	1-5	Thermal Barrier
	1-6	TB Connection Piping (Include Flange)
2	2-1	Main Flange Bolts
	2-2	Seal Housing Bolts
3	3-1	Shaft
	3-2	Impeller Nut
4	4-1	Impeller
	4-2	Diffuser
5	4-3	Bearing Support
	5-1	Diffuser Adapter (Casing Wear Ring)
6	5-2	Thermal Sleeve
	5-3	Radial Bearing Bolts
	5-4	Turning Vane/Thermal Barrier Bolts
	5-5	Diffuser/Diffuser Adapter Bolts
	5-6	Impeller Nut Locking Bolt
	5-7	Seals—Mechanical Seal (Metallic)
	5-8	Bearings/Journals and Shaft Sleeves
	6-1	Flange Gaskets
	6-2	Seal Housing O-Ring
	6-3	Radial Bearing
	6-4	Mechanical Seal (Nonmetallic)

FIG. U-1500-1 TYPICAL FOR TYPE A, C, E, F, AND/OR SOME J (NB-3400) PUMPS

FIG. U-1500-1 TYPICAL FOR TYPE A, C, E, F, AND/OR SOME J (NB-3400) PUMPS

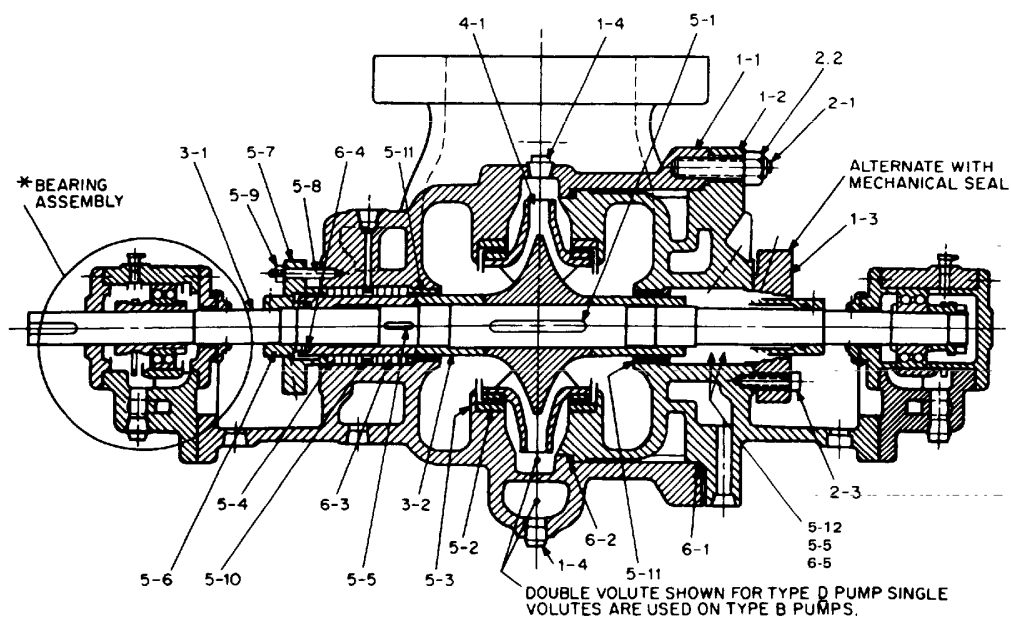


FIG. U-1500-2 TYPICAL TYPE B AND D PUMPS (NC AND ND-3400)

Key to Fig. U-1500-2

Cat.	Pump Item	Name (Typical)	Cat.	Pump Item	Name (Typical)
1	1-1	Case	5	5-5	Shaft Sleeve Key
	1-2	Head		5-6	Shaft Sleeve Nut
	1-3	Seal Plate		5-7	Packing Gland
	1-4	Case Plug		5-8	Packing Gland Stud
2	2-1	Case Stud		5-9	Packing Gland Nut
	2-2	Case Stud Nut		5-10	Lantern Ring
	2-3	Seal Plate Bolt		5-11	Packing Box Bushing
3	3-1	Pump Shaft		5-12	Mech. Seal Metallic Parts
	3-2	Impeller Locknut	6	6-1	Head Gasket
4	4-1	Impeller		6-2	Inner Head Gasket
				6-3	Packing
5	5-1	Impeller Key		6-4	Shaft Sleeve Seal Ring
	5-2	Case Wearing Ring		6-5	Mech. Seal Nonmetallic Parts
	5-3	Impeller Wearing Ring			
	5-4	Shaft Sleeve			
			* Bearing Assembly		

*Part not covered by this Appendix

FIG. U-1500-2 TYPICAL TYPE B AND D PUMPS (NC AND ND-3400)

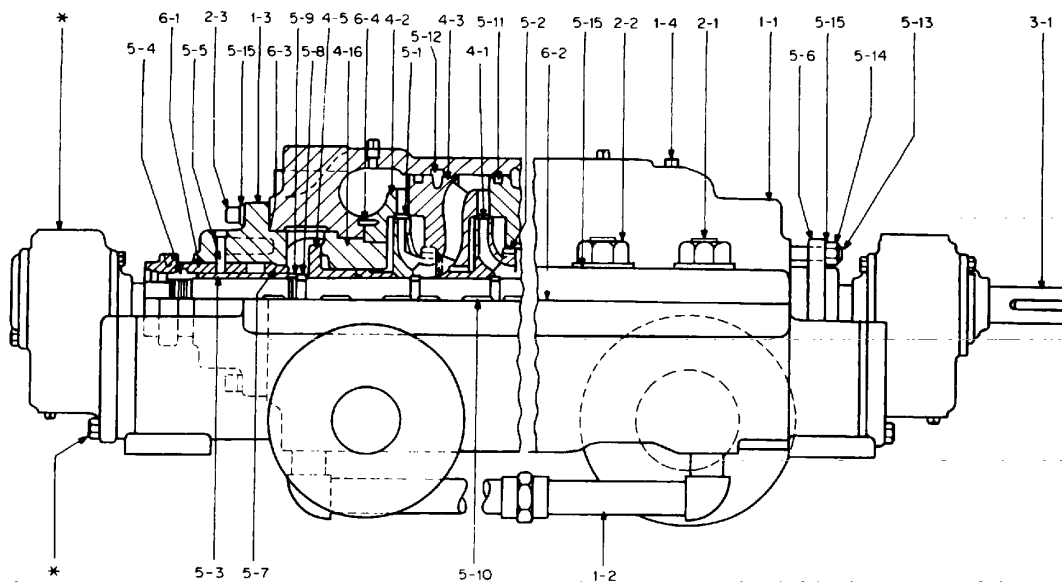
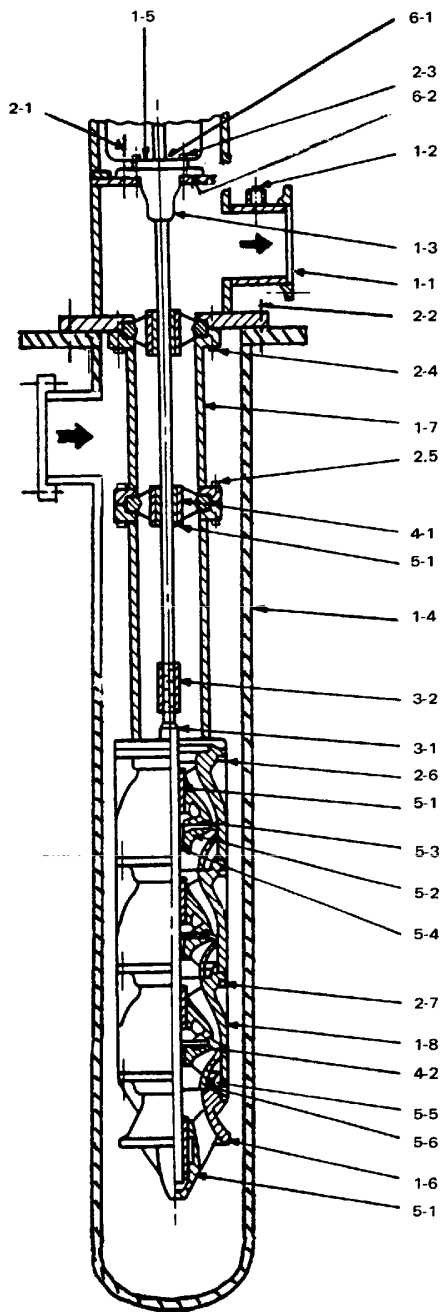


FIG. U-1500-3 TYPICAL FOR TYPE G AND H PUMPS (NC AND ND-3400)

Key to Fig. U-1500-3

Cat.	Pump Item	Name (Typical)	Cat.	Pump Item	Name (Typical)
1	1-1	Casing	5	5-3	Shaft Sleeve
	1-2	Piping, Balance Line (Including Fittings)		5-4	Nut, Shaft Sleeve
	1-3	Stuffing Box		5-5	Seal Cage (Metallic)
	1-4	Plugs, Casing		5-6	Gland Halves
2	2-1	Studs, Main Flange		5-7	Bushing, Stuffing Box
	2-2	Nuts, Main Flange		5-8	Split Ring
	2-3	Cap Screws, Stuffing Box		5-9	Retaining Ring
3	3-1	Shaft		5-10	Key
				5-11	Sealing Ring, Channel
				5-12	Pin
				5-13	Studs, Gland
				5-14	Nut, Gland
4	4-1	Impeller		5-15	Washer
	4-2	Diffuser	6	6-1	Packing, Stuffing Box
	4-3	Channel Ring		6-2	Gasket, Main Flange
	4-4	Balance Sleeve		6-3	Gasket, Metallic-Asbestos
	4-5	Balance Drum		6-4	O-Ring
5	5-1	Impeller Ring			
	5-2	Casing Ring			

FIG. U-1500-3 TYPICAL FOR TYPE G AND H PUMPS (NC AND ND-3400)

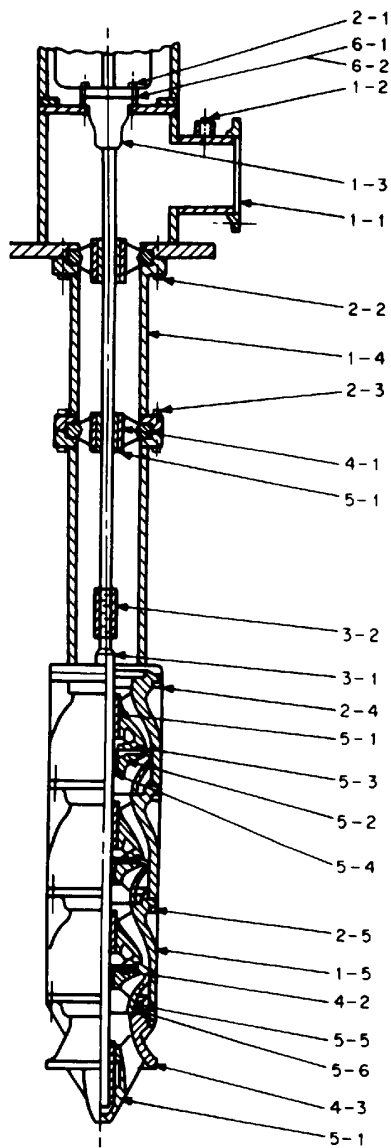


Key to Fig. U-1500-4

Cat.	Pump Item	Name (Typical)
1	1-1	Head
	1-2	Pipe Plug—Discharge
	1-3	Stuffing Box
	1-4	Barrel
	1-5	Packing Gland
	1-6	Suction Bail
	1-7	Column
	1-8	Bowl
2	2-1	Bolting—Stuffing Box to Head
	2-2	Bolting—Head to Barrel
	2-3	Bolting—Packing Gland to Stuffing Box
	2-4	Bolting—Column to Head
	2-5	Bolting—Column to Column
	2-6	Bolting—Bowl to Column
	2-7	Bolting—Bowl to Bowl
3	3-1	Shaft
	3-2	Coupling—Shaft
4	4-1	Spider
	4-2	Impeller
5	5-1	Bearing
	5-2	Split Ring—Thrust
	5-3	Capscrew—Split Ring
	5-4	Key—Impeller
	5-5	Wear Ring—Bowl
	5-6	Wear Ring—Impeller
6	6-1	Packing
	6-2	Gasket—Stuffing Box to Head

FIG. U-1500-4 TYPICAL FOR TYPE K PUMPS (NC AND ND-3400)

FIG. U-1500-4 TYPICAL FOR TYPE K PUMPS (NC AND ND-3400)



Key to Fig. U-1500-5

Cat.	Pump Item	Name (Typical)
1	1-1	Head
	1-2	Pipe Plug—Discharge
	1-3	Stuffing Box
	1-4	Column
	1-5	Bowl
2	2-1	Bolting—Stuffing Box to Head
	2-2	Bolting—Column to Head
	2-3	Bolting—Column to Column
	2-4	Bolting—Bowl to Column
	2-5	Bolting—Bowl to Bowl
3	3-1	Shaft
	3-2	Coupling—Shaft
4	4-1	Spider
	4-2	Impeller
	4-3	Suction Bell
5	5-1	Bearing
	5-2	Split Ring—Thrust
	5-3	Capscrew—Split Ring
	5-4	Key—Impeller
	5-5	Wear Ring—Bowl
	5-6	Wear Ring—Impeller
6	6-1	Packing
	6-2	Gasket—Stuffing to Head

FIG. U-1500-5 TYPICAL FOR TYPE L PUMPS (NC AND ND-3400)

FIG. U-1500-5 TYPICAL FOR TYPE L PUMPS (NC AND ND-3400)

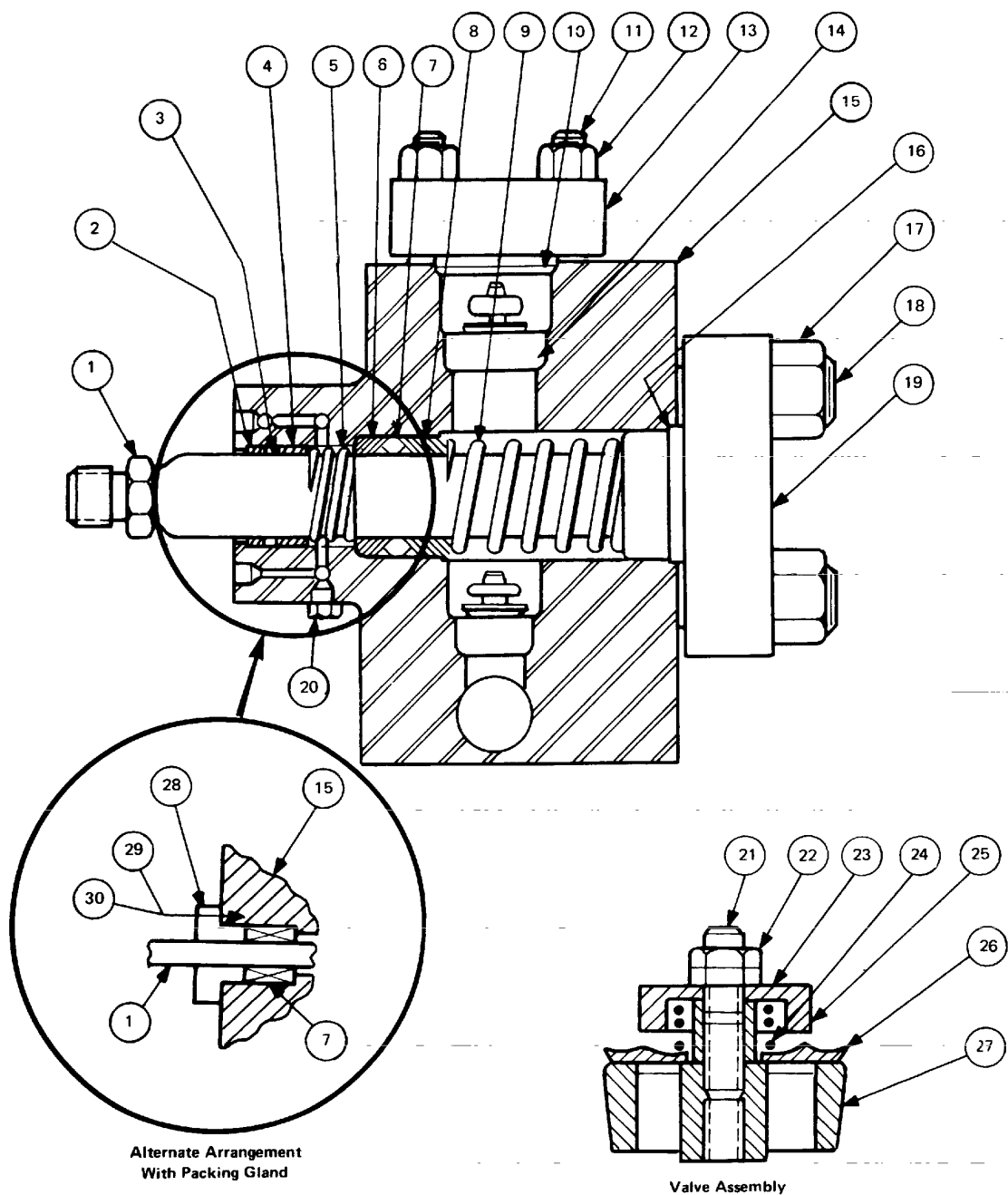


FIG. U-1500-6 RECIPROCATING PLUNGER PUMP (NC AND ND-3400)

FIG. U-1500-6 RECIPROCATING PLUNGER PUMP (NC AND ND-3400)

Key to Fig. U-1500-6

Cat.	Pump Item	Name (Typical)
1	13	Upper Cap
	15	Cylinder Block
	19	Front Cap
	28	Packing Gland
2	11	Upper Cap Stud
	12	Upper Cap Stud Nut
	17	Front Cap Stud Nut
	18	Front Cap Stud
	29	Stud (Gland)
	30	Nut (Gland)
3	1	Plunger
5	2	Packing Adj. Ring (Secondary)
	4	Plunger Ring (Secondary)
	5	Packing Spring (Secondary)
	6	Packing Adj. Ring (Primary)
	8	Plunger Ring (Primary)
	9	Packing Spring (Primary)
	14	Valve Assembly
	20	Plug
	21	Stud
	22	Double Locknut
	23	Sleeve
	24	Spring
	25	Guard Stop
	26	Valve
	27	Seat
6	3	Packing (Secondary)
	7	Packing (Primary)
	10	Upper Cap Gasket
	16	Front Cap Gasket

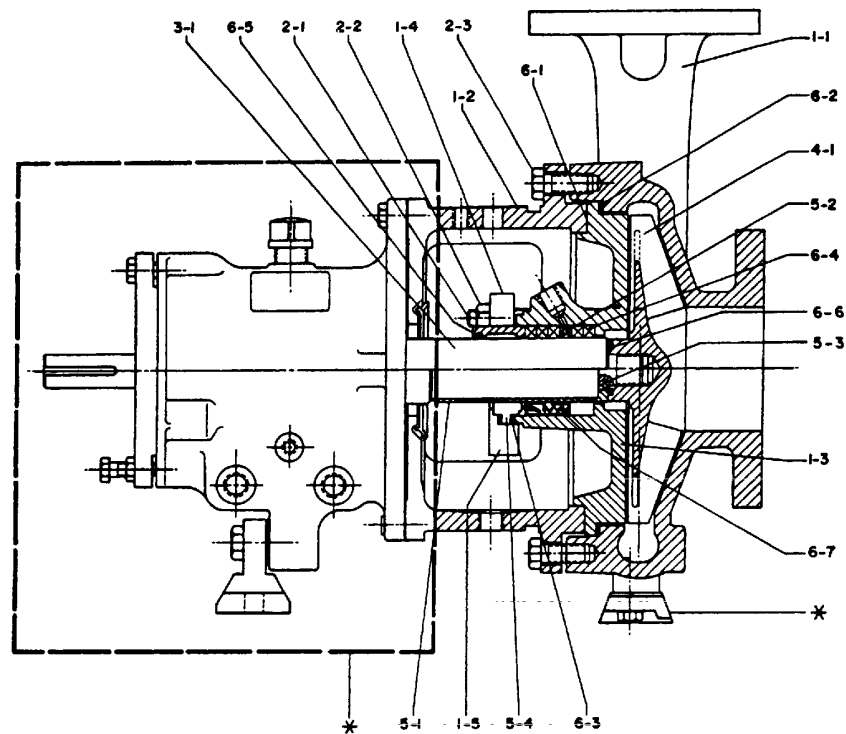


FIG. U-1500-7 TYPICAL TYPE A OR C PUMPS (NC AND ND-3400)

Key to Fig. U-1500-7

Cat.	Pump Item	Name (Typical)	Cat.	Pump Item	Name (Typical)
1	1-1	Casing	5	5-1	Shaft Sleeve
	1-2	Frame Adapter		5-2	Lantern Ring
	1-3	Stuffing Box Cover		5-3	Pin—Sleeve
	1-4	Gland—Packing		5-4	Mech. Seal (Metallic Parts)
	1-5	Gland—Mech. Seal	6	6-1	Gasket—Adapter/Cover
2	2-1	Stud-Gland		6-2	Gasket—Casing
	2-2	Nut—Gland Stud		6-3	Gasket—Gland
	2-3	Cap Screw—Case		6-4	Packing—Stuffing Box
3	3-1	Shaft		6-5	Packing—Gland
				6-6	O-Ring—Shaft Sleeve
4	4-1	Impeller		6-7	Mech. Seal (Nonmetallic Parts)

*Part not covered by this Appendix

FIG. U-1500-7 TYPICAL TYPE A OR C PUMPS (NC AND ND-3400)

TABLE U-1610-1 MATERIALS FOR PUMP INTERNAL ITEMS FOR CLASS 1, 2, AND 3 PUMPS

TABLE U-1610-1 (CONT'D) MATERIALS FOR PUMP INTERNAL ITEMS FOR CLASS 1, 2, AND 3 PUMPS

TABLE U-1610-1 (CONT'D)
MATERIALS FOR PUMP INTERNAL ITEMS FOR CLASS 1, 2, AND 3 PUMPS

Cond.	Tensile Strength psi, min	Yield Strength psi, min	Minimum Tempering or Aging Temp. F	Spec No.
A	70,000	25,000	NA	B-164
A	70,000	28,000	NA	B-165
A	70,000	25,000	NA	B-165
PH	140,000	100,000		AMS 4676
PH	135,000	95,000		AMS 4676
SHT	62,000	25,000	NA	A-351

TABLE U-1610-1 (CONT'D)
MATERIALS FOR PUMP INTERNAL ITEMS FOR CLASS 1, 2, AND 3 PUMPS

Material	Product Form	Spec. No. (8)	Type or Grade	Notes	Diameter or Thickness, in.
Ni-Cu	Bar, Rod	B-164	400 Class A		
	Pipe, Tube	B-165	400		Up to 5"
	Pipe, Tube	B-165	400	(2)	Over 5"
	FFBS	AMS 4676	Alloy 500	(5)	12" max
	Rounds	AMS 4676	Alloy 500	(5)	4" max
Cr-Ni-Cu-Mo	Casting	A-351	CN7M		

NOTES:

- (1) Not to be used with Category 3 items, except for pumps with inlet piping connections 2 in. nominal pipe size and less.
- (2) Welding of these materials is not permitted.
- (3) Where the tensile strength, yield strength, tempering temperature, or aging temperature listed in Table U-1610-1 differ from the requirements of the material specification, the minimum requirements listed in Table U-1610-1 shall apply. The material shall be identified with this Appendix number in addition to the requirements for identification of para. U-1316.
- (4) Cross-bracketing indicates that any of the bracketed materials may be used with any of the bracketed properties.
- (5) The maximum tensile strength shall not exceed the minimum specified tensile strength listed in this Table by more than 40,000 psi.
- (6) Welding of this material is permitted provided the carbon content is 0.25% or less.
- (7) Service temperatures shall not exceed temperatures of 100°F below the aging or tempering temperature.
- (8) Material shall conform to Edition specified by N-Certificate Holder.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D1 NMA APP V

APPENDIX V INTERRUPTION OF CODE WORK

Page 493

Page 495

[98]

ARTICLE V-1000 INTERRUPTION OF CODE WORK

[98]

V-1100INTRODUCTION

[98]

V-1110 Scope

The scope of this Appendix is confined to those situations where the Code activities of a Certificate Holder are interrupted prior to completion of all Code assigned responsibilities. When this occurs, all completed in-process work must be clearly documented to ensure remaining activities and Code responsibilities are readily identifiable.

[98]

[98]

V-1200DEFINITIONS

(a) *Interruption of Code Activities:* The cessation of Code work by a Certificate Holder prior to completion of all assigned Code responsibilities. The cessation may result from project suspension or transfer of Code responsibilities from one Certificate Holder to another Certificate Holder.

(b) *Completed In-Process Work:* A Code activity on an item, part, subassembly, appurtenance, component, or support which has been accepted by the ANI for the Certificate Holder that performed the Code activity, but which requires additional work before the item, part, subassembly, appurtenance, component, or support can be stamped with the applicable Code symbol. Examples of completed in-process work include design activities, an individual weld or a weld pass, heat treatment of weld joints, and examination of welds or items after heat treatment.

[98]

[98]

V-1300DOCUMENTATION

(a) A memorandum of understanding shall be approved by the parties involved which documents the status of Code activities and acceptance of transfer responsibilities, where applicable. The memorandum shall be approved by the existing Certificate Holder and its ANI, the Certificate Holder which will provide continuity of responsibility and its ANI, where applicable. When the work is being performed at a nuclear power plant site, the memorandum shall also be approved by the Owner and the jurisdictional enforcement authority having jurisdiction at the nuclear power plant site.

(b) The memorandum of understanding shall reference Code Data Reports for completed work. For completed in-process work, Code Data Reports may also be used to document the status of Code activities. Additionally, the status of completed in-process work may also be indicated on drawings, diagrams, or other means and referenced in the memorandum.

[98]

[98]

V-1400 OTHER CONSIDERATIONS

(a) If a quality program such as that used by a Certificate Holder is utilized during the period of interruption, a review of completed work will not be required by the Certificate Holder assuming responsibility for completion of Code activities. The Certificate Holder assuming responsibility or its Authorized Nuclear Inspector may require evidence that an acceptable quality program has been in place.

(b) Once completed work or completed in-process work is accepted by an ANI, it meets Code requirements and need not be scrutinized by another Certificate Holder or ANI.

(c) To meet Code requirements, completed work shall be documented on the applicable Code Data Report and stamped as applicable.

(d) Completion of the applicable Code Data Report and application of the Code symbol stamp, where applicable, expressly signifies the Code status of completed work and completed in-process work.

[98]

[98]

V-1500 RESUMPTION OF CODE ACTIVITIES

Resumption of Code activities may be undertaken at any time by updating the original memorandum of understanding documenting the status of Code activities. The updated memorandum shall be approved by any new parties involved such as the Certificate Holder assuming responsibility for completion of Code activities, the Certificate Holder's ASME Accredited Authorized Nuclear Inspection Agency, and the organization contracting for the completion of Code activities. For Code activities to be performed at a nuclear plant site, the Owner and jurisdictional and enforcement authority shall also approve the updated memorandum of understanding.

[98]

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 A98

1998 ADDENDA SUMMARY OF CHANGES

Page xxix

Changes given below are identified on the pages by a margin note, **98**, placed next to the affected area.

Page	Location	Change
26	Table CC-2442-1	Corrected by Errata
167	Table I-1.1	Deleted by Errata
248	Reference Material	American Public Health Association entry corrected by Errata

NOTE:

Volume 42 of the Interpretations to Section III, Divisions 1 and 2, of the ASME Boiler and Pressure Vessel Code follows the last page of the Edition to Subsection NCA.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 INTRODUCTION

INTRODUCTION

**1998 ASME
BOILER &
PRESSURE VESSEL CODE
AN INTERNATIONAL CODE**

III

Division 2

Code for

Concrete

Reactor

Vessels and

Containments

RULES FOR

CONSTRUCTION

OF NUCLEAR

POWER PLANT

COMPONENTS

[ASME logo] The American Society of
Mechanical Engineers



LOGO

ACI STANDARD 359-98

AN AMERICAN NATIONAL STANDARD

**IMPORTANT INFORMATION ON THE 1998 BOILER AND PRESSURE VESSEL CODE
ADDENDA DISTRIBUTION SCHEDULE**

There is a change in the way the Addenda to the 1998 Edition of the ASME Boiler and Pressure Vessel Code are distributed. The 1998 Edition, published July 1, 1998, incorporates the 1998 Addenda revisions, additions, or deletions. There will be no separate 1998 Addenda issued in a replacement page format. Two additional Addenda to the 1998 Edition, in the form of replacement pages, will be issued on July 1, 1999 and July 1, 2000.

The Summary of Changes published with the 1998 Edition lists and describes the revisions that are part of the 1998 Addenda. These changes are identified with a margin note, **98**, denoting the affected area.

The Addenda for 1999 and 2000 will also have a Summary of Changes and identifiers printed on the replacement pages. The revisions, additions, or deletions will be incorporated directly into the affected pages. It is advisable to retain the title sheets and all replaced pages for reference.

The effective dates for Code Editions and Addenda are described in the Foreword.

ASME BOILER AND PRESSURE VESSEL CODE
AN INTERNATIONAL CODE
(ACI STANDARD 359-98)

RULES FOR
CONSTRUCTION OF
NUCLEAR POWER
PLANT COMPONENTS

III

Division 2

Code for
Concrete
Reactor
Vessels and
Containments

1998 Edition
July 1, 1998

ASME BOILER AND
PRESSURE VESSEL
COMMITTEE
SUBCOMMITTEE ON
NUCLEAR POWER
ACI-ASME JOINT
TECHNICAL
COMMITTEE

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
NEW YORK, NEW YORK

Date of Issue - July 1, 1998
(Includes all Addenda dated December 1997 and earlier)

This code or standard was developed under procedures accredited as meeting the criteria for American National Standards. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment which provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not "approve," "rate," or "endorse" any item, construction, proprietary device, or activity.

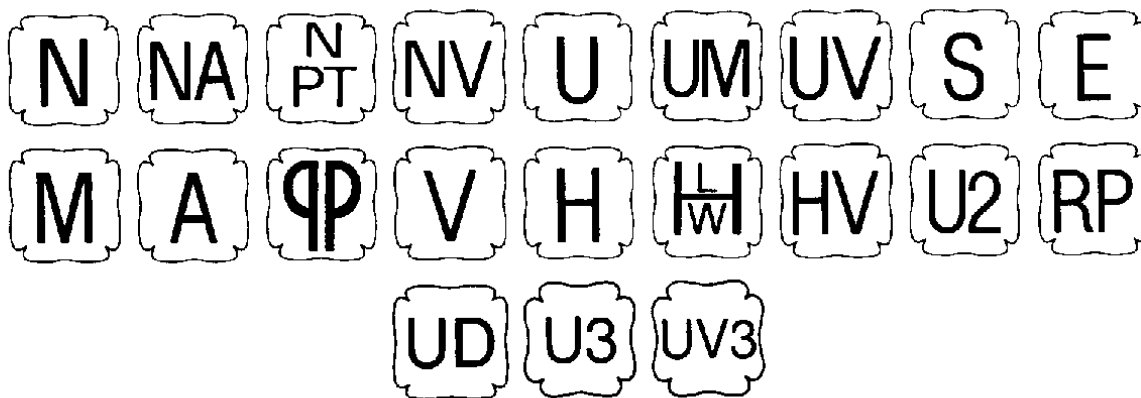
ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of any applicable Letters Patent, nor assume any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations issued in accordance with governing ASME procedures and policies which preclude the issuance of interpretations by individual volunteers.

The footnotes in this document are part of this American National Standard.

[ASME logo] ASME collective membership mark



LOGOS

The above ASME symbols are registered in the U.S. Patent Office.

"ASME" is the trademark of the American Society of Mechanical Engineers.

No part of this document may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Library of Congress Catalog Card Number: 56-3934

Printed in the United States of America

Adopted by the Council of the American Society of Mechanical Engineers, 1914.

Revised 1940, 1941, 1943, 1946, 1949, 1952, 1953, 1956, 1959, 1962, 1965, 1968, 1971, 1974, 1977, 1980, 1983, 1986, 1989, 1992, 1995, 1998

The American Society of Mechanical Engineers

Three Park Avenue, New York, NY 10016-5990

Copyright © 1998 by

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

All Rights Reserved

1998 ASME

BOILER AND PRESSURE VESSEL CODE

SECTIONS

I Rules for Construction of Power Boilers

II Materials

Part A - Ferrous Material Specifications

Part B - Nonferrous Material Specifications

Part C - Specifications for Welding Rods, Electrodes, and Filler Metals

Part D - Properties

III Subsection NCA - General Requirements for Division 1 and Division 2

III Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

III Division 2 - Code for Concrete Reactor Vessels and Containments

III Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

IV Rules for Construction of Heating Boilers

V Nondestructive Examination

VI Recommended Rules for the Care and Operation of Heating Boilers

VII Recommended Guidelines for the Care of Power Boilers

VIII Rules for Construction of Pressure Vessels

Division 1

Division 2 - Alternative Rules

Division 3 - Alternative Rules for Construction of High Pressure Vessels

IX Welding and Brazing Qualifications

X Fiber-Reinforced Plastic Pressure Vessels

XI Rules for Inservice Inspection of Nuclear Power Plant Components

ADDENDA

Colored-sheet Addenda, which include additions and revisions to individual Sections of the Code, are published annually and will be sent automatically to purchasers of the applicable Sections up to the publication of the 2001 Code. The 1998 Code is available only in the loose-leaf format; accordingly, the Addenda will be issued in the loose-leaf, replacement-page format.

INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code. The Interpretations for each individual Section will be published separately and will be included as part of the update service to that Section. They will be issued semiannually (July and December) up to the publication of the 2001 Code. Interpretations of Section III, Divisions 1 and 2, will be included with the update service to Subsection NCA.

CODE CASES

The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 1998 Code Cases book: (1) Boilers and Pressure Vessels and (2) Nuclear Components. Supplements will be sent automatically to the purchasers of the Code Cases books up to the publication of the 2001 Code.

Page v

FOREWORD

The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety governing the design, fabrication, and inspection during construction of boilers and pressure vessels, and to interpret these rules when questions arise regarding their intent. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property and to provide a margin for deterioration in service so as to give a reasonably long, safe period of usefulness. Advancements in design and material and the evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction,¹ and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

¹ Construction, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are responsible for the application of these programs to their design.

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practice as determined by the engineer.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Boiler and Pressure Vessel Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Mandatory Appendix covering preparation of technical inquiries). Proposed revisions to the Code resulting from inquiries will be presented to the Main Committee for appropriate action. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by ASME.

to invite comments from all interested persons. After the allotted time for public review and final approval by ASME, revisions are published annually in Addenda to the Code.

Code Cases may be used in the construction of components to be stamped with the ASME Code symbol beginning with the date of their approval by ASME.

Code Editions may be used on or after the date of issue shown in the Edition. After Code revisions are approved by ASME, they may be used beginning with the date of issue shown on the Addenda. Revisions to material specifications are originated by the American Society for Testing and Materials (ASTM) and other recognized national or international organizations, and are usually adopted by ASME. However, those revisions may or may not have any effect on the suitability of material, produced to earlier editions of specifications, for use in ASME construction. ASME material specifications approved for use in each construction Code are listed in the Appendices of Section II, Parts A and B. These Appendices list, for each specification, the latest edition adopted by ASME, and earlier and later editions considered by ASME to be identical for ASME construction.

Owners of nuclear power plants are cautioned that Code Editions, Addenda, and Cases to be used in construction shall be acceptable to the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

Each state and municipality in the United States and each province in Canada that adopts or accepts one or more Sections of the Boiler and Pressure Vessel Code is invited to appoint a representative to act on the Conference Committee to the Boiler and Pressure Vessel Committee. Since the members of the Conference Committee are in active contact with the administration and enforcement of the rules, the requirements for inspection in this Code correspond with those in effect in their respective jurisdictions. The required qualifications for an Authorized Inspector under these rules may be obtained from the administrative authority of any state, municipality, or province which has adopted these rules.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, method of fabrication, inspection, and safety devices. Permission may be granted to regulatory bodies and organizations publishing safety standards to use a complete Section of the Code by reference. If usage of a Section, such as Section IX, involves exceptions, omissions, or changes in provisions, the intent of the Code might not be attained.

Where a state or other regulatory body, in the printing of any Section of the Boiler and Pressure Vessel Code, makes additions or omissions, it is recommended that such changes be clearly indicated.

The National Board of Boiler and Pressure Vessel Inspectors is composed of chief inspectors of states and municipalities in the United States and of provinces in Canada that have adopted the Boiler and Pressure Vessel Code. This Board, since its organization in 1919, has functioned to uniformly administer and enforce the rules of the Boiler and Pressure Vessel Code. The cooperation of that organization with the Boiler and Pressure Vessel Committee has been extremely helpful.

The Code Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The Scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Code for vessels or components not considered to be within its Scope or may establish additions or deletions in that Scope. Accordingly, inquiries regarding such laws or regulations are to be directed to the issuing enforcement or regulatory body.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the ASME Boiler and Pressure Vessel Committee. ASME is to be notified should questions arise concerning improper use of an ASME Code symbol.

The specifications for materials given in Section II are identical with or similar to those of specifications published by ASTM, AWS, and other recognized national or international organizations. When reference is made in an ASME material

specification to a non- ASME specification for which a companion ASME specification exists, the reference shall be interpreted as applying to the ASME material specification. Not all materials included in the material specifications in Section II have been adopted for use in this Section. Usage is limited to those materials and grades listed in at least one of the tables of Section II, Part D, Subpart 1, identified as applicable to this Section. All materials allowed by this Section and used for construction within the scope of these rules shall be furnished in accordance with material specifications

Page ix

contained in Section II or referenced in Appendices A of Section II, Parts A and B except where otherwise provided in Code Cases or in this Section of the Code. Materials covered by these specifications are acceptable for use in items covered by the Code Sections only to the degree indicated in the applicable Section. Materials for Code use should preferably be ordered, produced, and documented on this basis. Material produced to an acceptable specification with requirements different from the requirements of the corresponding specification listed in Appendix A of Part A or Part B may also be used in accordance with the above, provided the material manufacturer or vessel manufacturer certifies with evidence acceptable to the Authorized Inspector that the corresponding ASME specification requirements of specifications listed in Appendix A of Part A or Part B have been met. Material produced to an acceptable material specification is not limited as to country of origin.

When required by context in this Section, the singular shall be interpreted as the plural, and vice-versa; and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

Publication of the SI (Metric) Edition of the ASME Boiler and Pressure Vessel Code was discontinued with the 1986 Edition. Effective October 1, 1986, the SI Edition was withdrawn as an ASME Boiler and Pressure Vessel Code document.

Page xi

STATEMENT OF POLICY ON THE USE OF CODE SYMBOLS AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use Code Symbols for marking items or constructions which have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the symbols, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications which might so indicate. An organization holding a Code Symbol and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code."

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified items will carry the symbol. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

The ASME logo, which is the cloverleaf with the letters ASME within, shall not be used by any organization other than ASME.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Code Symbol Stamp

described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the various Code Symbols shall not be used on any item which is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME which tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

Page xiii

PERSONNEL ASME Boiler and Pressure Vessel Committee Subcommittees, Subgroups, and Working Groups

As of December 31, 1997

MAIN COMMITTEE

D. A. Canonico, *Chair*

G. G. Karcher, *Vice Chair*

J. S. Brzuszkiewicz, *Secretary*

R. W. Barnes

F. P. Barton

D. L. Berger

M. D. Bernstein

M. N. Bressler

W. J. Carter

T. M. Cullen

J. R. Farr

R. E. Feigel

J. G. Feldstein

M. Gold

O. F. Hedden

A. J. Justin

D. F. Landers

W. M. Lundy

J. R. MacKay

T. J. Mawson

T. G. McCarty

G. C. Millman

R. A. Moen

C. C. Neely

C. J. Pieper

R. F. Reedy

B. W. Roberts

F. J. Schaaf, Jr.

A. Selz

K. K. Tam

D. E. Tanner

EXECUTIVE COMMITTEE (MAIN COMMITTEE)

G. G. Karcher, *Chair*

D. A. Canonico, *Vice Chair*
J. S. Brzuszkiewicz, *Secretary*
F. P. Barton
J. R. Farr
J. G. Feldstein
M. Gold
O. F. Hedden
A. J. Justin
J. R. MacKay
T. G. McCarty
T. P. Pastor
T. E. Quaka
R. F. Reedy
A. J. Spencer

HONORARY MEMBERS (MAIN COMMITTEE)

R. D. Bonner
R. J. Bosnak
H. M. Canavan
L. J. Chockie
J. S. Clarke
W. E. Cooper
W. D. Doty
R. C. Griffin
E. J. Hemzy
E. C. Kistner, Jr.
J. E. Lattan
J. LeCoff
F. N. Moschini
C. E. Rawlins
W. E. Somers
L. P. Zick, Jr.

HONORS AND AWARDS COMMITTEE

J. R. MacKay, *Chair*
A. J. Spencer, *Vice Chair*
F. R. Lyons, *Secretary*
F. P. Barton
W. J. Carter
J. G. Feldstein
M. Gold
F. E. Gregor
E. C. Kistner, Jr.
T. P. Pastor
R. F. Reedy

MARINE CONFERENCE GROUP

J. Tiratto, *Chair*

C. F. Banks
L. W. Douthwaite
J. L. Jones
G. F. Wright

CONFERENCE COMMITTEE

D. E. Tanner - Tennessee (*Chair*)
R. D. Reetz - North Dakota (*Vice Chair*)
A. J. Justin - National Board of Boiler and Pressure Vessel Inspectors (*Secretary*)
R. J. Aben, Jr. - Michigan
J. S. Aclaro - Los Angeles, California
E. A. Anderson - Chicago, Illinois
J. Anderson - South Dakota
R. Barkdoll - Washington
F. P. Barton - Virginia
C. Castle - Nova Scotia, Canada
R. R. Cate - Louisiana
L. Chase - Northwest Territories, Canada
R. A. Coomes - Kentucky
J. Corcoran - Connecticut
M. H. Diehl, Jr. - Maryland
D. A. Douin - Illinois
D. Eastman - Newfoundland and Labrador, Canada
G. L. Ebeyer - New Orleans, Louisiana
F. Ellis - New Hampshire
E. Everett - Georgia
P. C. Hackford - Utah
D. Hanrath - North Carolina
J. B. Harlan - Delaware
K. Hynes - Prince Edward Island, Canada
D. T. Jagger - Ohio
D. J. Jenkins - Kansas
M. Kotb - Quebec, Canada
J. P. Larson - Minnesota
K. T. Lau - Alberta, Canada
J. Lemire - California
G. A. Lundberg - Florida
W. C. Lundine - Oregon
M. A. Malek - Maine
I. W. Mault - Manitoba, Canada
H. T. McEwen - Mississippi
A. W. Meiring - Indiana
R. Mile - Ontario, Canada
T. J. Monroe - Oklahoma
Y. Nagpaul - Hawaii
J. D. Payton - Pennsylvania
D. K. Peetz - Missouri

D. C. Price - Yukon Territory, Canada
R. S. Pucek - Wisconsin
T. E. Rennie - Arizona
L. Roussinos - British Columbia, Canada
M. Shuff - West Virginia
R. Snyder - New Jersey
N. Surtees - Saskatchewan, Canada
M. J. Verhagen - Wisconsin
R. B. West - Iowa
M. J. Wheel - Vermont
K. A. White - Nevada
R. K. White - New York
T. F. Wickham - Rhode Island
C. S. Withers - Colorado

SUBCOMMITTEE ON POWER BOILERS (SC I)

J. R. MacKay, *Chair*
M. D. Bernstein, *Vice Chair*
P. D. Stumpf, *Secretary*
D. L. Berger
E. Everett
D. N. French
F. R. Gerety
J. Hainsworth
T. E. Hansen
J. S. Hunter
W. L. Lowry
T. C. McGough
P. A. Molvie
D. K. Parrish
J. T. Pillow
R. G. Presnak
B. W. Roberts
R. D. Schueler, Jr.
R. V. Wielgoszinski
R. L. Williams

Page xiv

Subgroup on Design (SC I)

M. D. Bernstein, *Chair*
R. D. Schueler, Jr., *Vice Chair*
P. A. Molvie, *Secretary*
M. A. Farrugia
J. D. Fishburn
C. F. Jeerings
K. C. Morrison
A. Nassif

N. Surtees
R. V. Wielgoszinski

Subgroup on Fabrication and Examination (SC I)

D. L. Berger, *Chair*
R. E. McLaughlin, *Secretary*
R. W. Boyce
D. N. French
J. Hainsworth
T. E. Hansen
M. H. Iken
J. M. Lyons
J. T. Pillow
M. E. Reese
R. D. Schueler, Jr.
R. F. Slack, Sr.
R. V. Wielgoszinski

Subgroup on General Requirements (SC I)

T. C. McGough, *Chair*
M. D. Bernstein, *Vice Chair*
W. L. Lowry, *Secretary*
D. L. Berger
E. Everett
F. R. Gerety
J. Hainsworth
C. F. Jeerings
J. M. Lyons
R. E. McLaughlin
D. K. Parrish
J. T. Pillow
W. E. Somers
R. L. Williams

Subgroup on Materials (SC I)

B. W. Roberts, *Chair*
C. E. Spaeder, Jr., *Chair*
J. S. Hunter, *Secretary*
T. M. Cullen
D. N. French
J. F. Henry
J. P. Libbrecht
F. Masuyama
J. M. Tanzosh

Subgroup on Piping (SC I)

T. E. Hansen, *Chair*
D. L. Berger
M. D. Bernstein

P. D. Edwards
W. L. Lowry
T. C. McGough
R. G. Presnak
E. Whittle
P. L. Ziegler

SUBCOMMITTEE ON MATERIALS (SC II)

M. Gold, *Chair*
T. M. Cullen, *Vice Chair*
F. R. Lyons, *Secretary*
A. P. Ahrendt
M. N. Bressler
A. Cohen
R. Dirscherl
W. D. Doty
W. D. Edsall
D. Gandy
M. H. Gilkey
J. J. Heger
J. F. Henry
G. C. Hsu
F. Masuyama
E. Michalopoulos
R. A. Moen
R. K. Nanstad
E. G. Nisbett
J. T. Parsons
D. W. Rahoi
B. W. Roberts
E. Shapiro
C. E. Spaeder, Jr.
R. W. Swindeman
J. M. Tanzosh
B. E. Thurgood
A. W. Zeuthen

Subgroup on External Pressure (SC II)

R. W. Mikitka, *Chair*
D. J. Green
D. S. Griffin
E. Michalopoulos
B. R. Morelock
D. Nadel
C. E. Spaeder, Jr.
C. H. Sturgeon

Subgroup on Ferrous Specifications (SC II)

E. G. Nisbett, *Chair*
B. M. Dingman
W. D. Edsall
T. Graham
W. N. Holliday
E. A. Jonas
D. C. Krouse
J. F. Longenecker
W. C. Mack
A. S. Melilli
J. T. Parsons
E. J. Rozic, Jr.
E. Upitis
A. W. Zeuthen
R. H. Zong

Subgroup on International Material Specifications (SC II)

J. T. Parsons, *Chair*
D. C. Agarwal
J. Cameron
R. Dirscherl
W. D. Doty
D. M. Fryer
M. Gold
M. H. Iken
W. M. Lundy
H. Masahisa
T. F. Miskell
F. Osweiller
A. P. Povilonis
R. D. Schueler, Jr.
R. R. Seeley
E. A. Steen
E. Upitis
E. O. Woolridge

Subgroup on Nonferrous Alloys (SC II)

D. W. Rahoi, *Chair*
D. C. Agarwal, *Secretary*
W. R. Apblett
L. G. Coffee
A. Cohen
R. Dirscherl
M. H. Gilkey
G. C. Hsu
M. Katcher
E. Shapiro
L. E. Shoemaker

R. C. Sutherlin

Subgroup on Strength, Ferrous Alloys (SC II)

B. W. Roberts, *Chair*

J. M. Tanzosh, *Secretary*

A. P. Ahrendt

W. R. Apblett

T. M. Cullen

M. Gold

J. J. Heger

C. L. Hoffmann

A. Iseda

F. Masuyama

R. A. Moen

D. W. Raho

C. E. Spaeder, Jr.

R. W. Swindeman

B. E. Thurgood

Subgroup on Strength of Weldments (SC II & SC IX)

C. E. Spaeder, Jr., *Chair*

W. D. Doty

D. W. Raho

B. W. Roberts

C. Robino

W. J. Sperko

J. M. Tanzosh

B. E. Thurgood

Subgroup on Toughness (SC II)

J. M. Barsom

D. A. Hansen

A. Selz

R. S. Vecchio

S. Yukawa

R. Zawierucha

Page xv

SUBCOMMITTEE ON NUCLEAR POWER (SC III)

C. J. Pieper, *Chair*

R. M. Jessee, *Vice Chair*

C. A. Sanna, *Secretary*

J. P. Allen III

Y. Asada

R. W. Barnes

J. N. Baysden

W. H. Borter

E. B. Branch

M. N. Bressler

F. C. Cherny
G. D. Cooper
R. P. Deubler
W. D. Doty
F. R. Drahos
K. Ennis
B. A. Erler
D. Hanrath
C. L. Hoffmann
K.-H. Hsu
D. F. Landers
W. C. LaRochelle
T. J. Mawson
W. N. McLean
R. A. Moen
D. B. Nickerson
R. F. Perrin
R. F. Reedy
M. W. Smith
J. D. Stevenson
R. E. Tome
K. R. Wichman

Subgroup on Containment Systems for Spent Fuel and High-Level Waste Transport Packagings (SC III)

J. D. Stevenson, *Chair*
H. H. Chung
R. R. Doggart
E. L. Farrow
K. Goldmann
R. H. Jones
W. H. Lake
R. W. Lambert
H. W. Lee
P. McConnell
R. E. Nickell
D. J. Nolan
D. T. Raske
T. Saegusa
R. H. Smith
K. B. Sorenson
P. Turula
N. Urabe
C. R. Witt
S. Yukawa

Subgroup on Design (SC III)

R. W. Barnes, *Chair*

E. B. Branch, *Vice Chair*
R. S. Hill III, *Secretary*
Y. Asada
M. N. Bressler
C. W. Bruny
J. R. Cole
G. D. Cooper
R. P. Deubler
N. W. Edwards
R. E. Gimple
D. Hanrath
R. W. Haupt
T. Iida
B. Jarman
D. F. Landers
W. N. McLean
D. B. Nickerson
E. C. Rodabaugh
J. R. Santangelo
G. C. Slagis
J. D. Stevenson
J. H. Wawrzeniak
K. R. Wichman
R. Wray

Working Group on Administration (SG-D) (SC III)

E. B. Branch, *Chair*
R. W. Barnes, *Vice Chair*
R. S. Hill III, *Secretary*
C. W. Bruny
G. D. Cooper
R. P. Deubler
J. T. Land
D. F. Landers
W. N. McLean
D. B. Nickerson
J. R. Santangelo
R. Wray

Working Group on Core Support Structures (SG-D) (SC III)

J. T. Land, *Chair*
R. H. Hansen
K. B. Larsen
J. F. Mullooly
B. L. Silverblatt

Working Group on Dynamic and Extreme Load Conditions (SG-D) (SC III)

R. Wray, *Chair*
A. E. Meligi, *Secretary*

P. L. Anderson
M. K. Au-Yang
R. D. Blevins
G. J. Bohm
D. L. Caldwell
P.-Y. Chen
A. Hadjian
M. Hartzman
W. S. LaPay
H. Lockert
P. R. Olson
R. F. Perry
J. Wallach

Working Group on Piping (SG-D) (SC III)

D. F. Landers, *Chair*
R. S. Hill III, *Vice Chair*
P. Hirschberg, *Secretary*
T. M. Adams
G. A. Antaki
J. R. Cole
A. B. Glickstein
R. W. Haupt
J. C. Hennart
R. D. Hookway
R. B. Jenkins
K. A. Manoly
J. C. Minichiello
S. E. Moore
A. N. Nguyen
D. B. Nickerson
O. O. Oyamada
R. D. Patel
E. C. Rodabaugh
J. R. Santangelo
M. S. Sills
G. C. Slagis
E. A. Wais

Working Group on Pumps (SG-D) (SC III)

D. B. Nickerson, *Chair*
H. L. Brammer
P. Burchett
R. E. Cornman, Jr.
A. A. Fraser
M. Higuchi
G. R. Jones

J. W. Leavitt
J. E. Livingston
R. A. Schussler
H. Tafarrodi
G. K. Vaghasia

Working Group on Supports (SG-D) (SC III)

R. P. Deubler, *Chair*
R. M. Dulin, Jr., *Secretary*
U. S. Bandyopadhyay
F. J. Birch
M. N. Bressler
J. R. Cole
J. C. Finneran, Jr.
R. W. Haupt
J. C. Hennart
A. S. Laurensen
A. Lee
R. J. Masterson
A. E. Meligi
A. N. Nguyen
J. R. Stinson

Working Group on Valves (SG-D) (SC III)

W. N. McLean, *Chair*
E. A. Bake
R. R. Brodin
W. G. Knecht
R. Koester
J. J. McGavin
S. N. Shields
H. R. Sonderegger
J. C. Tsacoyeanes
R. G. Visalli
J. R. Zahorsky

Working Group on Vessels (SG-D) (SC III)

C. W. Bruny, *Chair*
T. K. Burr, Sr.
G. D. Cooper
G. A. Deaver
N. W. Edwards
D. Hanrath
W. J. Heilker
B. Jarman
T. M. Khan
O. Maekawa
K. A. Manoly

A. Merend
G. K. Miller
W. Z. Novak
E. Pelling
H. S. Thornton

Page xvi

Special Working Group on Environmental Effects (SG-D) (SC III)

R. S. Hill III, *Chair*
Y. Asada
W. J. Heilker
C. L. Hoffmann
R. A. Moen
W. Z. Novak
S. Yukawa

Special Working Group on Seismic Piping Rules (SG-D) (SC III)

E. B. Branch, *Chair*
T. M. Adams
G. A. Antaki
R. D. Hookway
J. C. Minichiello
M. S. Sills
E. A. Wais

Subgroup on General Requirements (SC III & SC 3C)

W. C. LaRochelle, *Chair*
K. Ennis, *Secretary*
A. Appleton
J. R. Barbee
J. N. Baysden
L. M. Beason
B. H. Berg
R. E. Kelley
G. S. Korin
A. S. Laurenson
C. Lizotte
M. J. Meyer
M. R. Minick
L. C. Oakes
R. F. Perrin
U. Potapovs
B. B. Scott
D. E. Tanner
D. V. Walshe

Subgroup on Materials, Fabrication, and Examination (SC III)

C. L. Hoffmann, *Chair*
G. P. Milley, *Secretary*

C. W. Allison
D. Doyle
F. R. Drahos
G. M. Foster
G. B. Georgiev
J. E. Harris
R. W. Jackson
R. M. Jessee
C. C. Kim
R. A. Moen
C. J. Pieper
R. R. Seeley
N. M. Simpson
R. C. Soin
W. J. Sperko
K. B. Stuckey
S. Yukawa

Subgroup on Pressure Relief (SC III)

F. C. Cherny, *Chair*
S. F. Harrison, Jr.
E. M. Petrosky
M. W. Smith
A. L. Szeglin
B. S. York
J. R. Zahorsky

Special Working Group on Editing and Review (SC III)

R. F. Reedy, *Chair*
W. H. Borter
M. N. Bressler
R. P. Deubler
B. A. Erler
W. C. LaRochelle
M. W. Smith
J. D. Stevenson
E. O. Woolridge

JOINT ACI-ASME COMMITTEE ON CONCRETE COMPONENTS FOR NUCLEAR SERVICE (SC 3C)

B. A. Erler, *Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
R. M. Attar
A. C. Eberhardt
J. Gutierrez
D. J. Haavik
M. F. Hessheimer
T. E. Johnson
G. R. Murphy

G. R. Murphy
S. F. Putman
B. B. Scott
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Design (SC 3C)

D. G. Adams
A. C. Eberhardt
T. E. Johnson
S. F. Putman
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Materials, Construction, and Examination (SC 3C)

D. J. Haavik, *Chair*
J. F. Artuso
R. M. Attar
B. A. Erler
J. Gutierrez

SUBCOMMITTEE ON HEATING BOILERS (SC IV)

F. P. Barton, *Chair*
P. A. Molvie, *Vice Chair*
B. P. Feder, *Secretary*
R. B. Duggan
W. L. Haag, Jr.
W. M. Hiddleston
J. D. Hoh
K. M. McTague
R. I. Mullican
E. A. Nordstrom
J. L. Seigle
D. E. Tanner
S. V. Voorhees
R. H. Weigel
R. V. Wielgoszinski
J. I. Woodworth
T. L. Bedeaux, *Alternate*

Subgroup on Care and Operation of Heating Boilers (SC IV)

J. I. Woodworth, *Chair*
B. P. Feder, *Secretary*
K. J. Hoey
J. D. Hoh
F. M. Lucas
K. M. McTague

P. A. Molvie
R. I. Mullican
R. H. Weigel
T. F. Wickham
T. L. Bedeaux, Alternate

Subgroup on Cast Iron Boilers (SC IV)

K. M. McTague, *Chair*
R. B. Duggan
R. H. Weigel
T. F. Wickham
J. I. Woodworth
T. L. Bedeaux, Alternate

Subgroup on Water Heaters (SC IV)

W. L. Haag, Jr., *Chair*
T. D. Gantt
W. M. Hiddleston
F. M. Lucas
K. M. McTague
R. I. Mullican
D. Smith
D. E. Tanner
M. A. Taylor

Subgroup on Welded Boilers (SC IV)

P. A. Molvie, *Chair*
T. L. Bedeaux
D. H. Mapes
E. A. Nordstrom
J. L. Seigle
R. F. Slack, Sr.
R. P. Sullivan
D. E. Tanner
R. V. Wielgoszinski

SUBCOMMITTEE ON NONDESTRUCTIVE EXAMINATION (SC V)

T. G. McCarty, *Chair*
J. E. Batey, *Vice Chair*
F. S. Fitzgerald, *Secretary*
A. S. Birks
B. H. Clark, Jr.
W. T. Clayton
R. A. Coomes
N. Y. Faransso
H. C. Graber
O. F. Hedden
G. W. Hembree
F. B. Kovacs

Subgroup on General Requirements/Personnel Qualifications and Inquiries (SC V)

R D. McGuire, *Chair*
J. E. Batey
W. T. Clayton
N. Y. Faransso
H. C. Graber
G. W. Hembree
J. R. MacKay
J. P. Swezy

Subgroup on Surface Examination Methods (SC V)

H. C. Graber, *Chair*
S. J. Akrin
T. Alexander
A. S. Birks
B. H. Clark
R. A. Coomes
G. W. Hembree

Subgroup on Volumetric Methods (SC V)

J. E. Batey, *Chair*
S. J. Akrin
W. T. Clayton
N. Y. Faransso
H. C. Graber
G. W. Hembree
B. Kellerhall
E. K. Kietzman
F. B. Kovacs
R. W. Kruzic
J. F. Manning
W. C. McGaughey
J. R. Mitchell

Working Group on Acoustic Emissions (SG-VM) (SC V)

B. H. Clark, Jr.
P. M. Horrigan
J. F. Manning
J. R. Mitchell

Working Group on Radiography (SG-VM) (SC V)

G. W. Hembree, *Chair*
S. J. Akrin
T. Alexander
J. E. Batey

N. Y. Faransso
H. C. Graber
F. B. Kovacs

Working Group on Ultrasonics (SG-VM) (SC V)

W. T. Clayton, *Chair*
O. F. Hedden
B. Kellerhall
E. K. Kietzman
J. F. Manning
W. C. McGaughey
R. Paillaman
F. J. Sattler
M. L. Shakinovsky

SUBCOMMITTEE ON PRESSURE VESSELS (SC VIII)

T. P. Pastor, *Chair*
K. Mokhtarian, *Vice Chair*
A. J. Roby, *Secretary*
A. P. Ahrendt
V. Bogosian
S. M. Caldwell
W. J. Carter
S. C. Cyr
R. Dirscherl
R. M. Elliott
J. R. Farr
R. E. Feigel
J. G. Feldstein
G. L. Hollinger
M. J. Houle
W. S. Jacobs
G. G. Karcher
G. B. Komora
K. T. Lau
R. W. Mikitka
U. R. Miller
C. C. Neely
K. J. Schneider
A. Selz
J. R. Sims, Jr.
A. J. Spencer
E. A. Steen
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Design (SC VIII)

U. R. Miller, *Chair*

R. E. Knoblock, *Secretary*
M. R. Bauman
M. R. Breach
S. M. Caldwell
N. W. Edwards
J. R. Farr
J. A. Hayward
G. L. Hollinger
W. S. Jacobs
G. G. Karcher
G. B. Komora
R. W. Mikitka
K. Mokhtarian
T. P. Pastor
M. D. Rana
A. Selz
S. C. Shah
J. W. Stokes
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Fabrication and Inspection (SC VIII)

E. A. Steen, *Chair*
K. Mokhtarian, *Vice Chair*
W. J. Bees
R. W. Boyce
S. C. Cyr
R. E. Feigel
H. E. Gordon
M. J. Houle
W. S. Jacobs
R. A. Johnson
A. S. Lester III
F. C. Ouyang
M. J. Rice
W. P. Webb

Subgroup on General Requirements (SC VIII)

R. M. Elliott, *Chair*
A. P. Ahrendt
V. Bogosian
W. J. Carter
W. P. Crow
J. P. Glaspie
C. R. Good
D. B. Kadakia
J. C. Keenan
W. E. Laveck, Jr.

W. E. Laveck, Jr.
A. S. Mann
C. C. Neely
A. S. Olivares
K. J. Schneider
A. J. Spencer

Subgroup on Materials (SC VIII)

R. Dirscherl, *Chair*
D. C. Agarwal
A. P. Ahrendt
J. Cameron
W. D. Doty
W. D. Edsall
M. Katcher
W. M. Lundy
E. E. Morgenegg
E. G. Nisbett
J. T. Parsons
D. W. Rahoi
K. K. Tam
B. K. Thakur

Special Working Group on Heat Transfer Equipment (SC VIII)

G. B. Komora, *Chair*
R. P. Zoldak, *Secretary*
C. F. Andreone
D. E. Bolt
S. M. Caldwell
T. K. Haldas
M. J. Holtz
W. G. Jandrasits
R. Mahadeen
U. R. Miller
F. Osweiller
J. E. Soehrens
A. I. Soler
W. A. Treff
S. Yokell

Page xviii

Special Working Group on High-Pressure Vessels (SC VIII)

J. R. Sims, Jr., *Chair*
P. A. Reddington, *Secretary*
L. P. Antalffy
J. E. Baxter
R. C. Biel
T. B. Boyd
D. J. Burns

P. N. Chaku
E. L. Danfelt
R. E. Feigel
D. M. Fryer
J. L. Heck, Jr.
A. H. Honza
V. T. Hwang
M. M. James
P. Jansson
J. A. Kapp
D. P. Kendall
A. K. Khare
S. C. Mordre
G. J. Mraz
E. H. Perez
L. M. Picqueur
E. D. Roll
W. L. Stewart
J. F. Sullivan
F. W. Tatar

Special Working Group on Toughness (SC VIII)

W. S. Jacobs, *Chair*
J. Cameron
W. D. Doty
D. A. Hansen
G. G. Karcher
G. B. Komora
K. Mokhtarian
J. L. Mooney
C. C. Neely
M. D. Rana
J. W. Stokes

SUBCOMMITTEE ON WELDING (SC IX)

J. G. Feldstein, *Chair*
W. J. Sperko, *Vice Chair*
J. Labrador, *Secretary*
R. Barkdoll
D. A. Bowers
M. L. Carpenter
W. D. Doty
P. D. Flenner
M. J. Houle
R. A. Johnson
W. M. Lundy
R. D. McGuire

J. J. Meyer
A. H. Miller
B. R. Newmark
P. P. Norris
S. D. Reynolds, Jr.
W. K. Scattergood
G. W. Spohn III
M. J. Stanko
J. M. Tanzosh
R. R. Young

Subgroup on Brazing (SC IX)

M. J. Houle, *Chair*
A. S. Artayet
M. L. Carpenter
C. F. Jeerings
A. H. Miller
C. Robino

Subgroup on General Requirements (SC IX)

B. R. Newmark, *Chair*
R. Barkdoll
P. R. Evans
P. C. Filean
R. M. Jessee
D. W. Mann
A. S. Olivares
C. E. Wainwright
R. A. Weiss
K. R. Willens

Subgroup on Materials (SC IX)

M. L. Carpenter, *Chair*
L. P. Connor
P. D. Flenner
R. M. Jessee
A. H. Miller
H. A. Sadler
C. E. Sainz
C. E. Spaeder, Jr.
W. J. Sperko
M. J. Stanko
R. R. Young

Subgroup on Performance Qualification (SC IX)

J. J. Meyer, *Chair*
V. A. Bell
D. A. Bowers
L. P. Connor

R. A. Coomes
P. D. Flenner
G. Herrmann
M. J. Houle
W. M. Lundy
R. D. McGuire
S. R. Nordman
P. P. Norris
W. K. Scattergood
G. W. Spohn III

Subgroup on Procedure Qualification (SC IX)

J. J. Meyer, *Chair*
R. K. Brown, Jr.
R. A. Johnson
A. H. Miller
P. P. Norris
A. S. Olivares
F. C. Ouyang
S. D. Reynolds, Jr.
M. J. Rice
W. K. Scattergood
W. J. Sperko
T. C. Wiesner

SUBCOMMITTEE ON FIBER-REINFORCED PLASTIC PRESSURE VESSELS (SC X)

P. J. Conlisk, *Chair*
D. Eisberg, *Vice Chair*
A. J. Roby, *Secretary*
K. M. Agrawal
F. L. Brown
J. L. Bustillos
T. W. Cowley
T. J. Fowler
S. V. Hoa
L. E. Hunt
J. C. Murphy
A. L. Newberry
D. J. Painter
J. A. Rolston
B. F. Shelley
P. R. Wilt

SUBCOMMITTEE ON NUCLEAR INSERVICE INSPECTION (SC XI)

O. F. Hedden, *Chair*
T. J. Mawson, *Vice Chair*
G. L. Fechter, *Secretary*
C. W. Allison

W. H. Bamford, Jr.
R. L. Beverly
J. M. Bloom
R. W. Boyce
C. D. Cowfer
D. D. Davis
R. L. Dyle
T. N. Epps III
R. E. Gimple
F. E. Gregor
L. B. Gross
K. Iida
C. A. Ireland
R. D. Kerr
D. F. Landers
T. F. Lentz
J. T. Lindberg
G. C. Millman
C. R. Osman
P. C. Riccardella
L. Sage
F. J. Schaaf, Jr.
J. E. Staffiera
R. P. Sullivan
R. W. Swayne
R. J. Tamminga
J. C. Tobin
R. A. Yonekawa

Honorary Members (SC XI)

S. H. Bush
L. J. Chockie
J. P. Houstrup
L. R. Katz
R. R. MacCary

Page xix

Subgroup on Evaluation Standards (SC XI)

W. H. Bamford, Jr., *Chair*
M. Kupinski, *Secretary*
J. M. Bloom
R. C. Cipolla
R. M. Gamble
T. J. Griesbach
P. J. Hijeck
K. Iida
Y. Imamura
J. G. Merkle

S. Ranganath
P. C. Riccardella
D. A. Scarth
W. L. Server
C. A. Tomes
W. A. Van Der Sluys
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa

Working Group on Flaw Evaluation (SG-ES) (SC XI)

R. C. Cipolla, *Chair*
W. H. Bamford, Jr.
M. Basol
J. M. Bloom
E. Friedman
T. J. Griesbach
F. D. Hayes
D. N. Hopkins
K. Iida
Y. Imamura
M. Kupinski
H. S. Mehta
J. G. Merkle
J. S. Panesar
R. K. Qashu
S. Ranganath
D. A. Scarth
T. S. Schurman
W. L. Server
F. A. Simonen
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Working Group on Operating Plant Criteria (SG-ES) (SC XI)

T. J. Griesbach, *Chair*
W. H. Bamford, Jr.
H. Behnke
B. A. Bishop
W. F. Brady
E. Friedman
S. R. Gosselin
E. M. Hackett

E. M. Hackett
P. J. Hijeck
S. D. Leshnoff
P. Manbeck
J. S. Panesar
W. E. Pennell
J. H. Phillips
S. Ranganath
S. T. Rosinski
W. L. Server
E. A. Siegel
F. A. Simonen
T. D. Spry
K. K. Yoon
S. Yukawa

Working Group on Pipe Flaw Evaluation (SG-ES) (SC XI)

D. A. Scarth, *Chair*
G. M. Wilkowski, *Secretary*
W. H. Bamford, Jr.
J. M. Bloom
R. C. Cipolla
N. G. Cofie
S. K. Daftuar
G. H. De Boo
E. Friedman
D. N. Hopkins
K. Iida
H. S. Mehta
J. G. Merkle
J. S. Panesar
D. Quinones
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Subgroup on Liquid-Metal-Cooled Systems (SC XI)

C. G. McCargar, *Chair*
W. L. Chase
S. Hattori
R. Hundal
W. Kwant
J. C. Tobin

Working Group on Liquid-Metal Reactor Covers (SG-LMCS) (SC XI)

W. L. Chase, *Chair*
S. Hattori
R. Hundal

W. Kwant

Subgroup on Nondestructive Examination (SC XI)

R. L. Beverly, *Chair*

N. R. Bentley, *Secretary*

D. C. Adamonis

F. L. Becker

F. T. Carr

C. B. Cheezem

W. T. Clayton

C. D. Cowfer

F. J. Dodd

T. N. Epps III

D. O. Henry

M. R. Hum

S. N. Liu

R. D. McGuire

M. C. Modes

C. R. Osman

F. J. Schaaf, Jr.

J. C. Spanner, Jr.

C. J. Wirtz

Working Group on Personnel Qualification and Surface Visual and Eddy Current Examination (SG-NDE) (SC XI)

C. J. Wirtz, *Secretary*

B. L. Curtis

N. Economos

H. B. Garland

D. O. Henry

H. E. Houserman

J. J. McArdle III

R. D. McGuire

S. A. Redner

M. F. Sherwin

A. L. Smith

D. Spake

J. C. Spanner, Sr.

J. C. Spanner, Jr.

T. V. Tran

Working Group on Pressure Testing (SG-NDE) (SC XI)

G. P. Alexander

T. M. Anselmi

T. B. Basso

J. Boughman

T. R. Bugelholll

R. J. Cimocho

C. E. Jensen

W. N. Keisler
D. Lamond
F. J. Schaaf, Jr.
D. Terao

Working Group on Procedure Qualification and Volumetric Examination (SG-NDE) (SC XI)

C. D. Cowfer, *Chair*
C. E. Larsen, *Secretary*
D. C. Adamonis
F. L. Becker
N. R. Bentley
B. Bevins
F. T. Carr
C. B. Cheezem
W. T. Clayton
S. R. Doctor
F. J. Dodd
T. N. Epps III
B. Kellerhall
G. A. Lofthus
J. K. McClanahan
M. C. Modes
M. Saporito
T. T. Taylor
S. M. Walker

Subgroup on Repairs, Replacements, and Modifications (SC XI)

R. E. Gimple, *Chair*
W. C. Holston, *Secretary*
R. W. Boyce
M. N. Bressler
S. B. Brown
C. E. Hartz
R. A. Hermann
C. A. Ireland
R. D. Kerr
D. F. Landers
R. S. Lewis
T. J. Mawson
M. S. McDonald
R. R. Stevenson
R. P. Sullivan
R. W. Swayne
R. E. Tome
D. E. Waskey
R. A. Yonekawa

Working Group on Design Reconciliation (SG-RR&M) (SC XI)

W. C. Holston, *Chair*
J. T. Conner, *Secretary*
R. W. Boyce
S. B. Brown
J. E. Charnley
T. E. Hiss
E. V. Imbro
D. N. Irvine, Jr.
D. F. Landers
R. W. Swayne
F. Tehranchi
H. J. Thailer
R. E. Tome

Working Group on Responsibilities and Program Requirements (SG-RR&M) (SC XI)

R. A. Yonekawa, *Chair*
R. R. Stevenson, *Secretary*
S. K. Fisher
G. M. Foster
C. E. Hartz
R. S. Lewis
M. S. McDonald
U. Potapovs
S. M. Swilley
A. J. Walcutt
J. Ghergurovich, *Alternate*

Working Group on Welding and Special Repair Processes (SG-RR&M) (SC XI)

D. E. Waskey, *Chair*
R. E. Cantrell, *Secretary*
D. A. Delsignore
A. L. Finney
P. D. Fisher
A. J. Giannuzzi
R. A. Hermann
R. P. Indap
R. D. Kerr
B. R. Newton
P. P. Norris
J. E. O'Sullivan
J. H. Sodergren
K. R. Willens

Subgroup on Water-Cooled Systems (SC XI)

T. F. Lentz, *Chair*
K. Christian, *Secretary*
C. W. Allison

W. J. Briggs
T. R. Bugelhoff
D. D. Davis
A. F. Deardorff
R. L. Dyle
L. B. Gross
T. C. Hinkle
S. D. Kulat
M. P. Lintz
J. E. Staffiera
C. W. Tahnk
R. J. Tamminga
D. Terao
S. M. Walker
R. A. West

Working Group on Concrete Containment (SG-WCS) (SC XI)

W. J. Briggs, *Chair*
B. Talmadge, *Secretary*
H. G. Ashar
K. K. N. Chao
M. J. Ferlisi
H. T. Hill
R. D. Hough
C. N. Krishnaswamy
D. Naus
S. C. Petitgout
C. G. Ranganath

Working Group on Implementation of Risk-Based Examination (SG-WCS) (SC XI)

T. J. Mawson, *Chair*
A. McNeill III, *Secretary*
J. Agold
S. A. Ali
B. A. Bishop
J. W. Connor
A. F. Deardorff
H. Q. Do
R. Fougrousse
S. R. Gosselin
J. T. Lindberg
I. Mach
R. K. Mattu
P. J. O'Regan
J. H. Phillips
F. A. Simonen
T. V. Vo
R. A. West

Working Group on Inspection of Systems and Components (SG-WCS) (SC XI)

R. L. Dyle, *Chair*
G. C. Park, *Secretary*
G. L. Belew
T. W. Brombach
R. Fougerousse
T. C. Hinkle
M. R. Hum
S. D. Kulat
J. T. Lindberg
M. P. Lintz
T. K. McLellan
C. Pendleton
C. M. Ross
C. W. Tahnk
K. B. Thomas
E. Throckmorton
R. A. West
J. Whitman

Working Group on Metal Containment (SG-WCS) (SC XI)

J. E. Staffiera, *Chair*
W. E. Norris, *Secretary*
W. J. Briggs
K. K. N. Chao
M. J. Ferlisi
R. W. Hammelmann
M. P. Lintz
S. C. Petitgout
C. G. Ranganath
G. W. Robin
R. T. Zak

Special Working Group on Low-Temperature Heavy Water Reactors (SG-WCS) (SC XI)

C. D. Cowfer, *Chair*
J. M. Morrison, *Secretary*
B. Awadalla
K. F. Schmidt
P. R. Vormelker
S. H. Zaidi

Working Group on General Requirements (SC XI)

A. T. Roberts III, *Chair*
R. G. Edl, *Secretary*
D. A. Graham
L. B. Gross
C. A. Ireland
D. A. Jackson

R. K. Mattu
L. Sage
R. J. Scott
J. C. Shropshire
R. J. Tamminga

Special Working Group on Editing and Review (SC XI)

R. W. Swayne, *Chair*
R. L. Beverly
L. B. Gross
M. P. Lintz
J. E. Staffiera
C. J. Wirtz

Special Working Group on Plant Life Extension (SC XI)

F. E. Gregor, *Chair*
L. B. Gross, *Secretary*
D. D. Davis
D. A. Graham
D. L. Harrison
M. P. Lintz
P. Manbeck
H. W. Massie, Jr.
D. W. Peltola
D. A. Piccione
C. M. Regan
V. N. Shah
R. J. Tamminga

SUBCOMMITTEE ON TRANSPORT TANKS (SC XII)

A. Selz, *Chair*
P. D. Stumpf, *Secretary*
A. N. Antoniou
S. C. Cyr
K. Ennis
M. Hennemand
C. H. Hochman
G. G. Karcher
P. P. Laluc
G. McRae
M. R. Minick
T. P. Pastor
M. D. Rana
C. M. Serratella
G. R. Stoeckinger
N. Surtees
J. P. Swezy
A. P. Varghese

Subgroup on Design and Materials (SC XII)

M. D. Rana, *Chair*
D. A. Canonico
W. D. Doty
G. G. Karcher
P. P. Laluc
T. P. Pastor
T. A. Rogers
C. M. Serratella
A. P. Varghese
E. Whittle

Subgroup on Fabrication and Inspection (SC XII)

S. V. Voorhees, *Chair*
D. A. Canonico
M. L. Coats
M. Hennemand
D. J. Kreft
G. McRae
M. R. Minick
N. Surtees
J. P. Swezy

Subgroup on General Requirements (SC XII)

C. H. Hochman, *Chair*
T. Alexander
A. N. Antoniou
D. Carter
K. Ennis
M. A. Garrett
J. C. Keenan
F. A. Licari
G. R. Stoeckinger
W. L. White

SUBCOMMITTEE ON BOILER AND PRESSURE VESSEL ACCREDITATION (SC-BPVA)

A. J. Spencer, *Chair*
A. J. Justin, *Vice Chair*
K. I. Baron, *Secretary*
M. B. Doherty
D. A. Douin
P. D. Edwards
R. M. Elliott
C. E. Ford
J. J. Greene

R. C. Howard
B. B. MacDonald
M. L. Sisk
B. C. Turczynski
R. V. Wielgoszinski
R. L. Williams
V. A. Bell, Alternate
V. Bogosian, Alternate
M. A. De Vries, Alternate
J. R. Farr, Alternate
R. G. Friend, Alternate
W. C. LaRochelle, Alternate
A. S. Lester III, Alternate
K. M. McTague, Alternate
G. P. Milley, Alternate
R. E. Muise, Alternate
P. G. Scheckermann, Alternate
N. Surtees, Alternate

SUBCOMMITTEE ON NUCLEAR ACCREDITATION (SC-NA)

T. E. Quaka, *Chair*
R. R. Stevenson, *Vice Chair*
S. Griffin, *Secretary*
C. W. Allison
M. N. Bressler
G. Deily
F. R. Drahos
J. E. Harris
M. Kotb
W. C. LaRochelle
U. Potapovs
H. B. Prasse
A. J. Spencer
G. M. Tolson
L. M. Beason, Alternate
R. W. Boyce, Alternate
S. Dasgupta, Alternate
P. D. Edwards, Alternate
J. P. Ellenberger, Alternate
R. E. Feigel, Alternate
D. Hanrath, Alternate
K. A. Huber, Alternate
A. J. Justin, Alternate
N. C. Kist, Alternate
A. A. Lotfi, Alternate
R. P. McIntyre, Alternate
O. E. Trapp, Staff Representative

SUBCOMMITTEE ON DESIGN (SC-D)

W. J. Carter, *Chair*
F. S. Fitzgerald, *Secretary*
R. W. Barnes
C. Becht IV
O. F. Hedden
R. W. Mikitka
K. Mokhtarian
W. J. O'Donnell
R. D. Schueler, Jr.
M. P. Schwartz
A. Selz

Subgroup on Design Analysis (SC-D)

T. P. Pastor, *Secretary*
P. J. Conlisk
A. G. Eggers
J. L. Hechmer
G. L. Hollinger
D. P. Jones
A. Kalnins
W. J. Koves
T. H. Liu
O. Maekawa
A. Merend
T. V. Narayanan
E. L. Thomas, Jr.

Subgroup on Elevated Temperature Design (SC-D)

C. Becht IV, *Chair*
J. M. Corum, *Secretary*
C. R. Brinkman
R. D. Campbell
D. S. Griffin
R. I. Jetter
C. Lawton
W. J. O'Donnell
D. A. Osage
C. C. Schultz, Jr.
L. K. Severud
D. F. Shaw
A. L. Snow
B. E. Thurgood

Subgroup on Fatigue Strength (SC-D)

C. R. Brinkman
P. R. Donavin
J. A. Hayward

J. L. Hechmer
D. P. Jones
G. Kharshafdjian
C. Lawton
A. Merend
H. H. Ziada

Subgroup on Openings (SC-D)

M. P. Schwartz, *Chair*
R. W. Mikitka, *Secretary*
M. R. Breach
V. T. Hwang
S. C. Lou
R. B. Luney
J. P. Madden
K. C. Morrison
D. R. Palmer
M. D. Rana
E. C. Rodabaugh

Special Working Group on Bolted Flanged Joints (SC-D)

R. W. Mikitka, *Chair*
G. D. Bibel
G. Kharshafdjian
D. L. Kurle
E. Michalopoulos
S. N. Pagay
J. R. Payne
R. W. Schneider
R. D. Schueler, Jr.
A. Selz

SUBCOMMITTEE ON SAFETY VALVE REQUIREMENTS (SC-SVR)

E. C. Kistner, Jr., *Chair*
M. D. Bernstein, *Vice Chair*
U. D'Urso, *Secretary*
J. F. Ball
J. A. Cox
R. D. Danzy
R. J. Doelling
D. A. Douin
R. G. Friend
H. I. Gregg
S. F. Harrison, Jr.
C. F. Laitner
H. D. Michael
C. A. Neumann
J. W. Reynolds

M. Robinson
D. J. Scallan
C. M. Schroepfer
A. J. Spencer
J. C. Standfast
E. A. Steen
L. L. Thompson
J. A. West
T. J. Ferrigan, Alternate

Page xxii

Subgroup on Design (SC-SVR)

R. G. Friend, *Chair*
J. Cahoon, Jr.
R. D. Danzy
D. B. DeMichael
R. J. Doelling
H. I. Gregg
S. R. Irvin
C. F. Laitner
P. R. Sievert
A. J. Spencer
E. A. Steen
T. R. Tarbay
J. A. West

Subgroup on General Requirements (SC-SVR)

M. D. Bernstein, *Chair*
J. F. Ball
V. M. Deluca
D. A. Douin
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson
J. C. Standfast
L. L. Thompson

Subgroup on Testing (SC-SVR)

S. F. Harrison, Jr., *Chair*
S. Cammeresi
J. A. Cox
W. F. Hart
D. M. Papa
D. J. Scallan
C. M. Schroepfer
D. E. Snyder

Page xxiii

ORGANIZATION OF SECTION III

1. GENERAL

Section III consists of Division 1, Division 2, and Division 3. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter "N" for Division 1, by the letter "C" for Division 2, and by the letter "W" for Division 3. The following eleven books make up the three Divisions.

Subsection NCA - General Requirements for Division 1 and Division 2

Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

Division 2 - Code for Concrete Reactor Vessels and Containments

Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

The Division 2 book includes Subsection CC - Concrete Containments and Division 2 Appendices.

The Division 3 book includes Subsections WA and WB for General Requirements and Class TP (Type B) Containment, respectively.

2. SUBSECTIONS

Subsections are divided into Articles, Subarticles, paragraphs, and, where necessary, subparagraphs and subsubparagraphs.

3. ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections followed by Arabic numbers, such as NB-1000. Where possible, Articles dealing with the same topics are given the same number in each Subsection in accordance with the following general scheme:

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination
6000	Testing
7000	Overpressure Protection
8000	Nameplates, Stamping, and Reports

The numbering of Articles and the material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the rules have been prepared with some gaps in the numbering.

4. SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

5. SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as NB-2130, and generally have no text. When a number such as NB-1110 is followed by text, it is considered a paragraph.

6. PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

7. SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as NB-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

8. SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

Page xxiv

9. REFERENCES

References used within Section III generally fall into one of the following four categories.

A. References to Other Portions of Section III

When a reference is made to another Article, Subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to NB-3000 includes all material in Article NB-3000; reference to NB-3200 includes all material in Subarticle NB-3200; reference to NB-3230 includes all paragraphs NB-3231 through NB-3236.

B. References to Other Sections

Other Sections referred to in Section III are:

Section II, Materials. When a requirement for a material, or for the examination or testing of a material, is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II. These references begin with the letter "S."

Section V, Nondestructive Examination. Section V references begin with the letter "T" and relate to the nondestructive examination of material or welds.

Section IX Welding and Brazing Qualifications. Section IX references begin with the letter "Q" and relate to welding and brazing requirements.

Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components. When a reference is made to inservice inspection, the rules of Section XI shall apply.

C. Reference to Specifications and Standards Other Than Published in Code Sections

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials. At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E 71-64 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

² The American National Standards Institute (ANSI) was formerly known as the American Standards Association. Standards approved by the Association were designated by the prefix "ASA" followed by the number of the standard and the year of publication. More recently, the American National Standards Institute was known as the United States of American Standards Institute. Standards were designated by the prefix "ASAS" followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the numbers of the standards have remained unchanged.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by the American Society of Mechanical Engineers and approved by the American National Standards Institute.² When a product is to conform to such a standard, for example ANSI B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NB-3132-1, for example ANSI B16.5-1977. Standards published by the American Society of Mechanical Engineers are available from ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-6, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, 127 Park Street, N.E., Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NB-3132-1, for example MSS SP-6-1963.

(4) Specifications for welding and brazing materials are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33135. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix "SF," for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-620 and API-2000. When documents so designated are referred to in Section III, they are standards published by the American Petroleum Institute.

D. References to Appendices

Two types of Appendices are used in Section III and are designated Mandatory and Nonmandatory.

(1) Mandatory Appendices contain requirements which must be followed in construction; such references are designated by a Roman numeral followed by Arabic numerals. References to II-1100 or XI-3212, for example, relate to the Mandatory Appendices.

(2) Nonmandatory Appendices provide information or guidance for the use of Section III; such references are designated by a capital letter followed by Arabic numerals. A reference to D-1100, for example, relates to a Nonmandatory Appendix.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 INTRO

INTRODUCTION TO SECTION III, DIVISION 2

Page xxv

This document has been prepared by the Joint ACI-ASME Technical Committee on Concrete Pressure Components for Nuclear Service under the sponsorship of the American Concrete Institute and the American Society of Mechanical Engineers. The two Societies have agreed that it will be published as Section III, Division 2, of the ASME Boiler and Pressure Vessel Code. Any changes to it shall be subject to the standardization procedures of the two sponsoring Societies.

The basic materials for this document were provided by two committee reports, one by ACI and the other by ASME. The ACI Committee 349, Criteria for Nuclear Containment Vessels, and the ASME Boiler and Pressure Vessel Code Committee, Section III, Division 2, Subgroup on Concrete Components, submitted their completed committee reports in September 1971 to ACI and ASME, respectively.

These two documents were melded into a single document dated January 17, 1972, and entitled *Proposed Standard - Code*

for Concrete Reactor Vessels and Containments. A second draft was published August 1, 1972, that included new and revised technical material plus administrative agreements reached by the two Societies. Finally, after approval was received from the two Societies, a third and final draft was published in April 1973 for public "trial use and comment" for a period of about one year. During that year numerous public comments and suggestions were received from different segments of industry and regulatory agencies. In addition, two public hearings were held on the Code: the first on October 10, 1973, in Ottawa, Canada, the second on November 28, 1973, in Atlanta, Georgia. The consideration of all comments received as of November 28, 1973, resulted in a series of six Committee Addenda which were incorporated in the Code. The results of these three years of effort by the Committee have culminated in the present document.

The Joint Committee, whose membership includes individuals from both ACI and ASME and many others actively involved in the field, was formed in September 1971. The three primary goals established for the Committee are:

- (a) to establish rules in the form of a code for the design, construction, inspection, and testing of composite concrete and steel components for reactor vessels and containments for nuclear power reactors;
- (b) to interpret these rules when questions arise regarding their intent;
- (c) to periodically update code provisions, making full use of the expedited procedure for revision of standards as necessary.

It is expected that comments and discussions will continue to be received by the Joint Committee for review. Comments shall state clearly which area and wording of the Code is being discussed. Suggested revisions shall be worded as parallel text, giving both the present wording and showing how the proposed changed paragraphs should read, and shall be accompanied by a commentary (including references where appropriate) to support the proposed recommendations. Discussions, commentaries, and committee actions will be printed in the publications of the two Societies. Discussions may be sent to either the ACI or ASME headquarters marked to the attention of the Joint ACI-ASME Committee.

Page xxvii

THE AMERICAN CONCRETE INSTITUTE

The American Concrete Institute was organized in 1905 to provide industry standards in the field of concrete usage. The organization, which was formed as a result of meetings begun during the Engineering Congress at the Louisiana Purchase Exposition in St. Louis in 1904, was initially entitled the National Association of Cement Users. In 1913, the name of the Society was changed to the American Concrete Institute to better fit the actual scope of its activities and aims, which are to further engineering education, scientific investigation, and scientific research by organizing the efforts of its members for a nonprofit, public service in gathering, correlating, and disseminating information for the improvement of the design, construction, manufacture, use, and maintenance of concrete products and structures.

The day-to-day operation of ACI is administered by an Executive Director, under general supervision of its 18-member Board of Direction, which assigns a part of its administrative duties to standing committees, the ACI Standards Board, and various technical committees.

ACI - TECHNICAL ACTIVITIES COMMITTEE

The Technical Activities Committee, which is appointed by the Board of Direction, is responsible for Institute technical publications, review of standards, the technical program at conventions, and continuing studies of technical committees, from which arise recommendations for the activities, and the formation or discharge of these groups. TAC members are selected by the ACI Board to represent ACI's varied interests.

ACI - STANDARDS BOARD

The Standards Board, also appointed by the Board of Direction, is responsible for matters of policy, procedure, and appeal pertaining to ACI Standards. All proposed new standards or revisions to existing standards, including minority reports from sponsoring technical committees, are forwarded to the Standards Board through the Technical Activities Committee. On release by the Standards Board, these are published, and after ratification by letter ballot of the ACI membership at large are then available for public use. The primary functions of the Standards Board are to verify that proper standardization procedures have been followed and to rule on matters of policy as related to standards.

ACI - TECHNICAL AND EDUCATIONAL COMMITTEES

Much of the important work of the American Concrete Institute is performed by technical committees that prepare committee

reports and standards. Technical committees, composed of volunteer personnel, develop ACI recommendations in their respective fields. Their work, subject to review and approval by the Board of Direction through the Technical Activities Committee and the Standards Board, forms the basis for Institute Standards.

Educational committees, also composed of volunteer personnel, develop seminars, workshops, curriculum guides, and student manuals to further ACI's involvement in education. Their work, subject to review and approval by the ACI Educational Activities Committee, forms the basis for Institute manuals and training programs.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 CC-1000

ARTICLE CC-1000 INTRODUCTION

Page 1

SUBSECTION CC

CONCRETE CONTAINMENTS

(PRESTRESSED OR REINFORCED)

Page 3

CC-1100 SCOPE AND GENERAL REQUIREMENTS

CC-1110 SCOPE

Subsection CC establishes rules for material, design, fabrication, construction, examination, testing, marking, stamping, and preparation of reports for prestressed and reinforced concrete containments. The containments covered by this Subsection shall include the following:

- (a) structural concrete pressure resisting shells and shell components;
- (b) shell metallic liners;
- (c) penetration liners extending the containment liner through the surrounding shell concrete.

CC-1120 GENERAL REQUIREMENTS

The rules of Division 1 shall apply as required in this Subsection for parts and appurtenances not backed by structural concrete for load carrying purposes. Those parts or appurtenances stamped in accordance with Division 2 shall meet the requirements of Subsection NCA, CC-1000, CC-6000, CC-7000, and CC-8000 in lieu of the corresponding requirements of Division 1. Those parts or appurtenances stamped in accordance with Division 1 shall meet all the requirements of Division 1 and NCA-2134(e).

CC-1130 RULES FOR CONCRETE CONTAINMENTS

Containments having a Design Pressure greater than 5 psi (35 kPa) which are classified as Subsection CC containments shall be constructed in accordance with the rules of this Subsection.

CC-1140 BOUNDARIES OF JURISDICTION

(a) The jurisdiction of this Subsection for the containment shall conform to the requirements of NCA-3254.2 supplemented by the provisions below.

(b) When a structural concrete support is constructed as an integral part of the containment, it shall be included within the jurisdiction of these criteria.

July 1, 1998
American Society Of Mechanical Engineers
SEC III D2 CC-2000
ARTICLE CC-2000 MATERIAL

Page 7

CC-2100 GENERAL REQUIREMENTS FOR MATERIAL

CC-2110 SCOPE

CC-2111 Terms

- (a) The term *material* as used in this Subsection is defined in NCA-1220.
- (b) The terms *Metallic Material Manufacturer* and *Material Supplier* are defined in NCA-3800.
- (c) The terms *Nonmetallic Material Manufacturer* and *Constituent Supplier* are defined in NCA-3900.
- (d) The terms *pressure retaining* and *load bearing materials* apply to items such as concrete, reinforcing material, prestressing material, liners, attachments to liners and embedment anchors.
- (e) The requirements of this Article make reference to the term *thickness*. For the purpose intended, the following definitions of nominal thickness apply:
 - (1) *plate* - the thickness is the dimension of the short transverse direction
 - (2) *forgings* - the thickness is the dimension defined as follows:
 - (a) *hollow forgings* - the nominal thickness is measured between the inside and outside surfaces (radial thickness)
 - (b) *disk forgings* (axial length less than the outside diameter) - the nominal thickness is the axial length
 - (c) *flat ring forgings* (axial length less than the radial thickness) - for axial length ≤ 2 in. (51 mm), the axial length is the nominal thickness; for axial length > 2 in. (51 mm), the radial thickness is the nominal thickness
 - (d) *rectangular solid forgings* - the least rectangular dimension is the nominal thickness
 - (3) *castings* - the thickness shall be as defined in SA-613

CC-2112 Special Rules

Metallic material for parts and appurtenances which are not backed by concrete for load carrying purposes shall meet the requirements of Division 1. Material for attachments to parts meeting the requirements of Division 1 shall meet the requirements of this Article.

CC-2120 PRESSURE RETAINING AND LOAD BEARING MATERIAL

CC-2121 Permitted Material Specifications

- (a) Concrete constituents and concrete shall conform to the requirements of CC-2200. Metallic material for pressure retaining and load bearing purposes shall conform to the requirements of one of the specifications included in this Article or in Table I-1.2, Table I-2.2, and Table I-2.3 of Appendix I, and to all the special requirements of this Article which apply to the product form in which the material is used.
- (b) Metallic or nonmetallic material and constituents other than those described in (a) above shall not be used until the requirements of Appendix IV have been met.

(c) The requirements of this Article only apply to items associated with the pressure retaining or load bearing function of a component. Other construction equipment or apparatus such as forms, tie wires, chairs, supports, form ties, grease and grout fittings, retaining caps, seals, packing, and gaskets are not covered by this Article.

(d) Welding and brazing materials used in the manufacture of items shall comply with an SFA specification, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article.

CC-2122 Special Requirements

CC-2122.1 Metallic Materials.

The special requirements stipulated in this Article shall apply in lieu of the requirements of the material specifications wherever these special requirements conflict with the material specification requirements. Where the special requirements include an examination, test, or treatment which is also required by the material specification, the examination, test, or treatment need be performed only once. All required examinations, tests, and treatments shall be performed as specified for each metallic product in this Article and may be performed by either the Metallic Material Manufacturer, Fabricator, or Constructor, as provided in CC-4121.

CC-2122.2 Nonmetallic Materials and Constituents.

All required examinations, tests, and treatments shall be performed as specified in this Article and

Page 12

may be performed by either the organization providing concrete constituents, the Nonmetallic Material Manufacturer, or the applicable Fabricator or Constructor, as provided in CC-4121.

CC-2122.3 Authorized Inspector.

Reports of all required examinations, tests, and treatments shall be made available to the Authorized Inspector of the applicable Fabricator or Constructor and provisions made for inspections as required by the Authorized Inspector.

CC-2123 Size Ranges of Metallic Material

Metallic material outside the limits of size or thickness given in any specification allowed by this Division may be used if the material is in compliance with the other requirements of the specification and no size limitation is given in the rules for construction. In those specifications in which chemical composition and mechanical properties are indicated to vary with size or thickness, any material outside the specification range shall be required to conform to the composition and mechanical properties shown for the nearest specified range.

CC-2130 CERTIFICATION OF MATERIAL

CC-2131 Introduction

A Certified Material Test Report (CMTR) or a Certificate of Compliance shall be provided for all metallic materials, nonmetallic materials, and concrete constituents in accordance with the following subparagraphs.

CC-2131.1 Certified Material Test Reports.

Certified Material Test Reports (CMTR) shall be provided for concrete constituents, plastic concrete, reinforcing system material, prestressing system material, liner material, other load bearing and pressure retaining material, and welding and brazing material, and shall include the following:

(a) certified reports of the actual results of all required chemical analyses, physical tests, mechanical tests, examinations (including radiographic film), repairs, and heat treatments (including times and temperatures) performed on the material;

(b) a statement listing any chemical analyses, tests, examinations, and heat treatment required by the material specification, which were not performed;

(c) a statement giving the manner in which the material is identified, including specific marking;

(d) the Manufacturer of plastic concrete shall provide a Certified Material Test Report consisting of a batch ticket with each individual batch of concrete. The information on the batch ticket shall include the weight or volume of constituents as provided in CC-4222.2.

CC-2131.2 Certificate of Compliance.

A Material Manufacturer's Certificate of Compliance with the material specification, grade, class, and heat treatment condition, as applicable, may be provided in lieu of a Certified Material Test Report for metallic material $\frac{3}{4}$ in. nominal pipe size and less (pipe, tube, flanges, and fittings), and bolting 1 in. nominal diameter and less. The Certificate of Compliance shall contain a description of the marking of the material.

CC-2131.3 Concrete Constituents

CC-2131.3.1 Laboratory Accreditation.

The tests required by CC-2200 shall be performed by an accredited laboratory that complies with ASTM C 1077, Standard Practice for Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation.¹

CC-2131.3.2 Certified Material Test Reports.

The Certified Material Test Reports (CMTR) for concrete constituents shall meet the following requirements.

(a) The CMTR for aggregate shall certify that the aggregates are from the same source (natural deposit) as the aggregate qualified in accordance with CC-2222.

(b) The CMTR for cement shall include the standard chemical and physical test results in accordance with ASTM C 150, Specification for Portland Cement, or ASTM C 595, Specification for Blended Hydraulic Cement, and any optional requirements in the Construction Specification. Sampling and testing frequencies shall meet the requirements of ASTM C 183, Sampling Hydraulic Cement.

(c) The CMTR for air-entraining admixtures shall include infrared spectrophotometry traces, percent solids, percent chlorides, and pH of each manufacturing lot. A statement shall be included to certify that these tests or other included tests have established equivalence with admixtures tested in accordance with ASTM C 260, Air-Entraining Admixtures for Concrete.

(d) The CMTR for fly ash and pozzolans shall include the standard chemical and physical test results in accordance with ASTM C 618, Fly Ash and Raw or Calcined Natural Pozzolans for Use in Portland Cement Concrete, and any requirements in the Construction Specification.

¹ Such laboratory inspections can be provided by the Cement and Concrete Reference Laboratory (CCRL) of the National Institute of Standards and Technology, with accreditation programs provided by the National Voluntary Laboratory Accreditation Program (NVLAP), American Association for Laboratory Accreditation (AALA), and American Materials Engineering Council (CEMC).

Sampling and testing frequencies shall meet the requirements of ASTM C 311, Sampling and Testing Fly Ash for Use as an Admixture in Portland Cement Concrete.

(e) The CMTR for chemical admixtures shall include infrared spectrophotometry traces, percent solids, and percent chlorides of each manufacturing lot. A statement shall be included to certify that these tests or other included tests have established equivalence with admixtures tested in accordance with ASTM C 494, Chemical Admixtures for Concrete, or ASTM C 1017, Chemical Admixtures for Use in Producing Flowing Concrete.

(f) A CMTR for water and ice is not required.

CC-2131.4 Personnel Qualification.

Laboratory testing personnel performing tests required by CC-2000 may be qualified using appropriate industry or laboratory standards. The qualification and certification rules of Appendix VII are not mandatory for personnel performing tests required in CC-2200.

CC-2132 Certification by Fabricator or Constructor

The Fabricator or Constructor shall provide a Certified Material Test Report for all operations performed by him or his subcontractors. The Fabricator or Constructor shall certify that the contents of his report are correct and accurate and that all operations performed by him or his subcontractors are in compliance with the requirements of the material specification and this Subsection. Alternatively, the Fabricator or Constructor shall provide a Certified Material Test Report for those operations he performed and a Certified Material Test Report from each of his subcontractors for operations they performed. Material identification, including any marking code, shall be described in the Certified Material Test Report.

CC-2140 DETERIORATION OF MATERIAL AND COATINGS DURING SERVICE

Consideration of deterioration of material caused by service is outside the scope of this Subsection. It is the responsibility of the Owner to select material suitable for the conditions stated in the Design Specifications (NCA-3250), with specific attention being given to the effects of service conditions upon the properties of the material.

CC-2150 HEAT TREATMENT TO ENHANCE MECHANICAL PROPERTIES OF METALLIC MATERIAL

CC-2151 Carbon and Low Alloy Steels

Carbon and low alloy steels may be heat treated by quenching and tempering to enhance notch toughness. Postweld heat treatment of the material at a temperature of not less than 1100°F (593°C) may be considered to be the tempering phase of the heat treatment when postweld heat treatment is a requirement of CC-4500.

CC-2152 Procedures for Heat Treatment of Material

When heat treating temperature or time is required by the material specification and the rules of the Subsection, the heat treating shall be performed in temperature-surveyed and -calibrated furnaces or shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. Heat treating shall be performed under furnace loading conditions such that the heat treatment is in accordance with the material specification and the rules of this Subsection.

CC-2153 Steels for Prestressing

Wire, strand, or bars for prestressing systems may be heat treated, as in stress relieving, under load to enhance stress relaxation properties. Quenching and tempering treatments to produce specific mechanical properties are not permitted.

CC-2160 DIMENSIONAL STANDARDS

Dimensions of standard items for pipe, tube, fittings, valves, flanges, and gaskets shall comply with the standards and specifications listed in Table CC-2160-1, unless otherwise specified in the Construction Specification or designated in the Design Drawings.

CC-2200 CONCRETE AND CONCRETE CONSTITUENTS

CC-2210 INTRODUCTION

This Subarticle establishes qualification requirements for concrete constituents and plastic concrete. Testing to establish conformance to the requirements shall be performed prior to use. The required tests in CC-2200 may be performed by the organizations providing

concrete constituents, the Nonmetallic Material Manufacturer, or applicable Fabricator or Constructor. The quality control tests described in CC-5200 shall be performed by the Nonmetallic Material Manufacturer, or applicable Fabricator or Constructor.

**TABLE CC-2160-1
DIMENSIONAL STANDARDS¹**

Standard	Designation
Pipes and Tubes	
Welded and Seamless Wrought Steel Pipe	ASME B36.10m
Stainless Steel Pipe	ASME B36.19m
Fittings, Flanges, and Gaskets	
Pipe Flanges and Flanged Fittings	ASME B16.5
Factory Made Wrought Steel Butt welding Fittings	ASME B16.9 [Note (2)]
Forged Steel Fittings, Socket-Welding and Threaded	ASME B16.11
Ring-Joint Gaskets and Grooves for Steel Pipe Flanges	ASME B16.20
Nonmetallic Flat Gaskets for Pipe Flanges	ASME B16.21
Butt welding Ends	ASME B16.25
Wrought Steel Butt welding Short Radius Elbows and Returns	ASME B16.28
Stainless Steel Butt welding Fittings	MSS SP-43
Steel Pipeline Flanges	MSS SP-44
Factory Made Butt welding Fittings for Class 1 Nuclear Piping Applications	MSS SP-87
Large Diameter Carbon Steel Flanges	API 605
Standard for Steel Pipe Flanges for Waterworks Services	AWWA C207
Bolting	
Square and Hex Bolts and Screws (Inch Series), Including Hex Cap Screws, and Lag Screws	ASME B18.2.1
Square and Hex Nuts (Inch Series)	ASME B18.2.2
Socket Cap, Shoulder, and Set Screws (Inch Series)	ASME B18.3
Threads	
Unified Inch Screw Threads (UN and UNR Thread Form)	ASME B1.1a
Pipe Threads — General Purpose (Inch)	ASME B1.20.1
Gaging for Dryseal Pipe Threads (Inch)	ASME B1.20.5
Valves	
Valves — Flanged, Threaded, and Welded End	ASME B16.34

NOTES:

- (1) Standards incorporated in this Division by reference. The names of the sponsoring organizations are shown in the Reference Materials portion of this Division.
- (2) Analysis in accordance with ASME B16.9, paragraph 2.2, is acceptable only for caps and reducers.

TABLE CC-2160-1 DIMENSIONAL STANDARDS¹

CC-2211 General Requirements

- (a) Consideration shall be given to minimizing the temperature rise in concrete due to heat of hydration, and to proper strength development with respect to formwork removal, construction stresses, and application of prestress.
- (b) The concrete and its constituents shall be sufficiently investigated prior to use to ensure acceptable creep and other properties under the environmental conditions and the long-term requirements described in the Construction Specification.
- (c) The water-cement ratio is the ratio of the weight of water to the weight of cement. Where mineral admixture is used, the weight of mineral admixture shall be added to the weight of cement to determine the water-cement ratio.

CC-2212 Substitutions

When an alternate constituent must be substituted for a previously qualified constituent as an alternative to a complete requalification in accordance with CC-2200, the following requirements apply.

(a) The alternate concrete constituent shall meet the requirements of qualification tests required by CC-2220.

Page 15

(b) Prior to use, the Designer shall confirm the similarity and compatibility of the alternate constituent with the other previously qualified constituents.

(c) Prior to use, the Designer shall establish the need for and extent of testing required by CC-2230.

CC-2220 CONCRETE CONSTITUENTS

CC-2221 Cement

CC-2221.1 Material Requirements.

Cement shall conform to the requirements of ASTM C 150, Specification for Portland Cement, Type I, Type II, Type IV, Type V, or ASTM C 595, Specification for Blended Hydraulic Cements, Type IP, Type IP (MS) or Type IP (MH).

CC-2222 Aggregates

CC-2222.1 General.

Aggregates shall conform to the requirements of ASTM C 33, Specification for Concrete Aggregates, with the following additional requirements.

(a) Gradation may be adjusted in the Construction Specification provided the requirements of CC-2231.1 are met. Coarse aggregate gradations must require at least two separate gradation sizes if aggregate larger than 1 in. is specified.

(b) Coarse and fine aggregate for normal weight concrete, placed by the preplaced aggregate method, shall meet the gradation requirements specified in ACI 304, Recommended Practice for Measuring, Mixing, Transporting, and Placing Concrete.

(c) Coarse aggregate shall be rounded or cubical and shall contain less than 15% (by weight) flat and elongated particles as determined by CRD-C 119, Method of Test for Flat and Elongated Particles in Coarse Aggregate.

NOTE: A *flat particle* is defined as one having a ratio of width to thickness greater than three; an *elongated particle* is defined as one having a ratio of length to width greater than three.

(d) A petrographic examination in accordance with ASTM C 295, Recommended Practice for Petrographic Examination of Aggregates for Concrete, shall be performed.

(e) Based upon the petrographic examination results, additional tests may be required using ASTM C 227, Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method); ASTM C 289, Potential Reactivity of Aggregates (Chemical Method); ASTM C 342, Potential Volume Change of Cement-Aggregate Combinations; or ASTM C 586, Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregate (Rock Cylinder Method), as applicable.

(f) The water soluble chloride content of the aggregate shall be established by the methods described in ASTM D 1411, Water Soluble Chlorides Present as Admixes in Graded Aggregate Road Mixes.

(g) For reinforced concrete containment designed in accordance with CC-3521.1.1, the maximum loss of weight of the coarse aggregate, when tested in accordance with ASTM C 131, Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine, shall not exceed 40%.

(h) The maximum size of coarse aggregate shall not be larger than one-fifth of the narrowest dimension of the finished wall or slab, nor larger than three-fourths of the minimum clear spacing between individual reinforcing bars or wires, bundles of bars, or prestressing ducts, or embedments.

CC-2222.2 Heavy Weight Aggregates.

Heavy aggregates required for concrete denser than 160 lb/cu ft shall conform to one of the following:

(a) ASTM C 637, Specification for Aggregates for Radiation Shielding Concrete; or

(b) requirements as provided in the Construction Specification for steel punchings, sheared reinforcing steel, iron shot, or materials containing boron used as concrete aggregate.

CC-2223 Mixing Water

CC-2223.1 General Requirements.

Water for mixing and for manufacturing ice shall be clean, with a total solids content of not more than 2000 ppm as measured in accordance with ASTM D 1888 tests for particulate and dissolved matter in water. The mixing water and ice shall be tested for chlorides (Cl⁻) as determined by ASTM D 512, Chloride Ion in Industrial Water and Industrial Waste Water.

CC-2223.2 Additional Requirements.

A comparison of the proposed mixing water properties shall be made with distilled water by determining compressive strength in accordance with ASTM C 109, Compressive Strength of Hydraulic Cement Mortars (Using 2 in. or 50 mm Cube Specimens). The results obtained for the proposed mixing water shall not be lower by more than 10% of those obtained for distilled water.

CC-2224 Admixtures

CC-2224.1 General Requirements for Admixtures.

When admixtures are to be used, the Construction Specification shall specify the type, quantity, and any

Page 16

additional limitations. Admixtures containing more than 1%, by weight, of chloride ions shall not be used for prestressed containments.

CC-2224.2 Air-Entraining Admixtures.

Air-entraining admixtures shall conform to the requirements of ASTM C 260, Air-Entraining Admixtures for Concrete.

CC-2224.3 Chemical Admixtures.

Chemical admixtures shall conform to the requirements of ASTM C 494, Chemical Admixtures for Concrete.

CC-2224.4 Mineral Admixtures.

When mineral admixtures (fly ash and pozzolan) are used, the Construction Specification shall specify the type, source, and any additional limitations, such as a maximum permitted amount of available alkalis and/or chloride ions.

Fly ash and pozzolanic admixtures shall conform to the requirements of ASTM C 618, Fly Ash and Raw or Calcined Natural Pozzolans for Use in Portland Cement Concrete.

CC-2224.5 Special Grouting Admixtures, Including Grout Fluidifier.

When special grouting admixtures, including grout fluidifier, are used, the Construction Specification shall specify the type and any additional limitations, such as a maximum permitted amount of available alkalis and/or chloride ions. In the preparation of cement grout, other types of admixtures, including those containing gels or gelling agents for the purpose of controlling loss of water from the grout, may be used, if permitted in the Construction Specification.

CC-2224.6 Grout Fluidifier.

Grout fluidifier for use with preplaced aggregate concrete shall conform to the requirements of ASTM C 937, Grout Fluidifier for Preplaced Aggregate Concrete.

CC-2224.7 Chemical Admixtures for Use in Producing Flowing Concrete.

Chemical admixtures for use in producing flowing concrete shall conform to the requirements of ASTM C 1017, Chemical Admixtures for Use in Producing Flowing Concrete.

CC-2230 CONCRETE MIX DESIGN

CC-2231 Concrete Properties

CC-2231.1 General Requirements.

The properties of concrete which influence the design of the containment shall be established in the Construction Specification. Concrete mixes will normally be established on the basis of strength, workability limits, and heat rise.

**TABLE CC-2231-1
CONCRETE PROPERTIES**

Property	Test Method
Slump	ASTM C 143
Compressive strength	ASTM C 39
Flexural strength	ASTM C 78
Splitting tensile strength	ASTM C 496
Static modulus of elasticity	ASTM C 469
Poisson's ratio	ASTM C 469
Coefficient of thermal conductivity	CRD-C 44
Coefficient of thermal expansion	CRD-C 39
Creep of concrete in compression	ASTM C 512
Shrinkage coefficient (length change of cement-mortar and concrete)	ASTM C 157
Density (specific gravity)	ASTM C 642
Maximum temperature rise in concrete	CRD-C 36

TABLE CC-2231-1 CONCRETE PROPERTIES

CC-2231.2 Chloride Content.

The water soluble chloride content of the concrete shall not exceed 0.15% by weight of portland cement for reinforced concrete containments and prestressed concrete containments where the prestressing tendons are placed in ducts and protected by cement grout or a permanent corrosion prevention coating in accordance with CC-2442.3.2. The water soluble chloride content of the concrete shall not exceed 0.06% by weight of portland cement for concrete that will be placed in direct contact with prestressing steel. The chloride content of the water and ice (CC-2223), aggregate (CC-2222), and liquid admixtures (CC-2224) shall be determined separately and combined to determine the total water soluble chloride content of the concrete.

CC-2231.3 Alkali Content.

If aggregate examination and testing [CC-2222.1(c) and (d)] indicates the presence of material known to be capable of participating in alkali-aggregate reaction, the Construction Specification shall establish an appropriate test program which will provide a rational basis to establish the suitability of each concrete constituent. Any additional limitation shall then be established in the Construction Specification.

CC-2231.4 Specified Properties

(a) The applicable concrete properties given in Table CC-2231-1 shall be defined in the Construction Specification. Testing shall be performed prior to construction with the exception of creep tests conforming to ASTM C 512, Standard Test Method for Creep of Concrete in Compression. Creep tests shall be completed prior to the start of prestressing. Testing required as a result

Page 17

of changes in concrete proportions or constituents shall be performed as soon as the change is initiated.

(b) The Construction Specification shall specify the age, strength, and temperature at which the applicable properties listed in Table CC-2231-1 shall be obtained and any environmental or design conditions which apply. If properties other than those listed in Table CC-2231-1 are required, they shall be defined in the Construction Specification.

CC-2231.5 Physical Properties

(a) Where the Construction Specification includes maximum allowable creep limits (rate and total), tests shall be performed at least for the limiting combination of stress-strength ratios, ages of loading, temperature levels, and cycles stated in the Construction Specification. The creep test procedure shall be based on ASTM C 512, Standard Test Method for Creep of Concrete in Compression, with modifications for specimen curing and sealing, and for testing temperatures as described in the Construction Specification.

(b) Where the Construction Specification defines an allowable range of secant moduli of elasticity, Poisson's ratios, and loading rates, concrete specimens shall be tested at those loading rates and the experimental values determined. The testing procedures and acceptance standards shall be based on ASTM C 469, Method of Test for Static Young's Modulus of Elasticity and Poisson's Ratio in Compression of Cylindrical Concrete Specimens, with suitable modifications.

CC-2231.6 Thermal Properties.

When required by the Construction Specification, the effect of thermal cycles on concrete properties shall be determined by the test standards described therein.

CC-2231.7 Durability

CC-2231.7.1 Concrete Subject to Freezing Temperatures.

Concrete that, after curing, will be subject to freezing temperatures while wet shall have an air content within the limits of Table CC-2231-2 and the water-cement ratio shall not exceed 0.50 by weight. For specified compressive strength f' of 5000 psi or greater, the air content indicated in Table CC-2231-2 may be reduced 1%.

CC-2231.7.2 Watertight Concrete.

Concrete that is intended to be watertight shall have a maximum water-cement ratio of 0.50 for exposure to fresh water and 0.45 for exposure to brackish or sea water.

CC-2231.7.3 Sulfate Resisting Concrete.

Concrete to be exposed to sulfate-containing solutions shall conform to the requirements of Table CC-2231.7.3-1.

**TABLE-CC-2231-2
CONCRETE AIR CONTENT FOR VARIOUS
SIZES OF COARSE AGGREGATES**

Nominal Maximum Size of Coarse Aggregate, in.	Total Air Content (volume), % [Notes (1), (2)]
$\frac{3}{8}$	6
$\frac{1}{2}$	5.5
$\frac{3}{4}$	5
1	4.5
$1\frac{1}{2}$	4.5
2	4
3	3.5

NOTES:

- (1) Air content shall not vary more than 1.5% from the listed value.
- (2) These air contents apply to total mix, as for the preceding aggregate sizes. When testing these contents, however, aggregate larger than $1\frac{1}{2}$ in. is removed by hand-picking or sieving and air content is determined on the minus $1\frac{1}{2}$ in. fraction of mix. (Tolerance on air content applies to this value.) Air content of total mix is computed from value determined on the minus $1\frac{1}{2}$ in. fraction.

TABLE CC-2231-2 CONCRETE AIR CONTENT FOR VARIOUS SIZES OF COARSE AGGREGATES

CC-2231.7.4 Corrosive Protection.

For protection of concrete exposed to brackish or sea water or frequent spray from these sources, the water-cement ratio shall not exceed 0.40 except that if the minimum concrete cover required by CC-3534.1 is increased by 0.5 in.

ratio shall not exceed 0.40 except that if the minimum concrete cover required by CC-3534.1 is increased by 0.5 in. (13 mm), the water-cement ratio may be increased to 0.45.

CC-2232 Selection of Concrete Proportions

CC-2232.1 Introduction.

Proportions of materials for concrete shall be established to provide:

- (a) workability and consistency to permit concrete to be worked readily into forms and around reinforcement under conditions of placement to be employed, without segregation or excessive bleeding;
- (b) resistance to special exposures as required by CC-2231.7;
- (c) conformance with the strength test requirements of CC-5232.3.

CC-2232.2 Different Materials.

Where different materials are to be used for different portions of proposed work, each combination shall be evaluated.

CC-2232.3 Basis of Selection.

Concrete proportions, including water-cement ratio, shall be established on the basis of field experience and/or trial mixtures with materials to be employed, except as required by CC-2231.7.

Page 18

**TABLE CC-2231.7.3-1
REQUIREMENTS FOR CONCRETE EXPOSED TO SULFATE-CONTAINING SOLUTIONS**

Sulfate Exposure	Water Soluble Sulfate (SO ₄) in Soil, Percent by Weight	Sulfate (SO ₄) in Water, ppm	Cement Type (CC-2221.1 and CC-2224.2.2)	Maximum Water-Cement Ratio, by Weight [Note (1)]
Negligible	0.00–0.10	0–150	...	...
Moderate [Note (2)]	0.10–0.20	150–1500	II, IP(MS), V	0.50
Severe	0.20–2.00	1500–10,000	V	0.45
Very Severe	Over 2.00	Over 10,000	V plus pozzolan [Note (3)]	0.45

NOTES:

- (1) A lower water-cement ratio or higher strength may be required for watertightness or for protection against corrosion of embedded items or freezing and thawing.
- (2) Seawater.
- (3) Pozzolan that has been determined by test or service record to improve sulfate resistance when used in concrete containing Type V cement.

TABLE CC-2231.7.3-1 REQUIREMENTS FOR CONCRETE EXPOSED TO SULFATE-CONTAINING SOLUTIONS

CC-2233 Proportioning on the Basis of Field Experience and/or Trial Mixtures

CC-2233.1 Standard Deviation.

Standard deviation shall be calculated using the methods of ACI 214, Recommended Practice for Evaluation of Strength Test Results of Concrete.

CC-2233.1.1 Test Record Requirements.

Where a concrete production facility has test records, a standard deviation shall be established. Test records from which a standard deviation is calculated shall:

(a) represent materials, quality control procedures, and conditions similar to those expected, and changes in materials and proportions within the test records shall not have been more restricted than those for proposed work;

(b) represent concrete produced to meet a specified strength or strengths f'_c within 1000 psi (6.9 MPa) of that specified for proposed work;

(c) consist of at least 30 consecutive tests or two groups of consecutive tests totaling at least 30 tests as defined in CC-5232.3.2(a), except as provided in CC-2233.1.2.

CC-2233.1.2 Alternative Test Record Requirements.

Where a concrete production facility does not have test records meeting the requirements of CC-2233.1.1, but does have a record based on 15 to 29 consecutive tests, a standard deviation may be established as the product of the calculated standard deviation and modification factor of Table CC-2233.1.2-1. To be acceptable, the test record must meet requirements (a) and (b) of CC-2233.1.1, and represent only a single record of consecutive tests that span a period of not less than 45 calendar days.

**TABLE CC-2233.1.2-1
MODIFICATION FACTOR FOR STANDARD DEVIATION
WHEN LESS THAN 30 TESTS ARE AVAILABLE**

Number of Tests ¹	Modification Factor for Standard Deviation ²
Less than 15	Use Table CC-2233.2.2-1
15	1.16
20	1.08
25	1.03
30 or more	1.00

NOTES:

(1) Interpolate for intermediate numbers of tests.

(2) Modified standard deviation to be used to determine required average strength f'_{cr} from CC-2233.2.1.

TABLE CC-2233.1.2-1 MODIFICATION FACTOR FOR STANDARD DEVIATION WHEN LESS THAN 30 TESTS ARE AVAILABLE

CC-2233.2 Required Average Strength

CC-2233.2.1 Standard Deviation Method.

Required average compressive strength f'_{cr} used as the basis for selection of concrete proportions shall be the larger of Eq. (1) or (2) using a standard deviation calculated in accordance with CC-2233.1.

$$f'_{cr} = f'_c + 1.34s \quad (1)$$

(1)

or

$$f'_{cr} = f'_c + 2.33s - 500 \quad (2)$$

(2)

where s is the standard deviation in psi.

**TABLE CC-2233.2.2-1
REQUIRED AVERAGE COMPRESSIVE STRENGTH
WHEN DATA ARE NOT AVAILABLE
TO ESTABLISH A STANDARD DEVIATION**

Specified Compressive Strength f'_c , psi	Required Average Compressive Strength f'_{cr} , psi
Less than 3000	$f'_c + 1000$
3000 to 5000	$f'_c + 1200$
Over 5000	$f'_c + 1400$

TABLE CC-2233.2.2-1 REQUIRED AVERAGE COMPRESSIVE STRENGTH WHEN DATA ARE NOT AVAILABLE TO ESTABLISH A STANDARD DEVIATION

CC-2233.2.2 Alternative Method.

When a concrete production facility does not have field strength test records for calculation of standard deviation meeting requirements of CC-2233.1.1 or CC-2233.1.2, required average strength f'_{cr} shall be determined from Table CC-2233.2.2-1 and documentation of average strength shall be in accordance with the requirements of CC-2233.3.

CC-2233.3 Documentation of Average Strength.

Documentation that proposed concrete proportions will produce an average compressive strength equal to or greater than required average compressive strength (CC-2233.2) may consist of a field strength test record, several strength test records, or trial mixtures.

CC-2233.3.1 Using Test Records.

When test records are used to demonstrate that proposed concrete proportions will produce the required average strength f'_{cr} (CC-2233.2), such records shall represent materials and conditions similar to those expected. Changes in materials, conditions, and proportions within the test records shall not have been more restricted than those for proposed work. For the purpose of documenting average strength potential, test records consisting of less than 30 but not less than 10 consecutive tests may be used provided test records encompass a period of time not less than 45 days. Required concrete proportions may be established by interpolation between the strengths and proportions of two or more test records, each of which meets other requirements of this section.

CC-2233.3.2 Using Trial Mixtures.

When an acceptable record of field test results is not available, concrete proportions may be established based on

trial mixtures made in accordance with ACI 211.1, Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete, meeting the following restrictions.

(a) Combination of materials shall be those for proposed work.

(b) Trial mixtures having proportions and consistencies required for proposed work shall be made using at least three different water-cement ratios or cement contents that will produce a range of strengths encompassing the required average strength f_{cr} .

(c) Trial mixtures shall be designed to produce a slump within ± 0.75 in. (± 19 mm) of maximum permitted, and for air-entrained concrete, within $\pm 0.5\%$ of maximum allowable air content.

(d) For each water-cement ratio or cement content, at least three test cylinders for each test age shall be made and cured in accordance with ASTM C 192, Method of Making and Curing Concrete Test Specimens in the Laboratory. Cylinders shall be tested at the test age designated in the Construction Specification for determination of f_c .

(e) From the results of cylinder tests, a curve shall be plotted showing the relationship between water-cement ratio or cement content and compressive strength at designated test age.

(f) Maximum water-cement ratio or minimum cement content for concrete to be used in proposed work shall be that shown by the curve to produce the average strength required by CC-2233.2, unless a lower water-cement ratio or higher strength is required by CC-2231.6.

CC-2240 CEMENT GROUT

The term *grout* as used in this Article applies to the following:

(a) grout for general purpose grouting, such as under base plates or around large penetrations;

(b) grout for prestressed tendons;

(c) grout for preplaced aggregate concrete.

CC-2241 Constituents for Cement Grout

CC-2241.1 Cement.

Cement for grout shall conform to ASTM C 150, Type I or II.

CC-2241.2 Aggregates.

Aggregates shall conform to the requirements of CC-2222.

CC-2241.3 Water.

Mixing water shall conform to the requirements of CC-2223.

CC-2241.4 Admixtures.

Admixtures shall conform to the requirements of CC-2224.

CC-2241.5 Other Material.

Other material, such as aluminum powder of the proper fineness and quality,

Page 20

may be added to the grout mix, provided adequate tests are made to demonstrate the suitability of the mix for the purpose intended.

CC-2242 Cement Grout for General Grouting Purposes

CC-2242.1 General Requirements

(a) Requirements described herein do not apply to grout which is used with grouted prestressing systems.

(b) The proportions of constituents for general purpose grout shall be based upon trial mixes using the same type and brand of cement, fine aggregate, and admixtures as will be used for construction. Insofar as is practical, the same type of mixer shall be used in preparing trial mixes as will be used for construction.

CC-2242.2 Compressive Strength.

The compressive strength of the grout shall be established by 2 in. (51 mm) cubes, molded, cured, and tested in accordance with ASTM C 109, except that, if fluid expansive grout is used, the tests shall be performed in accordance with CRD-C 621, Specification for Non-Shrink Grout.

CC-2242.3 Fly Ash and Pozzolans.

When fly ash or pozzolans are used as admixtures, the quantity shall be such that the requirements for strength, workability, and durability are met.

CC-2242.4 Water.

The water content shall be the minimum quantity necessary for the proper placement by the grouting method employed, dry pack or fluid grout.

CC-2242.5 Prepackaged Cement Grout

CC-2242.5.1 Permitted Uses.

Prepackaged cement grout (product) may be used in lieu of site-mixed cement grout for general grouting purposes.

CC-2242.5.2 Modification of Product.

The product shall be used as received from the supplier, except for the addition of water or aggregate where required by the manufacturer's instructions.

CC-2242.5.3 Approval of Designer.

The Designer shall specify the use and required properties of the product in the Construction Specification. The Designer shall consider the effect of the product on the design strength and its effect on other materials based on experience and test data. The product shall be approved by the Designer prior to use.

CC-2242.5.4 Construction Procedures.

All storing, batching, mixing, conveying, depositing (including pressure assisted placement), consolidating, curing, testing, and surface preparation shall be in accordance with the requirements of the Construction Specification.

CC-2242.5.5 Aggregate.

Aggregate added to the product in accordance with the manufacturer's instructions shall conform to CC-2222 and be tested in accordance with CC-5223.

CC-2242.5.6 Water.

Water added to the product in accordance with the manufacturer's instructions shall conform to CC-2223 and be tested in accordance with CC-5224.

CC-2242.5.7 Quality Assurance Program Requirements.

The product shall be manufactured under a Quality Assurance Program approved by the Constructor which

includes as a minimum:

- (a) control of the manufacturing processes that are performed in the manufacture of the product;
- (b) document control;
- (c) handling, storage, and shipping requirements;
- (d) identification and marking of product containers;
- (e) establishment of examination, test, inspection, and report procedures, including proper documentation and controls related to the product measuring and testing equipment.

CC-2242.5.8 Certified Material Test Reports.

Certified Material Test Reports shall be provided for each lot or shipment to verify that the product meets the physical properties specified in the Construction Specification.

CC-2242.5.9 In-Process Testing.

The product shall be tested in accordance with the requirements for general purpose grout in the Construction Specification and CC-5234.2.

CC-2242.6 Epoxy Grouts and Bonding Agents

CC-2242.6.1 Permitted Uses.

Epoxy grouts (product) may be used for general purpose grout and grouting/sealing small or fine cracks in hardened concrete. Epoxy bonding agents (product) may be used to improve the bond between hardened concrete and plastic concrete or grout that is placed thereon.

CC-2242.6.2 Modification of Product.

The product shall be used as received from the supplier except for the addition of aggregate where required by the manufacturer's instructions.

CC-2242.6.3 Approval of Designer.

The Designer shall specify the use and required properties of the product in the Construction Specification. The Designer shall consider the effect of the product on the design strength and its effect on other materials based on experience and test data. The effect of high and low temperature, radiation, moisture, and other conditions to which the product might be subjected during its

Page 21

service life shall also be considered. The product shall be approved by the Designer prior to use.

CC-2242.6.4 Construction Procedures.

All storing, batching, mixing, conveying, curing, depositing (including pressure assisted placement), consolidating, testing, and surface preparation shall be in accordance with the requirements of the Construction Specification.

CC-2242.6.5 Aggregate.

Aggregate added to the product in accordance with the manufacturer's instructions shall conform to CC-2222 and be tested in accordance with CC-5223.

CC-2242.6.6 Quality Assurance Program Requirements.

The product shall be manufactured under a Quality Assurance Program approved by the Constructor which includes as a minimum:

- (a) control of the manufacturing processes that are performed in the manufacture of the products;
- (b) document control;
- (c) handling, storage, and shipping requirements;
- (d) identification and marking of product containers;
- (e) establishment of examination, test, inspection, and report procedures, including proper documentation and controls related to the products measuring and testing equipment.

CC-2242.6.7 Certified Material Test Reports.

Certified Material Test Reports shall be provided for each lot or shipment to verify that the product meets the physical properties specified in the Construction Specification.

CC-2242.6.8 In-Process Testing.

Epoxy grout shall be tested as specified in the Construction Specification.

CC-2243 Cement Grout for Grouted Tendon Systems

CC-2243.1 General Requirements

(a) Grout for grouted tendon systems shall consist of a mixture of cement, water, and an admixture. If the gross inside area of the tendon tube exceeds five times the tendon area, fine aggregate may be used provided the mix can penetrate all spaces and can maintain the desired expansion and sedimentation (bleeding) characteristics for both horizontal and vertical tendons.

(b) The choice of admixture shall be based on tests that have demonstrated to the satisfaction of the designee that its use improves the properties of the grout, e.g., increases workability, reduces or controls bleeding, entrains air, expands the grout, prevents water separation when pumped at high pressure, or reduces shrinkage.

(c) The proportion of materials to be used shall be based upon trial mixes using the same type and brand of cement admixture and fine aggregate (when applicable) as will be used for grouting. Insofar as practical, the same type of mixer shall be used in preparing trial mixes as will be used for construction and shall be specified in the Construction Specification.

CC-2243.2 Physical Properties of the Grout

CC-2243.2.1 Water-Cement Ratio.

The water-cement ratio should be as low as possible, consistent with adequate workability, but in no case shall it exceed 0.50.

CC-2243.2.2 Fluidity (Not Applicable to Thixotropic Grouts)

(a) The fluidity of the grout shall be measured in accordance with ASTM C 939.

(b) The efflux time at the pump discharge shall not be less than 11 sec at zero quiescent time and shall not increase less than 3 sec nor more than 8 sec at 20 min of quiescent time.

NOTE: *Quiescent time* is defined as the amount of time that a sample of grout remains undisturbed (quiescent) in the flow cone and is expressed in minutes. *Efflux time* is the amount of time that a sample of grout requires to run out of the flow cone after the plug is pulled, expressed in seconds, and should be measured by a stopwatch.

CC-2243.2.3 Viscosity (Applicable to Thixotropic Grouts Only).

The viscosity of the grout, as a measure of its pumpability, shall be determined by methods and within the limits established in the Construction Specification.

CC-2243.2.4 Bleeding

(a) The bleeding of the grout at $73^{\circ}\text{F} \pm 3^{\circ}\text{F}$ ($23^{\circ}\text{C} \pm 2^{\circ}\text{C}$) should not exceed 2% of the volume 3 hr after mixing or a maximum of 4%. In addition, the separated water shall be absorbed within 24 hr. Bleeding should be measured in a tube approximately $1\frac{1}{2}$ in. (38 mm) in diameter using a grout column approximately 1 yd (0.9 m) high. During the test, the tube should be covered to prevent evaporation.

(b) In the case of thixotropic grouts, the Construction Specification may require additional or alternate tests to check for bleeding, including tests with the grout subjected to specified pressure in a filter.

CC-2243.2.5 Compressive Strength.

The grout mix shall attain a minimum compressive strength of 2500 psi (17 MPa) at 28 days. The test specimens

Page 22

shall be fabricated, cured, and tested in accordance with CRD-C 621.

CC-2243.3 Chemical Requirements.

The grout constituents shall be controlled so that the chloride and nitrate contents of the grout do not exceed the following limits:

(a) chlorides as Cl^- - 0.015% maximum by weight of portland cement

(b) nitrates as NO_3^- - 0.015% maximum by weight of portland cement

CC-2250 MARKING AND IDENTIFICATION OF CONCRETE CONSTITUENTS

CC-2251 Cement

Before leaving the place of manufacture, conveyances of bulk cement shall be sealed and tagged showing lot number, controlling specification, date of manufacture, and type. If bag cement is used, each shipment shall be tagged with the same identification as for bulk cement. All tags and markings shall be maintained with the material at site storage.

CC-2252 Aggregates

Aggregates shall be identified to show size, source, and controlling specification. The identification shall remain with the aggregate during transit and concrete plant storage.

CC-2253 Admixtures

All containers of admixtures shall be clearly marked, showing storage requirements and controlling specification. Bulk storage tanks for admixtures at batch plants shall be identified with the name of the admixture stored, the controlling specification, and the storage requirements.

CC-2300 MATERIAL FOR REINFORCING SYSTEMS

CC-2310 INTRODUCTION

(a) The material to be used for reinforcing bars for containments shall conform to ASTM A 615 or A 706 and the special requirements described in CC-2330.

(b) The material to be used for bar-to-bar splice sleeves in reinforcing bars shall conform to ASTM A 513, A 519, or A 576.

(c) The material to be used for reinforcing bar splice sleeves attached to liner plates or structural steel shapes shall be carbon steel conforming to ASTM A 513, A 519, or A 576 Grades 1008 through 1030.

(d) Only material listed in Table I-2.1 may be used for joining reinforcing bar to liner plate or structural steel shapes by welding.

CC-2320 MATERIAL IDENTIFICATION

Reinforcing systems material shall be tagged or marked to ensure traceability to the Certified Material Test Report during production and while in transit and storage.

CC-2330 SPECIAL MATERIAL TESTING

CC-2331 Tensile Tests

CC-2331.1 Number of Tests Required.

One full-diameter tensile bar of each bar size shall be tensile tested for each 50 tons, or fraction thereof, of reinforcing bars produced from each heat of steel. The tensile test procedures shall be in accordance with SA-370.

CC-2331.2 Acceptance Standards.

The acceptance standards shall be in conformance with the tensile requirements of ASTM A 615 or ASTM A 706, as applicable. If a test specimen fails to meet the tensile requirements, two additional specimens from the same heat and of the same bar size shall be tested. If either of the two additional specimens fails to meet the tensile requirements, the material represented by the tests shall not be accepted.

CC-2333 Chemical Analysis

A ladle analysis of each heat of reinforcing bar shall be made and reported in accordance with A 615 or A 706, as applicable.

CC-2333.1 Reinforcing Bar Intended for Welding

(a) ASTM A 706 and ASTM A 615 may be welded by any of the welding processes listed in XI-1400.

(b) The ladle analysis of ASTM A 615 reinforcing bar heats intended for welding shall be as follows:

carbon	0.30% maximum
manganese	1.50% maximum
sulfur	0.045% maximum
phosphorus	0.035% maximum
silicon	0.50% maximum

An analysis for the following residual elements shall also

Page 23

be performed and reported: copper, nickel, chromium, molybdenum, vanadium. The carbon equivalent of such bars shall comply with the 0.55% maximum carbon equivalent as computed in XI-1430.

(c) The results of the product verification analysis for ASTM A 706 reinforcing bar shall not exceed that specified in ASTM A 706. Product verification analysis for ASTM A 615 reinforcing bar shall not exceed the following:

carbon	0.33%
manganese	1.55%
sulfur	0.053%
phosphorus	0.043%
silicon	0.55%

CC-2400 MATERIAL FOR PRESTRESSING SYSTEMS

CC-2410 INTRODUCTION

This Subarticle establishes the requirements for the material to be used for bonded and unbonded containment prestressing systems.

CC-2420 PRESTRESSING STEEL

CC-2421 Permitted Material

Prestressing elements² are limited to those listed in Appendix I, Table I-1.1. The materials shall conform to their respective material specifications and to the additional requirements described in the following subparagraphs.

CC-2422 Test Specimen Sizes

All mechanical tests on prestressing elements shall be performed on full-diameter test pieces.

CC-2423 Tensile Tests

Material produced to an ASTM specification shall be sampled and tested as required by that specification. The tensile strength, yield strength, elongation, and other pertinent data shall be reported on the Certified Material Test Report.

² The term prestressing element is defined as an individual wire, strand, or bar, whether in a multiple or single wire, strand, or bar system.

CC-2424 Stress Relaxation Properties

The stress relaxation properties of the prestressing elements tested in accordance with ASTM E 328, Standard Recommended Practice for Stress-Relaxation Tests for Materials and Structures, shall be provided by the Material Manufacturer. Reports relating thereto shall be based upon tests performed on material previously manufactured to the same ASTM or other applicable specification, and produced in the same plant utilizing the same procedures that will be employed to produce the prestressing elements for the production tendons.

CC-2424.1 Data to Be Furnished.

The following data shall be furnished:

- (a) deviations from ASTM E 328 recommended testing;
- (b) specimen identification;
- (c) initial and final stress;
- (d) loss of stress at intervals during test;
- (e) temperature control limits;
- (f) predicted stress relaxation design life and basis for extrapolation.

CC-2424.2 Number of Tests.

A minimum of three relaxation tests of 1000 hr duration shall be performed and reported to document adequately that the relaxation losses are in compliance with the Construction Specification.

CC-2430 ANCHORAGE COMPONENTS

CC-2431 Permitted Material

Specific materials for anchorage components including bearing plates for prestressing systems are not given in this Subsection. The tendon Manufacturer is allowed to use any material he feels is compatible with his tendon system, taking into account the loading conditions that the tendons will undergo during testing and in service. It is a requirement, however, that the tendon Manufacturer performs the tests prescribed in CC-2460 and, accordingly, documents his anchorage component materials. The following subparagraphs describe the basic material tests the tendon Manufacturer

must perform on the material he selects and uses for production tendon anchorage components.

CC-2432 Bearing Plates

Materials for bearing plates shall conform to their respective material specifications. The dimensions, finish, alignment, and tolerances of the bearing plates

Page 24

shall be within the limits set forth in the Construction Specification.

CC-2433 Anchorhead Assemblies and Wedge Blocks

CC-2433.1 General.

Material for anchorhead assemblies and wedge blocks shall conform to their respective material specifications and the mechanical test requirements of CC-2433.2. The dimensions, finish, alignment, and tolerances of the anchorhead assemblies and wedge blocks shall be within the limits set forth in the Construction Specification. For items requiring heat treatment to develop mechanical properties, the alloy and heat treatment shall be selected to preclude embrittlement.

CC-2433.2 Mechanical Tests

CC-2433.2.1 Scope and Extent of Testing.

The tendon Manufacturer shall develop a production test program designed to ensure that all materials used in the production of anchorhead assemblies and wedge blocks will meet the strength and ductility requirements called for by the parts design and substantiated by the performance test.

As a minimum, the following tests shall be conducted.

(a) Tensile test specimen shall be taken in such locations and orientations to provide strength and ductility information reflecting the critical stress-strain direction in the piece.

For parts heat treated after machining, the tensile test specimen shall be heat treated together with the furnace load they represent.

The number of tests shall be set forth in the Construction Specification. The test shall be conducted in accordance with CC-2433.2.2.

(b) Hardness tests shall be conducted on heat treated materials. A minimum 10% random sample of the parts shall be tested for heat of steel, but not less than one sample from each furnace load. The tests shall be conducted in accordance with CC-2433.2.2.

(c) Liquid-dye penetrant or magnetic particle inspection shall be conducted on 100% of anchorhead assemblies and wedge blocks subject to heat treatment. The tests shall be conducted in accordance with CC-2433.2.2.

CC-2433.2.2 Test Procedures

(a) Tensile test procedures shall conform to SA-370, and report tensile strength, yield strength, elongation, and reduction of area at failure.

(b) Each hardness test shall consist of taking three measurements on each part. The test procedures for Rockwell Hardness Testing and for Brinell Hardness Testing shall conform to SA-370.

(c) Liquid-dye penetrant testing shall conform to SE-165. Magnetic particle testing shall conform to SE-109.

CC-2433.2.3 Acceptance Standards.

The results of all measurements shall be within the limits set forth in the Construction Specification.

Heat treated parts, where the liquid-dye penetrant or magnetic particle inspection reveals the presence of cracks,

shall be rejected.

CC-2433.2.4 Rework and Retests.

If the physical requirements are not met by any single part, then all parts of the heat or the lot shall be tested. For heat-treated parts, those parts failing to meet the physical requirements, may be rejected or reheat-treated once. Parts which are reheat-treated shall be retested in accordance with CC-2433.2.

CC-2434 Wedges and Anchor Nuts

CC-2434.1 General.

Materials for wedges and anchor nuts shall conform to their respective material specifications and the hardness test requirements of CC-2434.2. The dimensions, finish, alignment, and tolerances of the wedges and anchor nuts shall be within the limits set forth in the Construction Specification.

CC-2434.2 Hardness Tests

CC-2434.2.1 Scope and Extent of Testing.

Surface hardness tests shall be conducted on not less than 5% of the wedges and anchor nuts from each heat treatment lot. In addition, core hardness, and for wedges, case depth tests, shall be conducted on three samples of each heat treatment lot. The samples shall be taken at random after heat treatment. Each heat treatment lot shall consist of material from only one heat of steel.

CC-2434.2.2 Test Procedures.

The test procedures shall be the same as stated in CC-2433.2.2.

CC-2434.2.3 Acceptance Standards.

All measurements shall be within the limits set down in the construction procedures. Lots not meeting the requirements shall be rejected.

CC-2440 NONLOAD-CARRYING AND ACCESSORY MATERIALS

CC-2441 Tendon Ducts, Channels, Trumpets, and Transition Cones

Tendon duct, channel, trumpet, and transition cone material shall have the following properties.

Page 25

- (a) The material shall be ferrous and shall not cause harmful electrolytic reactions with the prestressing element.
- (b) Ducts and channels shall be strong enough to retain their shape and resist irreparable damage during vessel construction.
- (c) Ducts and their joints shall prevent intrusion of cement paste from the concrete.
- (d) When used for single element tendons, the inside diameter of ducts shall be at least $\frac{1}{4}$ in. larger than the nominal diameter of the tendon.
- (e) When used for multiple element tendons, the inside cross-sectional area of ducts shall be at least twice the nominal net area of the enclosed tendon.
- (f) When filler injection is required, ducts shall have openings at both ends. Vents shall be provided at high points. Drains shall be provided at low points.
- (g) Ducts and duct joints shall be capable of withstanding an internal pressure greater than the initial pumping pressure when adequately backed by concrete.

CC-2442 Corrosion Prevention Material

CC-2442.1 Introduction.

This subparagraph describes the requirements for material to be used for the temporary and permanent corrosion prevention of prestressing systems.

CC-2442.2 Temporary Coatings

CC-2442.2.1 Bonded Systems.

Temporary corrosion prevention for bonded tendons shall be provided by environmental control. If any temporary corrosion preventive coating is used, it shall allow the portland cement grout to bond uniformly to all parts of the tendon steel. The temporary coating shall be specified in the Construction Specification.

CC-2442.2.2 Unbonded Systems.

A temporary corrosion prevention coating shall be applied to all unbonded tendons during or after fabrication. The coating material shall be compatible with the permanent corrosion preventing coating described in CC-2442.3.2. The temporary coating shall be specified in the Construction Specification. It shall be made to be easily removable in the field with the use of nonchlorinated petroleum solvents for the installation of field attached anchorages.

CC-2442.3 Permanent Coatings

CC-2442.3.1 Permissible Types of Coatings.

The permanent corrosion prevention coating applied to the tendons shall be a microcrystalline wax (petrolatum) base material containing additives to enhance the corrosion inhibiting, wetting, and moisture displacing properties, as well as the ability to form a polar bond with the tendon steel.

CC-2442.3.2 Properties of the Coating.

The coating Manufacturer shall provide test data verifying that the following properties are met for the service life and temperature for evaluation and acceptance by the Designer:

- (a) freedom from cracking and brittleness;
- (b) continuous self-healing film over the coated surfaces;
- (c) chemical and physical stability;
- (d) nonreactivity with the surrounding and adjacent materials such as concrete, tendons, and ducts;
- (e) moisture displacing characteristics.

CC-2442.3.3 Physical and Chemical Analysis of Coating.

The coating Manufacturer shall provide Qualification Test Data for the Oil Separation, Salt Spray (Fog), Gamma Radiation Resistance tests, and Cone Penetration tests.

The coating Manufacturer shall supply with each shipment a test report with an analysis of the Flash Point; Congealing Point; Neutralization Number (TBN); Specific Gravity; Consistency (Cone Penetration); and Water Soluble Chlorides, Nitrates, and Sulfides.

The acceptance criteria and test methods shall conform to Table CC-2442-1.

CC-2450 PERFORMANCE REQUIREMENTS

CC-2451 Anchorages and Couplings

Anchorage and couplings shall be designed to assure that the mode of failure of the tendon system will be a rupture of the prestressing element. Each individual item of an anchorage or coupling shall be capable of developing at least 110% of the minimum specified ultimate tensile strength of the corresponding prestressing steel element or elements being anchored or coupled. This requirement shall apply to items manufactured to the most adverse combination of tolerances set forth in the Construction Specification.

CC-2452 Tendon Assemblies

CC-2452.1 Anchorages.

A full-capacity straight tendon, complete with anchorages, shall develop an ultimate strength equal to at least 100% of the minimum specified ultimate tensile strength of the prestressing steel without exceeding the anticipated set of the anchorage elements. The total elongation under ultimate load of the tendon shall not be less than 2% measured in a minimum gage length of 100 in. (2540 mm).

Page 26

Page 27

98

TABLE CC-2442-1
ANALYSIS LIMITS OF PERMANENT COATING MATERIAL
FOR CRV PRESTRESSING

Test	Acceptance Criteria	Test Method
Consistency (cone penetration) at 77°F	260 max.	ASTM D 937
Flash point, °F	400°F min.	ASTM D 92
Congeaing point, °F	135°F min.	ASTM D 938
Oil separation	3% by weight at 100°F max.	FTMS 791C, Method 321.3 [Note (1)]
Salt spray (fog) 0.5 mil coating	200 hr min.	ASTM B 117 [Note (2)]
Neutralization number (TBN — total base number)	35 mg KOH/g of sample, min.	ASTM D 974 (modified) [Note (3)]
Gamma radiation resistance 1 × 10 ⁶ rad	TBN 25 min. must meet all other specification limits in this Table	...
Water soluble chlorides, Cl ⁻	10 ppm max.	ASTM D 512 [Note (4)]
Water soluble nitrates, NO ₃ ⁻	10 ppm max.	ASTM D 992 [Note (4)]
Water soluble sulfides, S ⁻	10 ppm max.	APHA 4500-5; 17 th Edition [Note (4)]
Specific gravity at 60°F	0.88–1.10	ASTM D 1298

NOTES

- (1) Federal Test Methods (FTMS) — Nickel cone must be packed until product exudes through screen and then excess wiped off before test is begun.
- (2) Test specimens shall consist of steel meeting the requirements of ASTM D 609 Type 1B size 3 × 6 in., coating film thickness 0.5 ± 0.05 mils. Failure criteria: ASTM D 610 Rust Grade 8, on two out of three faces in an area that is 6.4 mm in from all edges or edge of coating.
- (3) Heat 10 g sample in a 500 ml Erlenmeyer flask. Add 10 ml isopropyl alcohol and 5 ml toluene. Heat until sample is solubilized. Add 90 ml distilled water and 20 ml 1N sulfuric acid. Place in steam bath for one-half hour. Stir well. Add phenolphthalein indicator and titrate with 1N sodium hydroxide. Calculate total base number mg KOH/g of sample [(20) (acid normality) — (ml base) × (base normality)] × 56/g of sample.
- (4) The inside (bottom and sides) of a 1L beaker, approximate O.D. 105 mm, height 145 mm, is thoroughly coated with 100 ± 10 g of the tendon sheathing filler coating material. The coated beaker is filled with approximately 900 cc of distilled water and heated in an oven at a controlled temperature of 100°F ± 2°F for 4 hr. The water extraction is tested by the noted test procedures for the appropriate water soluble ions. Results are reported as ppm in the extract water.

[98]

TABLE CC-2442-1 ANALYSIS LIMITS OF PERMANENT COATING MATERIAL FOR CRV PRESTRESSING

Specification No. _____	Date _____
Prestressing System Type _____ (wire, strand, or bar)	Single or Multiple Element _____
	If Multiple, No. of Elements _____
Prestressing Element Material _____	Nominal Size _____
Bearing Plate Material _____	Thickness _____ Diameter _____
Wedge Material _____	Hardness _____ (Attach diagram showing shape and size)
Buttonhead Shape and Size (Attach diagram)	
Swaged Fitting Material _____	Hardness _____ (Attach diagram showing shape and size)
Screwed Fitting Material _____	Hardness _____ (Attach diagram showing shape and size)

FIG. CC-2462-1 MANUFACTURER'S RECORD OF TENDON PERFORMANCE QUALIFICATION TESTS

FIG. CC-2462-1 MANUFACTURER'S RECORD OF TENDON PERFORMANCE QUALIFICATION TESTS

CC-2452.2 Couplings.

Tendons with couplings shall conform with the requirements of CC-2452.1. Couplings shall be enclosed in housings long enough to permit the necessary movements during tensioning.

CC-2452.3 Low Temperature Requirements.

The tendon assembly shall be designed to meet the requirements of CC-3000 when exposed to the lowest service temperature as specified in the Construction Specification.

CC-2460 PERFORMANCE TESTS

CC-2461 General Requirements

A series of performance tests shall be conducted to qualify the tendon system for use in the concrete containment. The required tests are designed to demonstrate that the combination of materials for the tendon system is adequate and to assess the overall strength and integrity of the tendon system.

CC-2462 Material to Be Used for Performance Tests

The materials to be used for the performance test tendons shall be those that the tendon Manufacturer proposes using for production tendons. All of the actual materials used and the necessary dimensions shall be documented on a form the same as or similar to that shown in Fig. CC-2462-1.

CC-2463 Type and Number of Performance Tests

CC-2463.1 Static Tensile Test.

The Construction Specification shall specify the number of static tensile tests (not less than two) to be conducted to destruction so that the following information may be obtained:

- (a) yield strength (or proof stress)

- (b) ultimate tensile strength
- (c) elongation (over 100 in. (2540 mm) minimum gage length)
- (d) number of failed wires or strands

The results shall comply with the requirements of CC-2462.

CC-2463.2 High Cycle Dynamic Tensile Test.

One high cycle dynamic tensile test shall be conducted so that the tendon shall withstand, without failure, 500,000 cycles of stress variation from 60% to 66% of the minimum specified ultimate tensile strength of the tendon. One cycle is defined as an increase from the lower load to the higher load and return.

CC-2463.3 Low Cycle Dynamic Tensile Test.

One low cycle dynamic tensile test shall be conducted so that the tendon shall withstand, without failure, 50 cycles of stress variation from 40% to 80% of the minimum specified ultimate tensile strength of the tendon. One cycle is defined as an increase from the lower load to the higher load and return.

NOTE: It is considered satisfactory to use the same test specimen for performing the tests prescribed in both CC-2463.2 and CC-2463.3.

CC-2464 Size of Performance Test Specimens

CC-2464.1 Length.

The test specimens for static tensile tests shall have a gage length not less than 100 in.

CC-2464.2 Number of Prestressing Elements¹

CC-2464.2.1 Single Element Tendons.

A single element specimen shall be used for both static and dynamic tensile tests.

CC-2464.2.2 Multiple Element Tendons

(a) *Static Tensile Tests.* All static tensile tests shall be performed on specimens having the full-anchorage capacity of the proposed tendons.

(b) *Dynamic Tensile Tests.* All dynamic tensile tests shall be performed on specimens having at least 10% of the full-size prestressing steel area of the proposed production tendons.

CC-2465 Test Results

The measurements and results obtained from the tests shall be documented on a form the same as or similar to that shown in Fig. CC-2465-1.

CC-2466 Essential Variables

CC-2466.1 General Requirements.

The performance tests must be completely reconducted when any of the applicable changes listed below are made to the tendon system material. Changes other than those listed below may be made in the tendon system material without the necessity for repeating the performance tests.

CC-2466.2 Essential Variables in Prestressing Element Material.

Essential variables in prestressing element material shall be as stipulated in (a) through (e) below:

- (a) a change in the prestressing element material from one ASTM or ASME specification to another;
- (b) a change in the tensile grade of the prestressing element material within the same ASTM or ASME specification;
- (c) a change in the heat treatment condition of the prestressing element material;
- (d) a change in the prestressing element diameter;
- (e) in multiple element systems, an increase of more than 10% in the number of elements in the tendon.

CC-2466.3 Essential Variables in Anchorage Items.

Essential variables in anchorage items shall be as stipulated in (a) through (f) below:

- (a) for buttonhead anchorage systems, a change in the shape or dimensions of the buttonhead;
- (b) for wedge anchorage systems, a change in the shape, size, material, or dimensions of the wedge;
- (c) for threaded nut anchorage systems, a change in the nut, thread size, or material;
- (d) for swaged systems, a change in the shape, size, or material of the swaged fitting;
- (e) a change in the anchor block material from one type to another;
- (f) a change in the bearing plate material from one P-Number to another P-Number from Section IX or any other material.

CC-2470 MARKING AND IDENTIFICATION OF PRESTRESSING MATERIAL

Prestressing system material shall be marked or tagged in such a manner as to ensure traceability to the Certified Material Test Report during production and while in transit and storage.

CC-2500 MATERIAL FOR LINERS

CC-2510 PERMITTED MATERIAL SPECIFICATIONS

CC-2511 General

Materials to be used for containment liners and attachments to liners are listed in Appendix I, Table I-2.2.

CC-2512 Permitted Stainless Steel Specifications

When the desired type of approved stainless steel is lacking in the specification covering the applicable form, the material may be furnished to the general requirements of an approved specification with the chemical composition and mechanical properties conforming to those shown in another approved specification for the desired grade.

CC-2513 Permitted Clad Plate Specifications

(a) Clad plate used in construction in which the design calculations are based on the total thickness including cladding shall conform to one of the following specifications:

- (1) SA-263, Corrosion-Resisting Chromium-Nickel Clad Plate, Sheet and Strip;
- (2) SA-264, Corrosion-Resisting Chromium-Nickel Steel Clad Plate, Sheet and Strip.

1—STATIC TENSILE TEST

Specimen No.	Effective Area, sq in.	Yield Load, lb	Tensile Load, lb	Yield Strength, psi	Tensile Strength, psi	Elongation in 100, %	Number of Failed Wires/Strands

2—HIGH CYCLE DYNAMIC TENSILE TEST

Specimen No.	Effective Area, sq in.	Low Load, lb	High Load, lb	Low Stress, psi	High Stress, psi	Cycle Period

3—LOW CYCLE DYNAMIC TENSILE TEST

Specimen No.	Effective Area, sq in.	Low Load, lb	High Load, lb	Low Stress, psi	High Stress, psi	Cycle Period

**FIG. CC-2465-1 RECORD OF MECHANICAL TEST RESULTS OBTAINED FROM
—TENDON PERFORMANCE QUALIFICATION TESTS**

FIG. CC-2465-1 RECORD OF MECHANICAL TEST RESULTS OBTAINED FROM TENDON PERFORMANCE QUALIFICATION TESTS

(b) Clad plate used in construction in which the design calculations are based on the clad-plate thickness, exclusive of the thickness of the cladding material, may consist of any base plate material satisfying the requirements of CC-2511 and any metallic cladding material of weldable quality that in the judgment of the user is suitable for the intended service.

(c) Integrally clad steel plate, in which any part of the cladding is included in the design calculations, shall show a minimum shear strength of 20,000 psi (138 MPa) when tested in the manner described in the plate specification. One shear test shall be made on each such clad plate as-rolled, and the results shall be reported on the CMTR.

(d) When any part of the cladding thickness is specified as an allowance for corrosion, such added thickness shall be removed before mill tension tests are made. When no part of the cladding thickness is specified as an allowance for corrosion, the cladding material need not be removed before testing.

CC-2514 Permanent Structural Attachment Material

Structural steel rolled shapes, which are permitted by CC-2121 to be furnished with a certificate of compliance, may be repaired by welding using the welders, documentation, and examination requirements specified in SA-6.

CC-2520 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIALS

CC-2521 Materials to Be Impact Tested

CC-2521.1 Materials for Which Impact Testing Is Required.

Carbon steel and low alloy steel for liners shall be tested either by drop weight tests or the Charpy V-notch impact test. Such tests are not required for:

(a) materials with a nominal section thickness of $\frac{5}{8}$ in. (16 mm) or less where the thickness shall be taken as defined in (1) through (4) below:

(1) for liners, use the nominal thickness of the shell or head as applicable;

(2) for nozzles or parts welded to liners, use the lesser of the liner thickness to which the item is welded, or the maximum radial thickness of the item exclusive of integral shell butt welding projections;

(3) for flat heads or flanges, use the maximum shell thickness associated with the butt welding hub;

(4) for integral fittings used to attach process piping to the liner (Fig. NE-1120-1), use the larger nominal thickness of the pipe connections.

(b) studs, attached to the liner, with a nominal size of 1 in. diameter or less;

(c) bars with a nominal cross-sectional area which does not exceed 1 sq in. (645 mm²);

(d) austenitic stainless steels;

(e) all thicknesses of material for pipe, tube, and fittings with a nominal pipe size of 6 in. and smaller;

(f) material for fittings with pipe connections of $\frac{5}{8}$ in. (16 mm) nominal wall thickness and less;

(g) bolting, including studs, nuts, and bolts with a nominal size of 1 in. or less;

(h) materials listed in Table CC-2521.1-1 for which the listed value of T_{NDT}^3 satisfied the equation, $T_{NDT}(\text{LSMT}-A)$, where LSMT⁴ is the lowest service metal temperature specified in the Construction Specification and A is a temperature increment determined from Fig. CC-2521.1-1. This exemption does not apply to either the weld metal impact tests required by CC-2612 or the welding procedure qualification impact tests required by CC-4533.5.

(i) material for which the lowest service metal temperature exceeds 150°F (66°C);

³ T_{NDT} - temperature at or above the nil-ductility transition temperature NDT (ASTM E 208); T_{NDT} is 10°F below the temperature at which at least two specimens show no-break performance.

⁴ The lowest service metal temperature shall be the lowest temperature which the metal may experience in service while the plant is in operation and shall be established by appropriate calculations based on atmospheric ambient conditions, the insulation or enclosure provided, and the minimum temperature which will be maintained inside the containment during the plant operation.

**TABLE CC-2521.1-1
EXEMPTIONS FROM IMPACT TESTING
UNDER CC-2521.1(h)**

Material [Note (1)]	Material Condition [Note (2)]	T_{NDT} , °F [Note (3)]
SA-537 Class 1	N	-30
SA-516 Grade 70	Q & T	-10
SA-516 Grade 70	N	0
SA-508 Class 1	Q & T	+10
SA-299 [Note (4)]	N	+20
SA-216 Grades WCB, WCC	Q & T	+30
SA-36 Plate	HR	+40

NOTES:

- (1) These materials are exempt from toughness testing when A or LSMT - T_{NDT} is above the curve in Fig. CC-2521.1-1 for the thickness as defined in CC-2524.2.1 or CC-2524.2.2.
- (2) Material Condition letters refer to:
N — Normalize
Q & T — Quench and Temper
HR — Hot Rolled
- (3) These values for T_{NDT} were established from data on heavy section steel (thickness greater than $2\frac{1}{2}$ in.). Values for sections less than $2\frac{1}{2}$ in. thick are held constant until additional data are obtained.
- (4) Materials made to a fine grain melting practice.

TABLE CC-2521.1-1 EXEMPTIONS FROM IMPACT TESTING UNDER CC-2521.1(h)

(j) material for embedment anchors when the maximum stress does not exceed 6000 psi (41 MPa) tension or is in compression;

(k) rolled structural shapes, when the thickness of a flange is $\frac{5}{8}$ in. (16 mm) or less.

CC-2522 Impact Test Procedures

CC-2522.1 Types of Tests

CC-2522.1.1 Drop Weight Tests

- (a) The drop weight test, when required, shall be performed in accordance with ASTM E 208, Standard Method for Conducting Drop Weight Test to Determine Nil-Ductility Temperature for Ferritic Steels.
- (b) Type P1, P2, or P3 specimens shall be prepared in accordance with ASTM E 208.

CC-2522.1.2 Charpy V-Notch Tests.

Charpy V-notch test (C_v), when required, shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Fig. 11, Type A. A test shall consist of a set of three full-size 10 mm × 10 mm specimens.

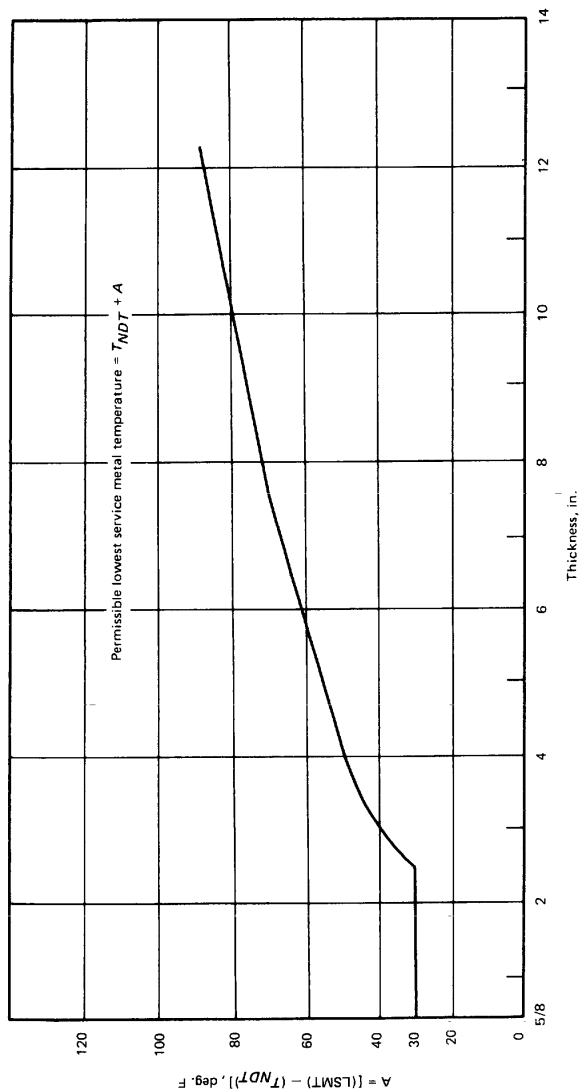


FIG. CC-2521.1-1 DETERMINATION OF PERMISSIBLE LOWEST SERVICE METAL TEMPERATURE

CC-2523 Test Specimens

CC-2523.1 Location of Test Specimens.

Impact test specimens shall be removed from a depth within the material that is at least as far from the material surface as that specified for tensile test specimens in the material specification. For bolting, the C_v impact test specimens shall be taken with the longitudinal axis of the specimen located at least one-half radius or 1 in. (25 mm) below the surface plus the machining allowance per side, whichever is less. The fracture plane of the specimen shall be at least one diameter or thickness from the heat treated end.

CC-2523.2 Orientation of Test Specimens

(a) Impact test specimens for Charpy V-notch tests shall be oriented in accordance with the requirements given for tensile test specimens in SA-370.

(b) Specimens for drop weight tests may have their axes oriented in any direction.

CC-2523.3 Structural Shapes.

The location and orientation of impact test specimens for structural shapes shall be as specified in ASTM A 673.

CC-2524 Test Requirements and Acceptance Standards

CC-2524.1 Liner Material Test Method and Temperature

(a) Liner material shall be impact tested in accordance with one of the test methods indicated below:

(1) Charpy V-notch testing at or below the lowest service metal temperature;⁵

(2) Drop weight testing to establish a T_{NDT} and demonstrate that $T_{NDT} \leq (\text{LSMT} - A)$.

(b) In addition, when the Construction Specification requires that the pneumatic pressure test (CC-6000) be performed at a temperature which is lower than the LSMT, the impact tests for liner material shall be performed in accordance with (a) above, at or below the lowest specified test temperature.

⁵ The requirements for impact testing of the heat affected zone (CC-4533.5) may result in reduced impact test temperatures for the base material.

⁶ The lowest overpressure test metal temperature shall be the lowest temperature which the metal may experience during the overpressure test and shall be established by appropriate calculations based on atmospheric conditions, the insulation or enclosure provided, and the temperature which will be maintained inside the vessel during the test.

As an alternative, a lowest overpressure test metal temperature⁶ shall be specified. In this case, Charpy V-notch testing, in addition to the tests required by (a) above, shall be performed as specified in CC-2522.1.2 at a temperature 30°F (17°C) or more below the lowest overpressure test metal temperature in accordance with CC-2524.4.

TABLE CC-2524.2-1
REQUIRED C_v LATERAL EXPANSION VALUES^{1,2}
FOR LINER MATERIAL OTHER THAN BOLTING

Nominal Wall Thickness, in.	Lateral Expansion, mils	
	Average of 3	Lowest 1 of 3
$\frac{5}{8}$ in. or less [Note (3)]	...	...
Over $\frac{5}{8}$ in. to 1 in., incl.	20	15
Over 1 in. to $1\frac{1}{2}$ in., incl.	25	20
Over $1\frac{1}{2}$ in. to $2\frac{1}{2}$ in., incl.	35	30
Over $2\frac{1}{2}$ in. [Note (4)]	45	40

NOTES:

- (1) Where weld metal tests of CC-2600 are made to these requirements, the impact lateral expansion shall conform to the requirements of either of the base materials being joined.
- (2) Where two base materials having different required lateral expansion values are joined, the weld metal lateral expansion requirements of CC-4533 shall conform to the requirements of either of the base materials.
- (3) No test required.
- (4) For use with CC-2524.2.2.

TABLE CC-2524.2-1 REQUIRED C_v LATERAL EXPANSION VALUES^{1,2} FOR LINER MATERIAL OTHER THAN BOLTING

CC-2524.2 Specific Test Methods and Acceptance Standards for Liner Material for Tests Based on Lowest Service Metal Temperature

CC-2524.2.1 Liner Material With $2\frac{1}{2}$ in. (64 mm) Maximum Thickness.

Except as limited in CC-4533.5, apply one of the methods of CC-2524.1(a) to test the following:

- (a) the base material;

(b) the base material, the heat affected zone, and the weld metal for the weld procedure qualification tests of CC-4533.5;

(c) the weld metal for CC-2612.1.

The impact test results shall meet one of the acceptance standards applicable to the specified test method.

(a) *Charpy V-Notch Testing for Lateral Expansion Values.* The test results of the three specimens collectively and singly shall meet the respective requirements of Table CC-2524.2-1.

(b) *Charpy V-Notch Testing for Absorbed Energy Values.* The test results of the three specimens collectively and singly shall meet the respective requirements of Table CC-2524.2-2.

(c) *Drop Weight Testing.* An acceptance test shall consist of at least two no-break specimens as described in ASTM E 208.

**TABLE CC-2524.2-2
REQUIRED C_V ENERGY VALUES¹ FOR LINER MATERIAL OTHER THAN BOLTING**

Nominal Wall Thickness, in.	Energy, ft-lb, for Base [Note (2)] Materials for Specified Minimum Yield Strength, ksi					
	55 ksi or below		Over 55 ksi to 75 ksi, incl.		Over 75 ksi to 105 ksi, incl.	
	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3
5/8 in. or less [Note (3)]	...	...	...	...	...	...
Over 5/8 in. to 1 in., incl.	20	15	25	20	30	25
Over 1 in. to 1 1/2 in., incl.	25	20	30	25	35	30
Over 1 1/2 in. to 2 1/2 in., incl.	35	30	40	35	45	40
Over 2 1/2 in. [Note (4)]	45	40	50	45	55	50

NOTES:

- (1) Where weld metal tests of CC-2600 are made to these requirements, the impact energy shall conform to the requirements of either of the base materials being joined.
- (2) Where two base materials having different required energy values are joined, the weld metal impact energy requirements of the procedure qualification tests of CC-4533 shall conform to the requirements of either of the base materials.
- (3) No test required.
- (4) For use with CC-2524.2.2.

TABLE CC-2524.2-2 REQUIRED C_V ENERGY VALUES¹ FOR LINER MATERIAL OTHER THAN BOLTING

CC-2524.2.2 Liner Material With Thickness Exceeding 2 1/2 in.

(a) The base material and the weld procedure qualification weld metal tests of CC-4533.5 shall be tested by the drop weight method as specified in CC-2522.1.1 and CC-2524.1(a)(2).

(b) Except as limited in CC-4533.5, apply one of the methods of CC-2524.1(a) to test the base material and the heat affected zone of the weld procedure qualification tests for CC-4533.5 and the weld metal for CC-2612.1.

(c) The acceptance standards shall be given in CC-2524.2.1(a), (b), or (c), as applicable.

CC-2524.3 Bolting Material.

The drop weight test is not applicable to bolting materials. For bolting material including nuts, studs, and bolts, a Charpy V-notch test shall be performed. Optionally, the test may be performed at the lowest service metal temperature or at a temperature 30°F (17°C) or more below the lowest service metal temperature.

(a) When tested at the lowest service metal temperature, lateral expansion and absorbed energy values shall be determined and all three specimens shall meet the requirements of Table CC-2524.3(a)-1.

(b) When tested at 30°F (17°C) or more below the lowest service metal temperature, lateral expansion and absorbed energy values shall be determined and all three specimens shall meet the requirements of Table CC-2524.3(b)-1.

**TABLE CC-2524.3(a)-1
REQUIRED C_v VALUES FOR BOLTING MATERIAL
TESTED IN ACCORDANCE WITH CC-2524.3(a)**

Nominal Diameter, in.	Lateral Expansion, mils	Absorbed Energy, ft-lb
1 or less	No test required	No test required
Over 1 through 4	25	No requirements
Over 4	25	45

TABLE CC-2524.3(a)-1 REQUIRED C_v VALUES FOR BOLTING MATERIAL TESTED IN ACCORDANCE WITH CC-2524.3(a)

**TABLE CC-2524.3(b)-1
REQUIRED C_v VALUES FOR BOLTING MATERIAL
TESTED IN ACCORDANCE WITH CC-2524.3(b)
AND CC-2524.4**

Nominal Diameter, in.	Lateral Expansion, mils	Absorbed Energy, ft-lb
1 or less	No test required	No test required
Over 1 through 4	15	30
Over 4	20	35

TABLE CC-2524.3(b)-1 REQUIRED C_v VALUES FOR BOLTING MATERIAL TESTED IN ACCORDANCE WITH CC-2524.3(b) AND CC-2524.4

CC-2524.4 Specific Test Methods and Acceptance Standards for Liner Material for Tests Based on Lowest Overpressure Test Metal Temperature

CC-2524.4.1 Liner Material.

Apply the method of CC-2524.1(a)(1) to test the following:

Page 34

TABLE CC-2524.4-1
REQUIRED C_v ENERGY VALUES¹ FOR LINER
MATERIAL FOR THE OVERPRESSURE TEST

Nominal Wall Thickness, in.	Energy, ft-lb, for Base ² Materials of Specified Minimum Tensile Strength, ksi			
	60 ksi or below		Over 60 ksi	
	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3
$\frac{5}{8}$ in. or less [Note (3)]	...	...	...	...
Over $\frac{5}{8}$ in.	15	10	20	15

NOTES:

- (1) Where weld metal tests of CC-2600 are made to these requirements, the impact energy shall conform to the requirements of either of the base materials being joined.
- (2) Where two base materials having different required energy values are joined, the weld metal impact energy requirements of the procedure qualification tests of CC-4533 shall conform to the requirements of either of the base materials.
- (3) No test required.

TABLE CC-2524.4-1 REQUIRED C_v ENERGY VALUES¹ FOR LINER MATERIAL FOR THE OVERPRESSURE TEST

(a) the base material;

(b) the base material, the heat affected zone, and the weld metal for the weld procedure qualification tests of CC-4533.5;

(c) the weld metal for CC-2612.1.

The impact test results of the three specimens collectively and singly shall meet the respective requirements of Table CC-2524.4-1.

CC-2524.4.2 Bolting Material.

For bolting material including nuts, studs, and bolts, a Charpy V-notch test shall be performed. Lateral expansion and absorbed energy values shall be determined and all three specimens shall meet the requirements of Table CC-2524.3(b)-1.

CC-2524.5 Data to Be Reported

(a) When Charpy V-notch tests are performed to meet the requirements of CC-2520, the test temperature, absorbed energy, lateral expansion, and percent shear shall be reported on the Certified Material Test Report.

(b) When drop weight tests are performed to meet the requirements of CC-2520, the test temperature and the results shall be reported on the Certified Material Test Report.

CC-2525 Number of Impact Tests Required

CC-2525.1 Plate.

One test shall be made from each plate as heat treated. Where plates are furnished in the nonheat-treated condition and qualified by heat treated test specimens, one test shall be made for each plate as-rolled. The term *as-rolled* refers to the ingot plate rolled from a slab or directly from an ingot, not to its heat treated condition.

CC-2525.2 Forgings and Castings.

When an individual forging or casting is less than 1000 lb (454 kg), one test shall be made to represent each heat in each heat treatment charge. When heat treatment is performed in continuous-type furnaces with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a heat treatment charge shall be considered as any continuous run not exceeding 8 hr duration or a total weight, so treated, not exceeding 2000 lb (907 kg). One test shall be made for each forging or casting of 1000 to 10,000 lb (454 to 4,540 kg) in weight. Ring or disk forgings, or castings larger than 10,000 lb (4,540 kg), shall have two tests per part for Charpy V-notch and one test for drop weight. The location of drop weight or Charpy V-notch test specimens shall be selected so that an equal number of specimens is obtained from positions in the forging or casting 180 deg. apart. When a separate forging or casting is used to represent forgings or castings of any size, one test shall be required.

CC-2525.3 Tubular Products and Fittings.

On products which are seamless or welded without filler metal, one test shall be made from each lot. On products which are welded with filler metal, one additional test with the specimens taken from the weld area shall also be made on each lot. A *lot* shall be defined as stated in the applicable material specification, but in no case shall a lot consist of products from more than one heat of material and of more than one diameter, with the nominal thickness of any product included not exceeding that to be impact tested by more than $\frac{1}{4}$ in. (6 mm). Such a lot shall be in a single heat treatment load or in the same continuous run in a continuous-type furnace controlled within a 50°F (28°C) range and equipped with recording pyrometers.

CC-2525.4 Bolting Material.

One test shall be made for each lot of material where a *lot* is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed the following:

$1\frac{3}{4}$ in. diameter and less	1,500 lb
Over $1\frac{3}{4}$ in. to $2\frac{1}{2}$ in. diameter	3,000 lb
Over $2\frac{1}{2}$ in. to 5 in. diameter	6,000 lb
Over 5 in. diameter	10,000 lb

CC-2525.5 Bars and Rolled Shapes

(a) One test shall be made for each lot of bars with a cross-sectional area greater than 1 sq in. (645 mm²)

where a *lot* is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed 6000 lb (2720 kg).

(b) For rolled shapes, the frequency of testing shall be one test (a set of three specimens) for at least each 15 tons (13,608 kg) or each single length of 15 tons (13,608 kg) or more, of the same nominal shape size, excluding length, for each heat in the as-rolled condition. If the shapes are heat treated, one test shall be taken from each heat of each nominal shape size, excluding length, in each furnace lot. For shapes heat treated in a continuous furnace, a lot shall not exceed 15 tons (13,608 kg).

CC-2526 Test Coupon Heat Treatment for Ferritic Material⁷

Where ferritic steel material is subject to heat treatment during fabrication or installation of a liner, the material used for the tensile and impact test specimens shall be heat treated in the same manner as the liner, except that test coupons and specimens for P-No. 1 materials with a nominal thickness of 2 in. or less are not required to be so heat treated. The Fabricator shall provide the Material Manufacturer with the temperature and heating and cooling rates to be used. In the case of postweld heat treatment, the total time at temperature or temperatures for the test material shall be at least 80% of the total time at temperature or temperatures during actual postweld heat treatment of the material, and the total time at temperature or temperatures for the test material may be performed in a single cycle.

CC-2527 Retests

CC-2527.1 Retests for Material Other Than Bolting

(a) For Charpy V-notch tests required by CC-2524, one retest at the same temperature may be conducted provided:

(1) the average value of the test results meets the average of three requirements specified in Table CC-2524.2-1, CC-2524.2-2, or CC-2524.4-1, as applicable;

(2) not more than one specimen per test is below the lowest one of three requirements specified in Table CC-2524.2-1, CC-2524.2-2, or CC-2524.4-1b, as applicable;

⁷ Any postweld heat treatment time which is anticipated to be applied to the material during fabrication or construction after completion of manufacture shall be specified in the Construction Specification. The Material Manufacturer shall include this time in the total time at temperature specified to be applied to the test specimens.

(3) the specimen not meeting the requirements is not lower than 5 ft-lb (6.8J) or 5 mils (0.13 mm) below the lowest one of three requirements specified in Table CC-2524.2-1, CC-2524.2-2, or CC-2524.4-1, as applicable.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall be equal to or greater than the average of three requirements specified in Table CC-2524.2-1, CC-2524.2-2, or CC-2524.4-1, as applicable.

CC-2527.2 Retests for Bolting Material

(a) For Charpy V-notch tests required by CC-2524, one retest at the same temperature may be conducted provided:

(1) not more than one specimen per test is below the acceptance requirements;

(2) the specimen not meeting the acceptance requirements is not lower than 5 ft-lb (6.8J) or 5 mils (0.13 mm) below the acceptance requirements.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall meet the specified acceptance requirements.

CC-2528 Calibration of Instruments and Equipment

Calibration of temperature instruments and Charpy V-notch impact test machines used in impact testing shall be performed at the following frequency.

(a) Temperature instruments used to control test temperature of specimens shall be calibrated and the results recorded to meet the requirements of NCA-3868 at least once in each 3 month interval.

(b) Charpy V-notch impact test machines shall be calibrated and the results recorded to meet the requirements of NCA-3868. The calibrations shall be performed at least once per year using methods outlined in ASTM E 23 and employing standard specimens obtained from the U.S. Army Materials Research Center.

CC-2530 EXAMINATION AND REPAIR OF LINER MATERIAL

CC-2531 Liner Material

Liner material shall be examined and repaired in accordance with the material specification and as otherwise required by this Article.

Page 36

CC-2532 Examination After Quenching and Tempering

Ferritic steel products which are used in the quenched and tempered condition shall be examined by the methods specified in this Article for each product form after the quenching and tempering phase of the heat treatment.

CC-2533 Examination and Repair of Plate

CC-2533.1 Required Examination.

Plates shall be examined in accordance with the requirements of the material specification.

CC-2533.2 Time of Examination.

Acceptance examinations shall be performed at the following times.

(a) Examinations shall be performed as required by the material specification.

(b) Radiographic examination of repair welds, when performed, may be performed prior to or after any required postweld heat treatment.

(c) Ultrasonic examination shall be performed after heat treatment.

(d) Magnetic particle or liquid penetrant examination of repair welds shall be performed after any required postweld heat treatment except for P-No. 1 material, which may be examined before or after any required postweld heat treatment.

CC-2533.3 Elimination of Surface Defects.

Unacceptable surface defects may be removed by grinding or machining provided:

(a) the depression, after defect elimination, is blended uniformly into the surrounding surface;

(b) elimination of the defect does not reduce the required section thickness by more than $\frac{1}{16}$ in. (1.6 mm);

(c) if the elimination of the defect reduces the required thickness of the section by more than $\frac{1}{16}$ in. (1.6 mm), the product shall be repaired by welding in accordance with CC-2533.4 or rejected.

CC-2533.4 Repair by Welding.

The Material Manufacturer may repair by welding materials from which defects have been removed, provided the requirements of the following subparagraphs are met. Prior approval of the Certificate of Authorization Holder shall be obtained.

CC-2533.4.1 Defect Removal.

The defect shall be removed or reduced to an acceptable size by suitable mechanical or thermal cutting or gouging

methods, and the cavity prepared for welding. The area shall be examined by magnetic particle or liquid penetrant testing before repair by welding. When thermal cutting and gouging methods are used, preheating in accordance with CC-4521.1.1 shall be used.

CC-2533.4.2 Qualification of Welding Procedures and Welders.

The welding procedures and welders or welding operators shall be qualified in accordance with CC-4500 and Section IX.

CC-2533.4.3 Blending of Repaired Areas.

After repair, the surface shall be blended uniformly into the surrounding surface.

CC-2533.4.4 Examination of Repair Welds.

Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, when the depth of the repair cavity exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 50% of the section thickness, the weld repair shall be radiographed and evaluated to the acceptance standards of CC-5542. The penetrameter and the acceptance standards for radiographic examination of repair welds shall be based on the section thickness of the repair area.

CC-2533.4.5 Heat Treatment After Repairs.

The product shall be heat treated after repair in accordance with the heat treatment requirements of CC-4554.

CC-2533.4.6 Material Report Describing Defects and Repairs.

Each defect repair exceeding $\frac{3}{8}$ in. (10 mm) in depth or 50% of the section thickness shall be described in the CMTR when the repair is made by the Material Manufacturer. The CMTR for each piece shall include a chart which shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and a report of the results of the examinations, including radiographic film.

CC-2534 Examination and Repair of Forgings and Bars

CC-2534.1 Required Examinations.

Forgings and bars shall be examined visually for the presence of chip marks, blemishes, or other surface irregularities.

CC-2534.2 Time of Examination.

Acceptance examinations shall be performed at the time of manufacture and in accordance with CC-2533.1.

CC-2534.3 Elimination of Surface Defects.

Elimination of surface defects shall be made in accordance with CC-2533.3.

CC-2534.4 Repair by Welding.

Repair by welding shall be made in accordance with CC-2533.4.

Page 37

CC-2535 Examination of Wrought Seamless and Welded (Without Filler Metal) Tubular Products and Fittings

In addition to the requirements of the material specification and of this Article, seamless and welded (without filler metal) tubular products shall comply with the following.

CC-2535.1 Wrought Seamless and Welded (Without Filler Metal) Pipe and Tubing.

Wrought seamless and welded (without filler metal) pipe and tubing shall comply with the requirements for Class 2 seamless and welded (without filler metal) pipe and tubing of SA-655, Special Requirements for Pipe and Tubing for Nuclear and Other Special Applications.

CC-2535.2 Wrought Seamless and Welded (Without Filler Metal) Fittings.

Wrought seamless and welded (without filler metal) fittings shall comply with the requirements of SA-652, Special Requirements for Wrought Steel Welding Fittings for Nuclear and Other Special Applications, for Class 2 seamless or Class 2 welded (without filler metal) fittings.

CC-2536 Examination and Repair of Tubular Products and Fittings Welded With Filler Metal

CC-2536.1 Required Examination

(a) Welded (with filler metal) tubular products, such as pipe made in accordance with SA-358 and fittings made in accordance with the WPW grades of SA-234, SA-403, and SA-420, which are made by welding with filler metal, shall be treated as material; however, inspection by an Inspector and stamping with an NPT symbol shall be in accordance with the material specification. In addition to the NPT symbol, a numeral 2 shall be stamped below and outside the official Code symbol.

(b) In addition to the requirements of the material specification and of this Article, pipe and fittings shall comply with the following.

(1) Pipe shall comply with the requirements of SA-655, Special Requirements for Pipe and Tubing for Nuclear and Other Special Applications, for Class 2 welded (with filler metal) pipe.

(2) Fittings shall comply with the requirements of SA-652, Special Requirements for Wrought Steel Welding Fittings for Nuclear and Other Special Applications, for Class 2 welded (with filler metal) fittings.

(c) Tubular products and fittings which have been radiographed shall be marked to indicate that radiography has been performed. The radiographic film and a radiographic report showing film locations shall be provided with the Certified Material Test Report.

(d) The Authorized Inspector shall certify by signing the Partial Data Report Form NM-1 (Appendix V of Section III, Division 1, Appendices) in accordance with NCA-5290.

CC-2537 Examination and Repair of Statically and Centrifugally Cast Products

CC-2537.1 Required Examinations.

Cast material shall be examined by either radiographic or ultrasonic methods, or a combination of the two methods. Castings or sections of castings, which have coarse grains or configurations which do not yield meaningful results by ultrasonic examination, shall be examined by radiographic methods.

CC-2537.2 Ultrasonic Examination of Ferritic Steel Castings.

The requirements for ultrasonic examination of statically and centrifugally cast products are given in the following subparagraphs.

CC-2537.2.1 Straight Beam Method.

When ferritic castings are to be examined ultrasonically, all sections, regardless of thickness, shall be examined in accordance with SA-609, Specification for Longitudinal Beam Ultrasonic Inspection of Carbon and Low-Alloy Steel Castings; however, supplementary angle beam examination in accordance with CC-2537.2.2 or radiographic examination in accordance with CC-2537.3 shall be performed in areas where a back reflection cannot be maintained during the straight beam examination or where the angle between the two surfaces of the casting is more than 15 deg.

CC-2537.2.2 Angle Beam Method.

Examinations shall be conducted in accordance with T-540 of Section V, except that the acceptance standards of CC-2537.2.3 apply.

CC-2537.2.3 Acceptance Standards

(a) The Quality Levels of SA-609 shall apply for the casting thicknesses indicated in (1) through (3) below:

- (1) Quality Level 1 for thicknesses up to 2 in. (51 mm);
- (2) Quality Level 3 for thicknesses 2 in. to 4 in. (102 mm);
- (3) Quality Level 4 for thicknesses greater than 4 in. (102 mm);

(b) In addition to the Quality Level requirements stated in (a) above, the requirements in (1) through (5) below shall apply for both straight beam and angle beam examination.

Page 38

(1) Areas giving indications exceeding the Amplitude Reference Line with any dimension longer than those specified in the following tabulation are unacceptable:

UT Quality Level	Longest Dimension of Area, in.
1	1.5
2	2.0
3	2.5
4	3.0

NOTES:

(1) The area for the Ultrasonic Quality Levels in SA-609 refers to the surface area on the casting over which a continuous indication exceeding the corrected transfer distance amplitude curve is maintained.

(2) Area is to be measured from dimensions of the movement of the search unit, using the center of the search unit as the reference point.

(3) In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases, other criteria which incorporate a consideration of beam angles or beam spread must be used for realistic evaluation of the discontinuity.

(2) Quality Level 1 shall apply for the volume of castings within 1 in. (25 mm) of the surface regardless of the overall thickness.

(3) Discontinuities indicated to have a change in depth equal to or greater than one-half the wall thickness or 1 in. (25 mm), whichever is less, are unacceptable.

(4) Two or more indications in the same plane, with amplitudes exceeding the Amplitude Reference Line and separated by a distance less than the longest dimension of the larger of the adjacent indications, are unacceptable if they cannot be encompassed within an area less than that of the Quality Level specified in (b)(1) above.

(5) Two or more indications greater than permitted for Quality Level 1 for castings less than 2 in. (51 mm) in thickness, greater than permitted for Quality Level 2 for thicknesses 2 in. (51 mm) through 4 in. (102 mm), and greater than permitted for Quality Level 3 for thicknesses greater than 4 in. (102 mm), separated by a distance less than the longest dimension of the larger of the adjacent indications, are unacceptable if they cannot be encompassed in an area less than that of the Quality Level requirements stated in (a) above.

CC-2537.3 Radiographic Examination

CC-2537.3.1 Extent, Methods, and Acceptance Standards.

Radiographic examination, when required, shall be performed on castings. The extent of radiographic coverage shall be of the maximum feasible volume. The radiographic methods shall be in accordance with ASTM E 94,

shall be of the maximum feasible volume. The radiographic methods shall be in accordance with ASTM E 94, Recommended Practice for Radiographic Testing, and ASTM E 142, Controlling Quality of Radiographic Testing, and shall meet the acceptance requirements of Severity Level 2 of ASTM E 446, Reference Radiographs for Steel Castings up to 2 in. (51 mm) in Thickness, ASTM E 186, Reference Radiographs for Heavy-Walled (2 to 4¹/₂ in.) (102 mm to 114 mm) Steel Castings, or ASTM E 280, Reference Radiographs for Heavy-Walled (4¹/₂ to 12 in.) (114 mm to 305 mm) Steel Castings, as applicable, for the thickness being radiographed (except that Category D, E, F, or G defects are not acceptable). The requirements of ASTM E 280 shall apply for castings over 12 in. in thickness.

NOTE: The reference radiographs accompanying previous editions of ASTM E 186, E 280, and E 446 may be used with later editions of the specification provided the text of the specified edition is used.

CC-2537.3.2 Procedure.

The supplemental requirements of (a) through (d) below apply to the radiographic methods specified by ASTM E 94 and ASTM E 142.

(a) Type 4 film is not permitted.

(b) For those areas where relatively uniform thicknesses occur, the minimum film density shall be 1.5 for single viewing and 2.0 for composite viewing of multiple film exposures; each film of a composite set shall have a minimum density of 1.0, and the maximum film density permitted shall be 4.0.

(c) For those sections where the thickness varies sufficiently to cause difficulty in meeting the density requirements with one penetrometer, two penetrameters shall be used representing the thinnest and thickest sections in the area to be interpreted. Densities at or between the densities on the penetrameters shall be considered acceptable, except that the minimum density of the penetrometer image shall be 1.3 for single film viewing and 2.0 for composite film viewing of multiple film exposures; each film of a composite set shall have a minimum density of 1.0.

(d) The radiographic quality level shall be 2-4T for section thicknesses up to and including ³/₄ in. (19 mm) and 2-2T for section thicknesses greater than ³/₄ in. (19 mm) Radiographic quality is defined in Note 2 of ASTM E 94.

CC-2537.4 Magnetic Particle Examination

CC-2537.4.1 Examination Procedure.

The procedure for magnetic particle examination shall be in accordance with the methods of Article 7 of Section V.

CC-2537.4.2 Evaluation of Indications

(a) Mechanical discontinuities at the surface will be indicated by the retention of the examination medium.

Page 39

All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant to the detection of unacceptable discontinuities.

(b) Any indication in excess of the CC-2537.4.3 acceptance standards which is believed to be nonrelevant shall be regarded as a defect and shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications which would mask indications of defects are unacceptable.

(c) Relevant indications are those which result from unacceptable mechanical discontinuities. Linear indications are those indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length less than three times the width. Indications resulting from nonmetallic inclusions are not considered relevant indications.

CC-2537.4.3 Acceptance Standards

(a) Only indications with major dimensions greater than ¹/₁₆ in. shall be considered relevant.

(b) The relevant indications of (1) through (4) below are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for material less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for material 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thickness less than $\frac{5}{8}$ in. (16 mm), and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more indications in any 6 sq in. (3871 mm²) of area whose major dimension is no more than 6 in. (152 mm), with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

CC-2537.5 Liquid Penetrant Examination

CC-2537.5.1 Examination Procedure.

The procedure for liquid penetrant examination shall be in accordance with the methods of Article 6 of Section V.

CC-2537.5.2 Evaluation of Indications

(a) Mechanical discontinuities at the surface will be indicated by bleeding out of the penetrant; however, localized surface imperfections such as may occur from machining marks or surface conditions may produce similar indications which are not relevant to the detection of unacceptable discontinuities.

(b) Any indication in excess of the CC-2537.5.3 acceptance standards which is believed to be nonrelevant shall be regarded as a defect and shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask indications of defects are unacceptable.

(c) Relevant indications are those which result from unacceptable mechanical discontinuities. Linear indications are those indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length less than three times the width.

CC-2537.5.3 Acceptance Standards

(a) Only indications with major dimensions greater than $\frac{1}{16}$ in. shall be considered relevant.

(b) The relevant indications of (1) through (4) below are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for material less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for material 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm), and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more indications in any 6 sq in. (3871 mm²) of area whose major dimension is no more than 6 in. (152 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

CC-2537.6 Time of Examination.

Acceptance examinations, including those for weld repairs, shall be performed at the time of manufacture as stipulated in the following subparagraphs.

CC-2537.6.1 Ultrasonic Examination.

Ultrasonic examination, if required, shall be performed at the stage of manufacture as required for radiography.

CC-2537.6.2 Radiographic Examination.

Radiography, when required, may be performed prior to heat treatment, and shall be performed at the stage of manufacture defined in this subparagraph. Castings, prior to finish machining, shall be radiographed at the limiting thicknesses stipulated in (a) and (b) below.

Page 40

(a) For thicknesses less than 6 in. (152 mm), castings shall be radiographed within 20% of the finished thickness. The penetrameter shall be based on the final thickness.

(b) For thicknesses 6 in. (152 mm) and greater, castings shall be radiographed within 10% of the finished thickness. The penetrameter shall be based on the final thickness.

CC-2537.6.3 Magnetic Particle or Liquid Penetrant Examination.

Magnetic particle or liquid penetrant examination shall be performed after the final heat treatment required by the material specification. Repair weld areas shall be examined after postweld heat treatment when a postweld heat treatment is performed, except that repair welds to P-No. 1 material 2 in. (51 mm) nominal thickness and less may be examined prior to postweld heat treatment. For cast products with machined surfaces, all finished machined surfaces, except threaded surfaces, shall also be examined by magnetic particle or liquid penetrant methods.

CC-2537.7 Elimination of Surface Defects.

Elimination of surface defects shall be in accordance with CC-2533.4.

CC-2537.8 Repair by Welding.

The Material Manufacturer may repair castings by welding after removing the material containing unacceptable defects. The depth of the repair is not limited. A cored hole or access hole may be closed by the Material Manufacturer by welding in accordance with the requirements of this paragraph, provided the hole is closed by filler metal only. If the hole is closed by welding in a metal insert, the welding shall be performed by a Certificate Holder in accordance with the requirements of CC-4000.

CC-2537.8.1 Defect Removal.

Prior to repair by welding, material containing unacceptable defects shall be removed by suitable mechanical or thermal cutting or gouging methods to sound metal or until any defect remaining is within the acceptance standards, and the cavity shall be prepared for welding.

CC-2537.8.2 Qualification of Welding Procedures and Welders.

The welding procedure and welders or welding operators shall be qualified in accordance with CC-4000 and Section IX.

CC-2537.8.3 Blending of Repaired Areas.

After welding, the surface shall be blended uniformly into the surrounding surface.

CC-2537.8.4 Examination of Repair Welds.

Each repair weld shall be examined by the magnetic particle method (CC-2537.4) or by the liquid penetrant method (CC-2537.5). In addition, when radiography of the casting is required, repair welds in cavities, the depth of which exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness, shall be radiographed in accordance with CC-2537.3. The radiographic method and acceptance standards of CC-2537.3 shall apply, except that weld slag, including elongated slag, shall be considered as an inclusion under Category B of the applicable reference radiographs. The total area of all inclusions, including slag inclusions, shall not exceed the limits of the applicable severity level of Category B of the reference radiographs.

CC-2537.8.5 Heat Treatment After Weld Repair.

After repair, the casting shall be heat treated in accordance with CC-4552, except that the heating and cooling limitations of CC-4552.3 do not apply.

CC-2537.8.6 Material Report Describing Defects and Repairs.

Each repair weld exceeding in depth either $\frac{3}{8}$ in. or 10% of the section thickness shall be described in the Certified Material Test Report. The Certified Material Test Report shall include a chart for each repaired casting, which shows the location and size of the repaired cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographic film.

CC-2540 MATERIAL IDENTIFICATION

The identification of liner material shall meet the requirements of NCA-3866.6 except that materials for leak-chase systems, embedments, and attachments may be bundled and tagged when permitted by the SA material specifications. Materials for small items shall be controlled during manufacture so that they are identifiable as acceptable materials at all times. Welding materials shall be controlled during the repair of material and the manufacture of liners so that they are identifiable as acceptable until the materials are actually consumed in the process (CC-4122).

CC-2600 WELDING MATERIAL

CC-2610 WELDING MATERIAL REQUIREMENTS

All welding materials used in the construction and repair of components or materials, except welding materials used for hard surfacing, shall conform to the requirements of the welding material specification or to the requirements for other welding materials as

Page 41

permitted by Section IX. In addition, welding materials shall conform to the requirements of this Subarticle.

CC-2611 Required Tests

(a) The required tests shall be conducted:

- (1) for each *lot* of covered, flux cored, or fabricated electrodes;
- (2) for each *heat* of bare electrodes, rod, or wire for use with the FGW, GMAW, GTAW, PAW, and EGW (electrode gas welding) processes (QW-492 of Section IX);
- (3) for each *heat* of backing filler metal (consumable inserts);
- (4) for each combination of *heat* of bare electrodes and *lot* of submerged arc flux;
- (5) for each combination of *lot* of fabricated electrodes and *lot* of submerged arc flux;
- (6) for each combination of *heat* of bare electrodes and *lot* of electroslag flux;

(b) Tests performed on welding material during the qualification of weld procedures shall satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used, provided the tests required by CC-4533 and this Subarticle are made and the results conform to the requirements of this Subarticle. The definitions of (1) through (7) below apply.

(1) A *dry batch* of covering mixture is the quantity of dry covering ingredients mixed at one time in one mixing vessel; a dry batch may be used singly or may be subsequently subdivided into quantities to which the liquid binders may be added to produce a number of wet mixes (3).

(2) A *dry blend* is defined as one or more dry batches mixed in a mixing vessel and combined proportionately to produce a uniformity of mixed ingredients equal to that obtained by mixing the same total amount of dry ingredients at one time in one mixing vessel.

(3) A *wet mix* is the combination of a dry batch (1) or dry blend (2) and liquid binder ingredients at one time in one mixing vessel.

(4) A *lot of covered, flux cored, or fabricated electrodes* is defined as the quantity of electrodes produced from the same combination of heat of metal and dry batch or dry blend of flux or core materials. Alternatively, a lot of covered, flux cored, or fabricated electrodes may be considered one type and size of electrode, produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45,360 kg), from chemically controlled tube, wire or strip, and chemically controlled mixes of flux, provided each container of welding materials is coded for identification and traceable to the production period, the shift, line, and the analysis range of both the mix and the rod, tube, or strip used to make the electrode.

(a) *Chemically controlled tube, wire, or strip* is defined as consumable tube, wire, or strip material supplied on coils with a maximum of one splice per coil that has been chemically analyzed to assure that the material conforms to the electrode Manufacturer's chemical control limits for the specific type of electrode. Both ends of each coil shall be chemically analyzed, except that those coils which are splice free need only be analyzed on one end of the coil.

(b) *Chemically controlled mixes of flux* are defined as flux material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the electrode Manufacturer's standard for each chemical element for that type electrode. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending.

(5) A *heat of bare electrode, rod, wire, or consumable insert* is defined as the material produced from the same melt of metal.

(6) Alternatively, for carbon and low alloy steel bare electrode, rod, wire, or consumable inserts for use with SAW, FGW, GMAW, GTAW, PAW, and EGW processes, a *heat* may be defined as either the material produced from the same melt of metal, or the material produced from one type and size of wire when produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45,360 kg), from chemically controlled wire subject to the requirements of (a), (b), and (c) below.

(a) For the chemical control of the product of the rod mill, coils shall be limited to a maximum of one splice prior to processing the wire. Chemical analysis shall be made from a sample taken from both ends of each coil of mill coiled rod furnished by mills permitting spliced coil practice of one splice maximum per coil. A chemical analysis need be taken from only one end of rod coils furnished by mills prohibiting spliced coil practice.

(b) Carbon, manganese, silicon, and other intentionally added elements shall be determined to identify the material to ensure that it conforms to the SFA or user's material specification.

(c) Each container of wire shall be coded for identification and traceability to the lot, production period, shift, line, and analysis of rod used to make the wire.

(7) A *lot of submerged arc or electroslag flux* is defined as the quantity of flux produced from the same combination of raw materials under one production schedule.

CC-2612 Weld Metal Tests

CC-2612.1 Mechanical Properties Tests.

Tensile and impact tests shall be made for welding material which is used to join P-No. 1 base material with the exceptions listed below:

(a) austenitic stainless steel welding material used to join P-No. 1 base material;

(b) consumable inserts (backing filler material);

(c) welding material to be used for the welding of base material exempted from impact testing by CC-2521.1(a) through (g) shall likewise be exempted from the impact testing required by this paragraph.

CC-2612.1.1 General Test Requirements.

The welding test coupon shall be made in accordance with the requirements of (a) through (f) below for each process with which the weld material will be used in production welding.

(a) Test coupons shall be of sufficient size and thickness so that the required test specimens can be removed.

(b) The weld metal to be tested for all processes except electroslag welding shall be deposited in such a manner as to substantially eliminate the influence of the base material on the results of the tests. Weld metal to be used with the electroslag process shall be deposited in such a manner as to conform to one of the applicable Welding Procedure Specifications (WPS) for production welding, Section IX, QW-201.1. The base material shall conform with the requirements of Section IX, QW-403.1 or QW-403.4, as applicable.

(c) The welding of the test coupon shall be performed with the range of preheat and interpass temperatures that will be used in production welding. Coupons shall be tested in the as-welded condition, or, where indicated by the WPS, they shall be postweld heat treated⁶ to the specified temperatures. The postweld heat treatment holding time shall be at least 80% of the maximum time to be applied to the weld metal in production application. The total time for postweld heat treatment of the test coupon may be applied in one heating cycle. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the component. In addition, weld coupons for weld metal to be used with the electroslag process that are tested in the as-welded condition, or following a postweld heat treatment within the holding temperature ranges of Table CC-4552-1 or CC-4552-3, shall have a thickness within the range of 0.5 to 1.1 times the thickness of the welds to be made in production. Electroslag weld coupons to be tested following a postweld heat treatment, which will include heating the coupon to a temperature above the holding temperature range of Table CC-4552-1 for the type of material being tested, shall have a thickness within the range of 0.9 to 1.1 times the thickness of the welds to be made in production.

(d) Regardless of the welding process or welding material being tested, the tensile specimens and the Charpy V-notch impact specimens, where required, shall be located and prepared in accordance with the requirements of SFA-5.1, Specification for Mild Steel Covered Electrodes. Drop weight impact test specimens, where used, shall be oriented so that the longitudinal axis is transverse to the weld with the notch in the weld face, or in a plane parallel to the weld face. For impact specimen preparation and testing, the applicable parts of CC-2522.1.1 and CC-2522.1.2 shall apply. The longitudinal axis of the specimens shall be at a minimum depth of $1/4t$ from a surface, where t is the nominal thickness of the test weld.

(e) One all-weld-metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the base material specification. Where base materials of different specifications are to be welded, the tensile strength requirements shall conform to the specified minimum tensile strength requirements of either of the base material specifications.

(f) Impact specimens of the weld metal shall be tested where impact tests are required for either of the base materials of the production weld. The weld metal shall conform to the parts of CC-2524.2.1, CC-2524.2.2, or CC-2524.4.1, as applicable.

CC-2612.1.2 Standard Test Requirements.

In lieu of the use of the general test requirements specified in CC-2612.1.1, tensile and impact tests may be made in accordance with this paragraph where they are required for mild and low alloy steel covered electrodes. The material combinations to require weld material testing as listed in CC-2612.1 shall apply for the standard test requirements option. The limitations and testing under the standard test option shall be in accordance with (a) through (f) below.

(a) Testing to the requirements of this subparagraph shall be limited to electrode classifications included in SFA-5.1 or SFA-5.5.

(b) The test assembly required by SFA-5.1 or SFA-5.5, as applicable, shall be used for test coupon preparation, except that it shall be increased in size to obtain the number of Charpy V-notch specimens or the drop weight test specimens required by CC-2524 or CC-2525, where applicable.

(c) The welding of the test coupon shall conform to the requirements of the SFA specification for the classification of electrode being tested. Coupons shall

be tested in the as-welded condition and also in the postweld heat treated condition. The postweld heat treatment temperature shall be in accordance with Table CC-4552-1 for the applicable P-Number equivalent. The time at postweld heat treatment temperature shall be 8 hr, which qualifies postweld heat treatments of 10 hr or less. Where the postweld heat treatment (PWHT) of the production weld exceeds 10 hr, or the PWHT temperature is other than that required above, the general test of CC-2612.1.1 shall be used.

**TABLE CC-2613.1-1
SAMPLING OF WELDING MATERIALS FOR
CHEMICAL ANALYSIS**

	GTAW/ PAW	GMAW	All Other Processes
A-No. 8 filler metal	Filler metal or weld deposit	Weld deposit	Weld deposit
All other filler metal	Filler metal or weld deposit	Filler metal or weld deposit	Weld deposit

TABLE CC-2613.1-1 SAMPLING OF WELDING MATERIALS FOR CHEMICAL ANALYSIS

(d) The tensile and Charpy V-notch specimens shall be located and prepared in accordance with the requirements of SFA-5.1 or SFA-5.5, as applicable. Drop weight impact test specimens, where required, shall be located and oriented as specified in CC-2612.1.1(d).

(e) One all-weld-metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirement of the SFA specification for the applicable electrode classification.

(f) The requirements of CC-2612.1.1(f) shall be applicable to the impact testing of the standard test.

CC-2613 Chemical Analysis Test

Chemical analysis of filler metal or weld deposits shall be made in accordance with CC-2611 and as required by the following subparagraphs.

CC-2613.1 Test Method.

The chemical analysis test shall be performed in accordance with this subparagraph and Table CC-2613.1-1, and the

results shall conform to CC-2613.2.

(a) A-No. 8 welding material to be used with gas tungsten-arc welding (GTAW) and plasma-arc welding (PAW) processes and any other welding material to be used with any GTAW, PAW, or GMAW process shall have chemical analysis performed on either the filler metal or on a weld deposit made with the filler metal in accordance with (c) or (d) below.

(b)(1) A-No. 8 welding material to be used with other than the GTAW and PAW processes and other welding materials to be used with other than the GTAW, PAW, or GMAW process shall have chemical analysis performed on a weld deposit of the material or combination of materials being certified in accordance with (c) and (d) below. The removal of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c) below.

(2) As an alternative, the deposit shall be made in accordance with (d) for material that will be used for corrosion resistant overlay cladding. Where the Welding Procedure Specification or the welding material specification specifies percentage composition limits for analysis, it shall state that the specified limits apply for the filler metal analysis, the undiluted weld deposit analysis, or for in situ cladding deposit analysis in conformance with the above required certification testing.

(c) The preparation of samples for chemical analysis of undiluted weld deposits shall comply with the method given in the applicable SFA specification. Where a weld deposit method is not provided by the SFA specification, the sample shall be removed from a weld pad, groove, or other test weld⁸ made using the welding process that will be followed when the welding material or combination of welding materials being certified is consumed. The weld for A-No. 8 material to be used with the GMAW or EGW process shall be made using the shielding gas composition specified in the Welding Procedure Specification that will be followed when the material is consumed.

The test sample for ESW shall be removed from the weld metal of the mechanical properties test coupon. Where a chemical analysis is required for a welding material which does not have a mechanical properties test requirement, a chemical analysis test coupon shall be prepared as required by CC-2612.1.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of CC-2612.1.1(c) do not apply.

⁸ The methods given in the Appendix of SFA-5.9, Specification for Corrosion-Resisting Cr and Cr-Ni Steel Welding Rods and Bare Electrodes, shall be used to establish a welding and sampling method for the pad, groove, or other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution.

(d) The alternative method provided in (b)(2) above for the preparation of samples for chemical analysis of welding material to be used for corrosion resistant overlay cladding shall require a test weld made in accordance with the essential variables of the Welding

Procedure Specification that will be followed when the welding material is consumed. The test weld shall be made in conformance with the requirements of Section IX, QW-214.1. The removal of chemical analysis sample shall conform with QW-214.3 for the minimum thickness for which the Welding Procedure Specifications are qualified.

TABLE CC-2613.2-1
WELDING MATERIAL CHEMICAL ANALYSIS

Cr-Ni stainless materials	C, Cr, Mo, Ni, Mn, Si, Cb
----------------------------------	----------------------------------

TABLE CC-2613.2-1 WELDING MATERIAL CHEMICAL ANALYSIS

CC-2613.2 Requirements for Chemical Analysis.

The chemical elements to be determined, the composition requirements of the weld metal, and the recording of results of the chemical analysis shall be in accordance with (a), (b), and (c) below.

(a) Welding material of ferrous alloy A-No. 8 (QW-442, Section IX) shall be analyzed for the elements listed in Table CC-2613.2-1 and for any other elements specified either in the welding material specification referenced by the Welding Procedure Specification or in the Welding Procedure Specification.

(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition limits. Where the Welding Procedure Specification contains a modification of the composition limits of SFA or other referenced welding material specifications, or provides limits for additional elements, these composition limits of the Welding Procedure Specification shall apply for acceptability.

(c) The results of the chemical analysis shall be reported in the Certified Material Test Report. Elements listed in Table CC-2613.2-1, but not specified in the welding material specification or Welding Procedure Specification, shall be reported for information only.

CC-2613.3 Delta Ferrite Determination.

A determination of delta ferrite shall be performed on A-No. 8 weld material (QW-442, Section IX), backing filler metal (consumable inserts), bare electrode, rod, or wire filler metal, or weld metal, except that delta ferrite determinations are not required for SFA-5.4, Type 16-8-2, or A-No. 8 weld filler metal to be used for weld metal cladding.

CC-2613.3.1 Method.

Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of chemical analysis of CC-2613 in conjunction with Fig. CC-2613.3.1-1.

(a) Calibration of magnetic instruments shall conform to AWS-A4.2-74.

(b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with CC-2613.1(c).

(c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number.

CC-2613.3.2 Acceptance Standards.

The minimum acceptable delta ferrite shall be 5FN (Ferrite Number). The results of the delta ferrite determination shall be included in the Certified Material Test Report of CC-2130 or CC-4120.

CC-2614 Storage and Handling of Welding Material

Suitable storage and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by fluxes and cored, fabricated, and coated electrodes.

CC-2620 STUD WELDING MATERIAL

CC-2621 General Requirements

CC-2621.1 Material Specifications.

Stud material shall conform to ASTM A 108, Cold Finished Carbon Steel Bars and Shafting, Grades 1010, 1015, 1016, 1018, or 1020, and to the additional requirements described in this paragraph.

CC-2621.2 Definitions

- (a) Stud base as used herein shall be considered as the stud tip at the welding end, including flux and container, and 1/8 in. (3.2 mm) of the body of the stud adjacent to the tip.
- (b) Angle of bend in testing studs as used herein shall be measured between the original axis of the base material and a line passing through the centers of the two ends of the bent stud.

CC-2621.3 Stud Design.

Studs shall be of a design suitable for arc welding to steel members with automatically timed stud welding equipment. The type, size or diameter, and length of stud shall be as specified by the Construction Specification. Dimensions and tolerances of standard type studs are given in Fig. CC-2620-1.

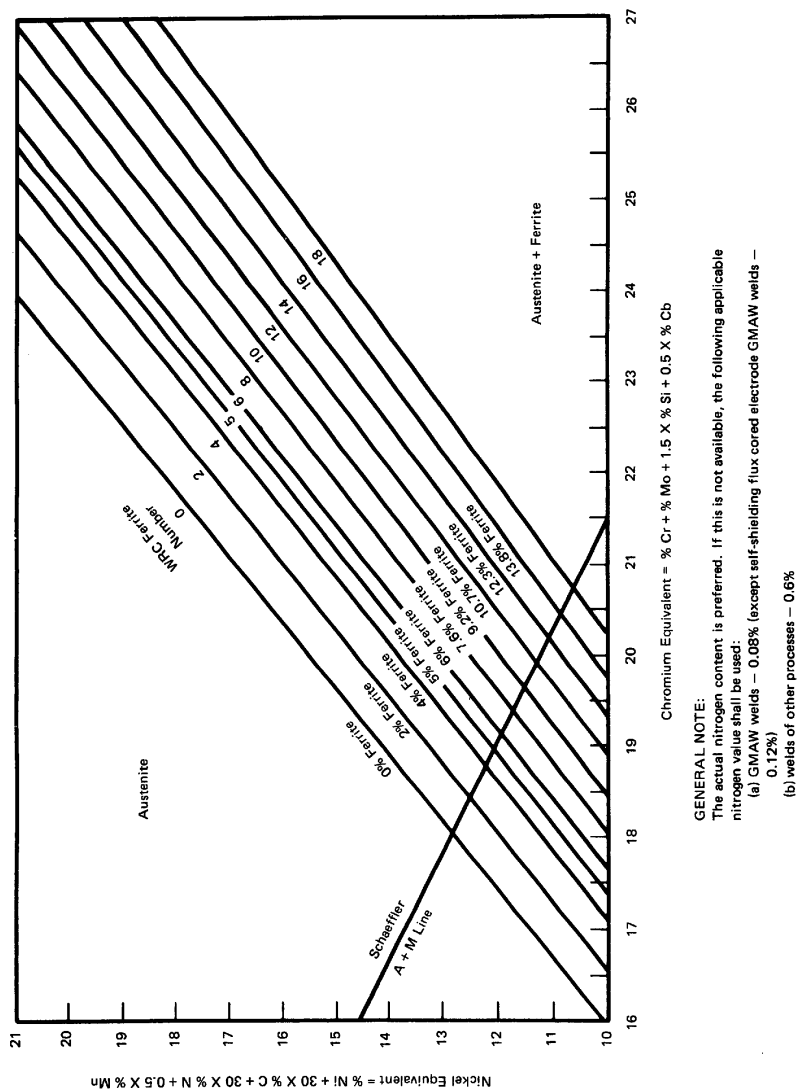
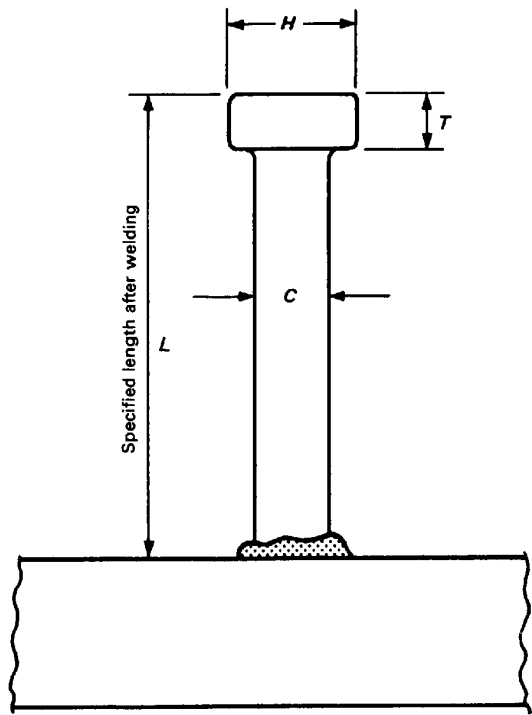


FIG. CC-2613.3.1-1 DELTA FERRITE CONTENT

FIG. CC-2613.3.1-1 DELTA FERRITE CONTENT



STANDARD DIMENSIONS, IN.

C	Length, L , Tolerances	H	T
$1/2$ $+0.000$ -0.010	$+1/16$ $-1/8$	$1 \pm 1/64$	$9/32$ min.
$5/8$ $+0.000$ -0.010	$+1/16$ $-1/8$	$1-1/4 \pm 1/64$	$9/32$ min.
$3/4$ $+0.000$ -0.015	$+1/16$ $-1/8$	$1-1/4 \pm 1/64$	$3/8$ min.
$7/8$ $+0.000$ -0.015	$+1/16$ $-1/8$	$1-3/8 \pm 1/64$	$3/8$ min.

FIG. CC-2620-1 DIMENSIONS AND TOLERANCES
OF STANDARD STUDS

FIG. CC-2620-1 DIMENSIONS AND TOLERANCES OF STANDARD STUDS

CC-2621.4 Surface Condition.

Finished studs shall be of uniform quality and condition, free of injurious laps, fins, seams, cracks, twists, bends, or other injurious defects. A stud with cracks or bursts deeper than one-half the distance from the periphery of the head to the shank shall be cause for rejection.⁹

CC-2622 Stud Base Requirements

CC-2622.1 Arc Shield.

An arc shield (ferrule) of heat resistant ceramic or other suitable material shall be furnished with each stud.

CC-2622.2 Flux.

A suitable deoxidizing and arc stabilizing flux for welding shall be furnished with each stud of $\frac{5}{16}$ in. (8 mm) diameter or larger. Studs less than $\frac{5}{16}$ in. (8 mm) diameter may be furnished with or without flux.

CC-2622.3 Base.

The stud base shall not be painted, galvanized, or plated.

CC-2622.4 Qualification Requirements

CC-2622.4.1 Introduction.

The stud base qualification tests described in this subparagraph shall constitute qualification of stud bases with the same geometry, material, flux, and arc shield, of the same diameter and down to but not including $\frac{1}{8}$ in. (3.2 mm) and smaller nominal diameters.

CC-2622.4.2 Duration of Qualification.

A size of stud base with arc shield, once qualified, is considered qualified until the Manufacturer makes any change in the stud base geometry, material, flux, or arc shield.

CC-2622.4.3 Preparation of Specimens

(a) Test specimens shall be prepared by welding representative studs to suitable plates of P-No. 1 material. Tests for threaded studs shall be on blanks (studs without threads).

(b) Studs shall be welded with power source, welding gun, and automatically controlled equipment. Welding voltage, current, and time shall be measured and recorded for each specimen.

⁹ Heads of studs are subject to cracks or bursts, which are terms that designate an abrupt interruption of the periphery of the head of the stud by radial separation of the metal. Such interruptions do not adversely affect the structural strength, corrosion resistance, or other functional requirements of studs.

CC-2622.4.4 Number of Test Specimens

(a) Thirty test specimens shall be welded consecutively with constant optimum time but with current 10% above optimum. Optimum current and time shall

be the midpoint range normally recommended for production welding.

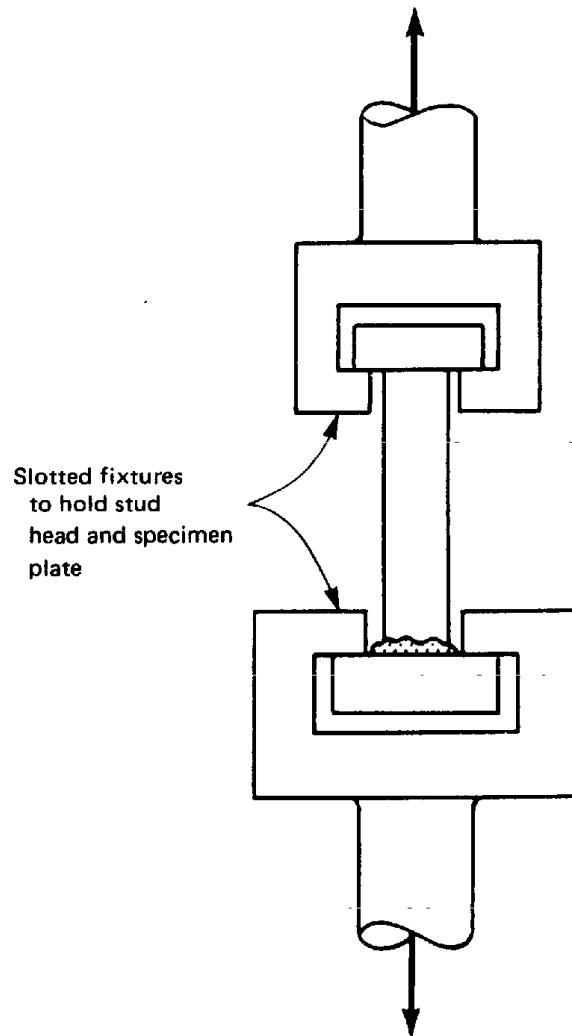


FIG. CC-2620-2 TYPICAL TENSILE TEST FIXTURE

FIG. CC-2620-2 TYPICAL TENSILE TEST FIXTURE

(b) Thirty test specimens shall be welded consecutively with constant optimum time but with current 10% below optimum.

CC-2622.4.5 Tensile Tests

(a) *Number of Tests.* Ten of the specimens welded in accordance with CC-2622.4.4(a) and 10 in accordance with CC-2622.4.4(b) shall be subjected to a tensile test in a fixture similar to that shown in Fig. CC-2620-2, except that studs without heads may be gripped on the unwelded end in the jaws of the tensile testing machine.

(b) *Acceptance Standards.* A stud base shall be considered qualified if all test specimens have a tensile strength equal to or greater than 60.0 ksi (410 MPa).

CC-2622.4.6 Bend Tests

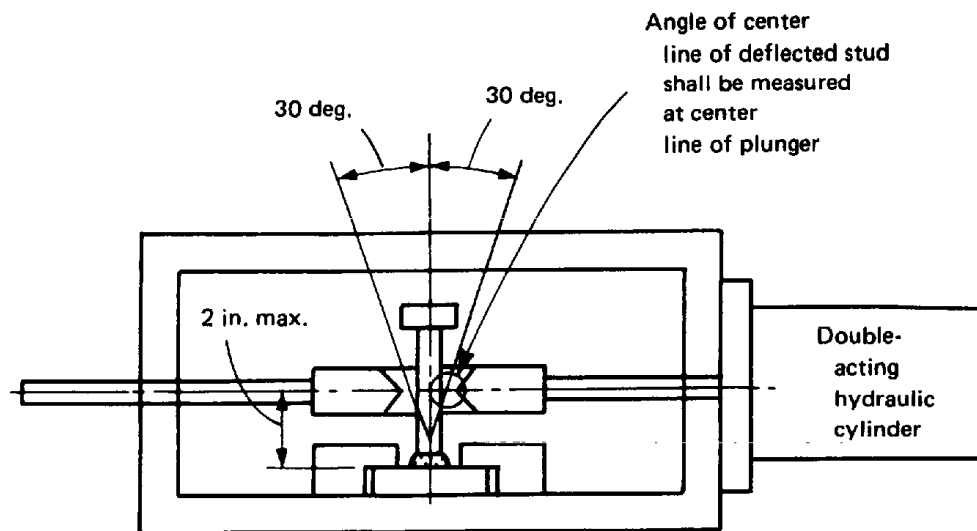
(a) *Number of Tests.* Twenty of the specimens welded in accordance with CC-2622.4.4(a) and 20 in accordance with CC-2622.4.4(b) shall be bend tested by being bent alternately 30 deg. in opposite directions until failure occurs. Studs shall be bent in a bend testing device as shown in Fig. CC-2620-3, except that studs less than $\frac{1}{2}$ in. diameter may be bent using a device as shown in Fig. CC-2620-4.

(b) *Acceptance Standards.* A stud base shall be considered qualified if, on all test specimens, fracture occurs in the shank of the stud or plate material and not in the weld or heat affected zone.

CC-2622.4.7 Retests.

If failure occurs at less than the specified minimum tensile strength of the stud during tensile tests, or in the weld or heat affected zone during bend testing, a new test group as specified in CC-2622.4.4(a) or CC-2622.4.4(b) shall be made and tested. If such failure is repeated, the lot of studs represented shall not be acceptable.

Page 48



GENERAL NOTE:

Fixture holds specimen and stud is bent 30 deg. in opposite directions alternately. Load can be applied with hydraulic cylinder (shown) or fixture adopted for use with tensile test machines.

FIG. CC-2620-3 BEND TESTING DEVICE

FIG. CC-2620-3 BEND TESTING DEVICE

CC-2622.4.8 Acceptance Standards.

For a Manufacturer's stud base and arc shield combination to be qualified, each stud of each group of 30 studs shall, by test or retest, meet the requirements of CC-2622.4.5 and CC-2622.4.6. Qualification of a given diameter of

shall, by test or retest, meet the requirements of CC-2622.4.5 and CC-2622.4.6. Qualification of a given diameter of stud base shall be considered qualification for stud bases of the same nominal diameter, stud base geometry, material flux, and arc shield.

CC-2623 Stud Requirements

CC-2623.1 Chemical Analysis.

A chemical analysis shall be made of each heat of stud material. The analysis shall conform to that required for the material specification.

CC-2623.2 Tensile Requirements

CC-2623.2.1 Tensile Tests.

Tensile tests shall be made on each heat of bar stock after drawing or on full-diameter finished studs. Tensile testing shall be performed in accordance with the applicable paragraphs of SA-370. When the tensile requirements for shear connector studs are determined from finished studs, the tensile tests may be made on studs welded to test plates of P-No. 1 material, using a test fixture similar to that shown in Fig. CC-2620-2. When the tensile requirements for studs other than shear connectors are determined from finished studs, the ends of the studs may be gripped in the jaws of a tensile testing machine. Plates of adequate size may be fillet welded to the unwelded end for studs without heads. If fracture occurs outside the middle half of the gage length, the test shall be repeated.

CC-2623.2.2 Acceptance Standards.

Studs are classified into four types according to strength levels. The tensile test specimens shall conform to the requirements of each type as shown in Table CC-2623.2-1.

CC-2624 Documentation Requirements

The following information shall be incorporated into the Certified Material Test Report (CMTR) in accordance with CC-2130:

- (a) drawings showing shape and dimensions, with tolerances, of studs, arc shields, and flux (when used);
- (b) results of stud base qualification requirements, including a description of the quantity and type of flux, and a description of the arc shield;
- (c) chemical analysis of the bar stock;
- (d) tensile test results from stud tensile tests;
- (e) drawing showing shape and dimensions with tolerances of studs, arc shields, and flux, when used.

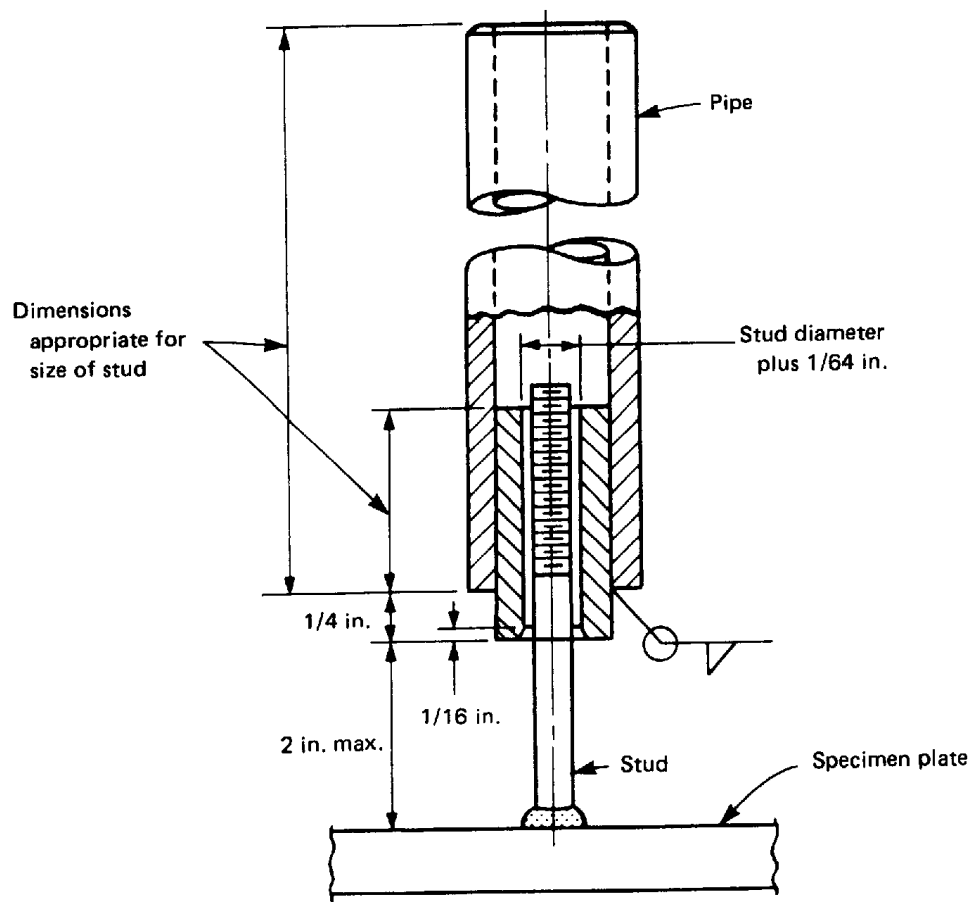


FIG. CC-2620-4 TYPICAL DEVICE FOR BEND TESTING OF SMALL STUDS

FIG. CC-2620-4 TYPICAL DEVICE FOR BEND TESTING OF SMALL STUDS

**TABLE CC-2623.2-1
STRENGTH REQUIREMENTS FOR STUDS**

	Type A [Note (1)]	Type B	Type C [Note (1)]	Type D [Note (1)]
Yield strength, psi (minimum)	...	...	50,000	55,000
Tensile strength, psi (minimum)	55,000	60,000	65,000	75,000
Elongation in 2 in., % (minimum)	20	20	20	20
Reduction of area, % (minimum)	...	50	...	...

NOTE:

(1) Not to be used as shear connector studs.

TABLE CC-2623.2-1 STRENGTH REQUIREMENTS FOR STUDS

CC-2630 IDENTIFICATION OF WELDING MATERIAL

- (a) The identification of welding material (including stud welding material) shall meet the requirements of NCA-3866.6(b).
- (b) Welding material shall be controlled during the repair of material and the manufacture and installation of components so that they are identifiable as accepted material until the material is actually consumed in the process (CC-4122).

CC-2700 MATERIAL FOR EMBEDMENT ANCHORS

CC-2710 INTRODUCTION

This Subarticle establishes the requirements for load bearing steel materials that are embedded in the concrete containment to perform a containment function. These requirements do not apply to liner, liner attachments or anchor components of prestressing systems.

CC-2711 Permitted Material Specifications

The material to be used for the construction of embedment anchors are listed in Table I-2.3 of Appendix I. Material listed in Table I-2.2 may also be used.

CC-2712 Requirements for Nuts and Washers

- (a) Material for nuts shall conform to ASTM A 563 or to the requirements for nuts in the specification for the bolting material which is to be used.
- (b) Nuts shall be threaded to Class 2B or finer tolerances according to ANSI B1.1. Materials for nuts and washers shall be selected as follows.
- (1) Carbon steel nuts and carbon steel washers may be used with carbon steel bolts or studs.
 - (2) Carbon or alloy steel nuts and carbon or alloy steel washers of approximately the same hardness as the nuts may be used with alloy steel bolts or studs.
- (c) Nuts shall be semifinished, extra heavy, chamfered and trimmed.

CC-2720 FRACTURE TOUGHNESS REQUIREMENTS FOR EMBEDMENT ANCHOR

MATERIALS

Fracture toughness requirements for embedment anchor materials shall be in accordance with CC-2520.

CC-2730 EXAMINATION AND REPAIR OF EMBEDMENT ANCHOR MATERIAL

CC-2731 Examination and Repair of Embedment Anchor Material Other Than Bolting

(a) Material for embedment anchors shall be examined in accordance with the material specification. Unacceptable defects may be repaired as permitted by the material specification.

(b) Structural steel rolled shapes, which are permitted by the section to be furnished with a certificate of compliance, may be repaired by welding using welders, documentation, and examination requirements specified in SA-6.

CC-2732 Examination of Bolting Material and Rods¹⁰

Bolts, studs, and nuts shall be examined in accordance with the requirements of the material specification and CC-2733.

CC-2733 Visual Examination

The areas of threads, shanks, and heads of final machined parts shall be visually examined. Imperfections, such as laps, seams, or cracks as defined in ASTM F 788 are unacceptable.

CC-2734 Repair by Welding

Weld repairs of bolting material and rods are not permitted.

CC-2740 MARKING OF EMBEDMENT ANCHOR MATERIAL

10 The word rods as used in this Subarticle is intended to cover rods that are threaded. It also includes forged piston rods if they are threaded for a portion of their length. It does not apply to unthreaded bar stock.

CC-2741 Identification

The identification of material requiring Certified Material Test Reports shall meet the requirements of NCA-3866.6. Material furnished with Certificates of Compliance shall be identified by a controlled system meeting the requirements of the applicable material specification, grade, and class. Identification of the material to the Material Manufacturer's Certificate of

Page 51

Compliance is not required after the embedment anchor manufacturer, or after the Material Supplier who furnishes embedment anchors as material has verified that the material meets the requirements of this Section.

Material for small items shall be controlled during the manufacture of the embedment anchor so that they are identifiable as acceptable material at all times. Welding material shall be controlled during the repair of material and the manufacture and installation of embedment anchors so that it is identifiable as acceptable material until the material is actually consumed in the process.

CC-2800 MATERIAL MANUFACTURER'S QUALITY SYSTEM PROGRAMS

CC-2810 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS

CC-2811 General

Material Manufacturers, Material Suppliers, and Constituent Suppliers shall document and maintain Quality System Programs (NCA-3800, NCA-3900).

CC-2812 Manufacturers of Nonmetallic Material and Constituent Suppliers

Nonmetallic Material Manufacturers and Constituent Suppliers shall have a Quality System Program which meets the

Nonmetallic Material Manufacturers and Constituent Suppliers shall have a Quality System Program which meets the requirements of NCA-3900.

CC-2813 Manufacturers of Metallic Material and Material Suppliers

Material Manufacturers and Material Suppliers shall have a Quality System Program which meets the requirements of NCA-3800.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 CC-3000

ARTICLE CC-3000 DESIGN

Page 53

CC-3100 GENERAL DESIGN

CC-3110 CONCRETE CONTAINMENT

- (a) These design criteria apply to concrete containments with steel reinforcement, prestressed tendons or a combination thereof, and metallic liners.
- (b) The requirements for radiation shielding, allowable leak rate, design life span of the structure, and quantitative values of the design loads shall be presented in the Design Specification.
- (c) The metallic liner shall be designed within limits of stress, strain, and deformation specified in this Article.
- (d) The criteria for the containment as demonstrated by the design calculations shall consider factored as well as service load conditions. For factored load conditions, the following requirements shall be met.
 - (1) Primary forces shall not bring the local section to a general yield state with respect to any component of section membrane strain or section flexural curvature. General yield state is the point beyond which additional section deformation occurs without increase in section forces.
 - (2) Under combined primary and secondary forces on a section, the development of a general yield state with respect to those membrane strains and/or flexural curvatures which correspond to secondary stress components is acceptable, subject to rebar and concrete strain limits in CC-3420. The concept of a general yield state is not applicable to strains associated with radial shear stress.
- (e) The design of parts designated to meet the requirements for Class MC and which are not backed up by concrete for load carrying purposes shall meet the requirements of NE-3000 and Subsection NCA.

CC-3120 METALLIC LINER

CC-3121 General

The liner shall not be used as a strength element. Interaction of the liner with the containment shall be considered in determining maximum strains.

CC-3122 Liner

The general requirements to be used in the design of metallic liners are as follows.

- (a) The liner shall be designed to withstand the effects of imposed loads and to accommodate deformation of the concrete containment without jeopardizing leak-tight integrity.
- (b) The liner shall be welded using weld details which do not jeopardize leak-tight integrity of the containment.

(c) The liner shall be anchored to the concrete containment. This does not preclude local flexural deformation between anchor points.

CC-3123 Liner Anchors

(a) The liner anchorage system shall be designed to accommodate all design loads and deformations without loss of structural or leak-tight integrity.

(b) The anchorage system shall be so designed that a progressive failure of the anchorage system is precluded in the event of a defective or missing anchor.

CC-3124 Penetration Assemblies

Penetration assemblies, including nozzles, reinforcing plates, and penetration anchors, shall be designed to accommodate all design loads and deformations without loss of structural or leak-tight integrity. Effects such as temperature, concrete creep, and shrinkage shall be considered.

CC-3125 Brackets and Attachments

Temporary or permanent brackets and attachments shall be designed to resist the design loads without loss of the liner integrity due to excessive deformation or load from bracket or attachment loads.

Page 58

CC-3130 DEFINITION OF TERMS

CC-3131 Service Load Category

Service loads are any loads encountered during construction and in the normal operation of a nuclear power plant. Included in such loads are any anticipated transient or test loads during normal and emergency startup and shutdown of the nuclear steam supply, safety, and auxiliary systems. Also included in this category are those severe environmental loads which may be anticipated during the life of the facility.

CC-3132 Factored Load Category

Factored loads include loads encountered infrequently, such as severe environmental, extreme environmental, and abnormal loads.

CC-3133 Serviceability

Serviceability defines behavior for service or factored load conditions which are not defined by strength or stress limitations. It includes those items where distortion, concrete crack size, or strain are limited. Examples are weathering of concrete, mechanism distortion at hatches and penetrations, liner leakage, and containment interaction with adjacent structures.

CC-3134 Reinforced Concrete

Reinforced concrete is concrete containing reinforcement and designed on the assumption that the two materials act together in resisting forces.

CC-3135 Prestressed Concrete

Prestressed concrete is reinforced concrete in which there have been introduced internal stresses of such magnitude and distribution that the stresses resulting from loads are counteracted to a desired degree.

CC-3136 Stresses and Forces

CC-3136.1 Membrane Stress.¹

Membrane stress is the component of normal stress, hoop or meridional, which is uniformly distributed and equal to the average of stress across the thickness of the section under consideration.

1 As applied in this Division, not to be substituted for principal stress or stress intensity.

CC-3136.2 Bending Stress.

Bending stress is the variable component of normal stress. The variation may or may not be linear across the thickness.

CC-3136.3 Shear Stress.

Shear stress may be radial, tangential, peripheral (punching), or torsional.

(a) Radial shear stress is a flexural shear stress which acts perpendicular to the plane of the wall or other element of the containment structure.

(b) Tangential shear stress is a membrane shear stress which acts in the plane of the wall or other element of the containment structure.

(c) Peripheral shear stress is a shear stress around a punching type shear surface, produced by local externally applied forces acting perpendicular to the plane of the wall or other element.

(d) Torsional shear stress is a stress in the plane of the wall or other element of the containment structure produced by components of local externally applied moments about an axis perpendicular to the wall or other element.

CC-3136.4 Primary Force.

Primary force is a local, internal force (kips/ft) or moment (kip-ft/ft) which is required to equilibrate applied loads. In some regions of the shell, and for some loadings, there is a redundancy of internal force systems. In such cases the primary, load equilibrating force system shall be justified in the Design Report.

CC-3136.5 Secondary Force.

Secondary force is a local, internal force (kips/ft) or moment (kip-ft/ft) which is not required for equilibrating the applied loads. Thus, a secondary force may be either:

(a) a local, internal, force, or moment which results from applied loads, but which is not required to equilibrate such loads; or

(b) a local, internal force, or moment which results from nonload, volume change effects, such as shrinkage strain and thermal strain.

CC-3136.6 Classification of Forces.

Forces shall be classified in accordance with Table CC-3136.6-1.

CC-3140 TOLERANCES

The Construction Specification shall delineate the tolerance requirements for fabrication and construction. The Designer shall ensure that the tolerances specified in the Construction Specification are compatible with the design assumptions.

TABLE CC-3136.6-1
CLASSIFICATION OF FORCES IN CONCRETE CONTAINMENTS FOR STEEL REINFORCING
AND CONCRETE ALLOWABLE STRESSES¹

Location	Origin of Loads	Type of Force	Classification
Regions away from discontinuities	External (2)	Membrane	Primary
		Bending	Primary
		Shear (3)	Primary
	Volume change effects such as creep shrinkage and thermal strains	Membrane	Secondary
		Bending	Secondary
		Shear	Primary
Regions at and near gross changes in shell geometry	External (2)	Membrane	Primary
		Bending	Primary (4)
		Shear	Primary
	Volume change effects such as creep shrinkage and thermal strains	Membrane	Secondary
		Bending	Secondary
		Shear	Primary
Regions near large openings	External (2)	Membrane	Primary
		Bending	Primary
		Shear	Primary
	Volume change effects such as creep shrinkage and thermal strains	Membrane	Secondary
		Bending	Secondary
		Shear	Primary

NOTES:

- (1) Allowable stresses for concrete may be considered secondary in the region defined in CC-3422.1(c)(3).
(2) Includes prestressing.
(3) Includes both radial and tangential shear force.
(4) For allowable stresses, bending at discontinuities due to external loads is considered primary.

TABLE CC-3136.6-1 CLASSIFICATION OF FORCES IN CONCRETE CONTAINMENTS FOR STEEL REINFORCING AND CONCRETE ALLOWABLE STRESSES¹

CC-3200 LOAD CRITERIA

CC-3210 GENERAL

The containment shall be designed to resist the loads and load combinations given in this Article and as specified in the Design Specification (NCA-3250). The design shall not be limited to the loads specified herein if any other loads are applicable to the particular site conditions.

CC-3220 LOAD CATEGORIES

CC-3221 Service Loads

CC-3221.1 Normal Loads.

Normal loads are loads which are encountered during normal plant operation and shutdown.

- D* = dead loads, including hydrostatic and permanent equipment loads
- L* = live loads, including any movable equipment loads and other loads which vary with intensity and occurrence, such as

	soil pressures
F	= loads resulting from the application of prestress
G	= loads resulting from relief valve or other high energy device actuation
T_o	= thermal effects and loads during normal operating or shutdown conditions, based on the most critical transient or steady state condition
R_o	= pipe reactions during normal operating or shutdown conditions, based on the most critical transient or steady state condition
P_v	= external pressure loads resulting from pressure variation either inside or outside the containment

CC-3221.2 Construction Loads.

Construction loads are loads which are applied to the containment from start to completion of construction. The definitions for D , L , F , and T_o given in CC-3221.1 are applicable but shall be based on construction conditions.

Page 60

CC-3221.3 Test Loads.

Test loads are loads which are applied during structural integrity or leak rate testing. The definitions for D , L , and F given in CC-3221.1 are applicable but shall be based on test conditions. In addition, the following shall also be considered:

P_t	= pressure during the structural integrity and leak rate tests
T_t	= thermal effects and loads during the test

CC-3222 Factored Loads

CC-3222.1 Severe Environmental Loads.

Severe environmental loads are loads that could infrequently be encountered during the plant life.

W	= loads generated by the design wind specified for the plant site
E_o	= loads generated by the operating basis earthquake. Only the actual dead load and existing live load weights need be considered in evaluating seismic response forces.

CC-3222.2 Extreme Environmental Loads.

Extreme environmental loads are loads which are credible but are highly improbable.

E_{ss}	= loads generated by the safe shutdown earthquake. Weights considered shall be the same as for E_o .
W_t	= tornado loading including the effects of missile impact. Included in W_t are the following:
W_{tq}	= the loads due to tornado wind pressure

W_{tp}

= the differential pressure loads due to rapid atmospheric pressure change

W_{tm}

= the tornado generated missile impact effects. The type of impact, such as plastic or elastic, together with the ability of the structure to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the impact.

CC-3222.3 Abnormal Loads.

Abnormal loads are loads generated by the design basis accident (DBA).

H_a

= load on the containment resulting from internal flooding, if such an occurrence is defined in the Design Specification as a design basis event

P_a

= Design Pressure load within the containment generated by the DBA, based upon the calculated peak pressure with an appropriate margin

T_a

= thermal effects and loads generated by the DBA including T_o

R_a

= pipe reaction from thermal conditions generated by the DBA including R_o

R_r

= the local effects on the containment due to the DBA. The local effects shall include the following:

R_{rr}

= load on the containment generated by the reaction of a ruptured high energy pipe during the postulated event of the DBA. The time-dependent nature of the load and the ability of the containment to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the effects of R_{rr} .

R_{rj}

= load on the containment generated by jet impingement from a ruptured high energy pipe during the postulated event of the DBA. The time-dependent nature of the load and the ability of the containment to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the effects of R_{rj} .

R_{rm}

= the load on the containment resulting from the impact of a ruptured high energy pipe during the DBA. The type of impact, for example, plastic or elastic, together with the ability of the containment to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the impact.

CC-3230 LOAD COMBINATIONS

(a) Table CC-3230-1 lists the load combinations and applicable load factors for which the containment shall be designed.

(b) The live load shall be considered to vary from zero to full value for all load combinations.

(c) The maximum effects of P_a , T_a , R_a , R_r , and G shall be combined unless a time-history analysis is performed to justify lower combined values.

CC-3240 LOAD DEFINITIONS

CC-3241 Static and Seismic Loads

Static loads are defined as those loads which are considered to remain constant with respect to time or which have a long period of application or rise time relative to the response period of the containment. This category also includes seismic loads for which the dynamic effects have been included in their determination. The following are examples of loads in this category:

- (a) dead load D , live load L , and prestress F ;
- (b) accident pressure P_a ;
- (c) pipe reactions during normal and postulated accident conditions R_o and R_a ;

Page 61

TABLE CC-3230-1
LOAD COMBINATIONS AND LOAD FACTORS

Category	D	$L(1)$	F	P_t	G	P_a	T_t	T_o	T_a	E_o	E_{ss}	W	W_t	R_o	R_a	R_r	P_v	H_a
Service																		
Test	1.0	1.0	1.0	1.0	...	...	1.0	...	...	...	...	...	...	...	...	...	...	...
Construction	1.0	1.0	1.0	...	...	...	...	1.0	...	...	...	1.0	...	...	...	...	...	...
Normal	1.0	1.0	1.0	...	1.0	...	...	1.0	...	...	...	...	...	1.0	...	...	1.0	...
Factored																		
Severe environmental	1.0	1.3	1.0	...	1.0	...	...	1.0	...	1.5	...	...	...	1.0	...	...	1.0	...
	1.0	1.3	1.0	...	1.0	...	...	1.0	...	...	...	1.5	...	1.0	...	...	1.0	...
Extreme environmental	1.0	1.0	1.0	...	1.0	...	...	1.0	...	...	1.0	...	...	1.0	...	...	1.0	...
	1.0	1.0	1.0	...	1.0	...	...	1.0	...	...	...	...	1.0	1.0	...	...	1.0	...
Abnormal	1.0	1.0	1.0	...	1.0	1.5	...	...	1.0	...	...	...	...	...	1.0	...	...	...
	1.0	1.0	1.0	...	1.0	1.0	...	...	1.0	...	...	...	...	...	1.25	...	...	...
	1.0	1.0	1.0	...	1.25	1.25	...	...	1.0	...	...	...	...	...	1.0	...	...	...
Abnormal/severe environmental	1.0	1.0	1.0	...	1.0	1.25	...	...	1.0	1.25	...	...	...	...	1.0	...	...	...
	1.0	1.0	1.0	...	1.0	1.25	...	...	1.0	...	...	1.25	...	...	1.0	...	...	...
	1.0	1.0	1.0	...	1.0	...	...	1.0	...	1.0	...	...	...	...	...	...	1.0	...
	1.0	1.0	1.0	...	1.0	...	...	1.0	...	...	...	1.0	...	...	...	...	...	1.0
Abnormal/extreme environmental	1.0	1.0	1.0	...	1.0	1.0	...	...	1.0	...	1.0	...	...	...	1.0	1.0	...	...

NOTE:

(1) Includes all temporary construction loading during and after construction of containment.

TABLE CC-3230-1 LOAD COMBINATIONS AND LOAD FACTORS

- (d) design wind W , tornado wind pressure W_{tg} , and differential pressure W_{tp} ;
- (e) operating and safe shutdown earthquake, E_o and E_{ss} , except when combined with impulse loading and impact effects.

CC-3242 Impulse Loads

Impulse loads are time dependent and include the following:

- (a) the dynamic effects of accident pressure P_a where rate of loading affects the response of the structure;
- (b) the effects of pipe rupture reactions R_{rr} and jet impingement loading R_{rj} ;
- (c) the dynamic effects of valve actuation G such as steam relief valve or other high energy device actuation effects where rate of loading affects the response of the structure.

CC-3243 Impact Effects

Impact effects are those that can be specified in terms of kinetic energy at impact. These include the impact energies resulting from tornado missiles W_{tm} , pipe rupture generated missiles R_{rm} , and any other specific site-dependent missiles, including the case where a gap exists between the pipe and its structural restraint.

CC-3300 CONTAINMENT DESIGN ANALYSIS PROCEDURES

CC-3310 GENERAL

- (a) Methods of analysis which are based on accepted principles of engineering mechanics and which are appropriate to the geometry of the containment shall

Page 62

be used. In the design of local sections, consideration shall be given to the redistribution of moments and forces in a statically indeterminate structure because of cracking of the concrete, and to the stiffening effect of buttresses or other integral portions of the containment.

- (b) The short-term as well as the long-term foundation soil properties shall be considered. In order to ensure consideration of the critical condition, a range of values of soil constants shall be considered.

- (c) For prestressed containments, the analytical methods selected for construction and normal category load combinations shall account for the creep characteristics and the thick section geometry that is characteristic at ring girders and buttresses.

CC-3320 SHELLS

- (a) Containments are normally thin shell structures. Elastic behavior shall be the accepted basis for predicting internal forces, displacements, and stability of thin shells. Effects of reduction in shear stiffness and tensile membrane stiffness due to cracking of the concrete shall be considered in methods for predicting maximum strains and deformations of the containment. Equilibrium check of internal forces and external loads shall be made to ensure consistency of results.

- (b) Although shell analysis may be based on membrane theory, additional consideration is required for bending and shear forces at penetrations, intersection with base mat, discontinuities, and the stresses and strains caused by temperature variations.

- (c) The stability of the containment shall be verified, giving consideration to the possible reduction in the buckling capacity caused by large deflections, creep effects, and specified construction tolerances.

- (d) Model tests may be used instead of the design analysis if they are conservative and represent the prototype containment.

- (e) Model tests may be used to check the validity of assumptions involved in mathematical analysis.

CC-3330 BASE MAT, FRAMES, BOX TYPE STRUCTURES, AND ASSEMBLIES OF SLABS

Analyses based on elastic behavior, or other methods generally accepted in conventional practice, shall be used. Effects of discontinuities and loading from the foundation soils shall be considered.

CC-3340 PENETRATIONS AND OPENINGS

- (a) Careful attention shall be given to the analysis of the containment in the vicinity of openings. The effect of an opening

on the overall containment shall be considered and the containment shall be thickened around the opening, if necessary, to satisfy allowable stresses and facilitate concrete placement.

(b) The thermal stresses caused by process piping passing through the wall shall be considered.

CC-3400 CONCRETE CONTAINMENT STRUCTURE DESIGN ALLOWABLES

CC-3410 GENERAL

In order to keep the containment basically elastic under service load conditions and below the range of general yield under factored primary loads, the allowable stresses and strains specified in this Subarticle shall be used. The allowable stresses given in CC-3421, CC-3422, CC-3423, CC-3431, CC-3432, and CC-3433 shall not be exceeded when the containment is subjected to the loads given in Table CC-3230-1.

CC-3420 ALLOWABLE STRESS FOR FACTORED LOADS

CC-3421 Concrete

CC-3421.1 Compression.

The allowable stresses for factored compression loads are summarized in Table CC-3421-1. These allowables shall be reduced, if necessary, to maintain structural stability.

CC-3421.2 Tension.

Concrete tensile strength shall not be relied upon to resist flexural and membrane tension.

CC-3421.3 Shear.

If the calculated shear is greater than the allowables given in the following paragraphs, then reinforcement or prestressing forces shall be provided in accordance with CC-3520.

CC-3421.4 Radial Shear.

Radial shear is a transverse shear and is similar to shear in beam analysis. It occurs in the vicinity of discontinuities in shell flexural or membrane behavior. An example of radial shear is the shear caused by self-constraint of a cylinder and base mat during pressurization of the containment. Another example is the shear in the base mat caused by primary vertical forces in structures supported by the mat. A third example is the shear resulting from discontinuity

Page 63

effects which can occur at the perimeter of penetrations or near other concentrated loads. In this example, peripheral shear must also be considered.

TABLE CC-3421-1
ALLOWABLE COMPRESSION STRESSES FOR FACTORED LOADS

Primary		Primary Plus Secondary [Note (1)]	
Membrane	Membrane Plus Bending [Note (2)]	Membrane	Membrane Plus Bending [Note (2)]
$0.60 f'_c$			
	$0.75 f'_c$		
		$0.75 f'_c$	
			$0.85 f'_c$ [Note (3)]

NOTES:

- (1) The primary portion of this calculated stress shall not exceed the allowable stress applicable when primary stress acts alone.
- (2) The membrane portion of this calculated stress shall not exceed the allowable stress applicable when membrane stress acts alone.
- (3) The maximum allowable primary-plus-secondary membrane and bending compressive stress of $0.85 f'_c$ corresponds to a limiting strain of 0.002 in./in.

CC-3421-1 ALLOWABLE COMPRESSION STRESSES FOR FACTORED LOADS

CC-3421.4.1 Reinforced Concrete

(a) The nominal shear stress v_c shall not exceed the lesser of:

$$(1) v_c = 3.5 \sqrt{f'_c}$$

$$(2) v_c = [(1.9 \rho \sqrt{f'_c} / 0.015) + 2500 \rho (V_u d / M_u)]$$

for $\rho < 0.015$, and

$$(3) v_c = 1.9 \sqrt{f'_c} + 2500 \rho (V_u d / M_u)$$

for $\rho \geq 0.015$, where $(V_u d / M_u)$ shall not exceed 1.0.

(b) For sections subjected to membrane compression either Eq. (4) or (5) may be used, but v_c shall not be larger than the value given by Eq. (6):

$$(4) v_c = 1.9 \sqrt{f'_c} + 2500 \rho (V_u d / M')$$

where $M' = M_u - N_u [(4t - d)/8]$ then M' can be less than $V_u d$. If M' is negative, use Eq. (6).

$$(5) v_c = 2(1 + 0.0005 N_u / A_g) \sqrt{f'_c}$$

$$(6) v_c = 3.5 \sqrt{f'_c} \sqrt{1 + 0.002 N_u / A_g}$$

The units for N_u / A_g are psi, and N_u is positive for compression.

(c) For sections subjected to membrane tension, Eq. (7) shall be used with N_u negative for tension:

$$(7) v_c = 2.0 \sqrt{f'_c} (1 + 0.002 N_u / A_g)$$

When $v_u \leq 0.5\sqrt{f'_c}$, v_c may be taken to equal v_u .

CC-3421.4.2 Prestressed Concrete.

The allowable shear stress v_e shall be the lesser of v_{ci} or v_{cw} , as calculated by Eqs. (8) and (9):

Page 64

$$v_{cw} = 3.5\sqrt{f'_c} \sqrt{1 + \frac{f_{pc}}{3.5\sqrt{f'_c}}} \quad (8)$$

$$v_{ci} = K\sqrt{f'_c} + \frac{(M_{cr} - M_i) \frac{V}{M} + V_i}{b'd} \quad (9)$$

(8-9)

For $\rho \geq 0.003$, $K = 1.75 - (0.036/\rho) + 4.0\rho$, but not less than 0.6.

For $\rho < 0.003$, K shall be taken as zero.

$$M_{cr} = (I/y_t) (6\sqrt{f'_c} + f_{pc})$$

and

$$n = 505/\sqrt{f'_c}$$

- (a) Loads shall be applied in their chronological order.
- (b) The loads at a particular time shall be divided into the following two categories:
 - (1) the applied load or loads;
 - (2) those loads existing prior to application of the applied load or loads under consideration.
- (c) If the actual chronological loading order cannot be determined between two or more loads, then the load with the least V/M ratio at the section under consideration shall be applied first.
- (d) If $(M_{cr} - M_i)$ is not positive in sign, then it shall be considered as zero.
- (e) All existing and applied shear loads shall be taken at the section under consideration.
- (f) All moments and other loads affecting the determination of M_{cr} shall be taken at a distance $d/2$ from the section being investigated for shear measured in the direction of decreasing moment.
- (g) If the section under consideration is subjected to membrane tension, then Eq. (7) shall be used in conjunction with Eqs. (8) and (9) with the lowest value of v_c used in the design.

(h) The following definitions shall be used:

V	= the applied shear load at the section under consideration
M	= the applied moment associated with the applied shear load
V_i	= the existing shear loads at the section under consideration (positive if applied in the same direction as V)
M_i	= the existing moments associated with the existing shear loads (positive if applied in the same direction as the applied moments)
M_{cr}	= the moment necessary to cause cracking (always positive)
f_{pc}	= the membrane stress, due to all loads, in the concrete at the centroid of the section where V is applied (positive if compression)
I	= moment of inertia at the distance $d/2$ from the section being investigated for shear, measured in the direction of decreasing moment
y_t	= distance from the centroidal axis of gross section, neglecting the reinforcement, to the extreme fiber in tension
ρ	= A_s/bd , ratio of bonded tension reinforcement

CC-3421.5 Tangential Shear.

Tangential shear is a membrane shear in the plane of the containment shell resulting from lateral load such as earthquake, wind, or tornado loading.

CC-3421.5.1 Reinforced Concrete.

No tangential shear strength shall be considered as provided by the concrete, i.e.,

$$V_c = 0$$

CC-3421.5.2 Prestressed Concrete.

Where a minimum prestress as defined in CC-3521.1.2 is present,

$$V_c = 4\sqrt{f'_c} bt \sqrt{1 + \left[\frac{f_m + f_h}{4\sqrt{f'_c}} \right] + \left[\frac{f_m f_h}{(4\sqrt{f'_c})^2} \right]} \quad (10)$$

(10)

where f_m and f_h are membrane stresses respectively in meridional and hoop directions, compression positive, psi. Thermal membrane stresses shall be included in f_m and f_h

CC-3421.6

CC-3421.6 Peripheral Shear.

Peripheral shear is a transverse shear and is similar to punching shear in slab analysis. It is the shear resulting from a concentrated force or reaction acting transverse to the plane of the wall. An example of peripheral shear is the transverse shear associated with a local concentrated load. Another example of peripheral shear is the transverse shear which can occur at the perimeter of penetrations. In this example, radial shear must also be considered.

(a) The value of v_c shall be calculated as a weighted average of v_{ch} and v_{cm} ; v_{ch} is the allowable shear stress on a failure surface perpendicular to a meridional line, and v_{cm} is the allowable shear stress on a meridional failure surface perpendicular to the plane of the shell. For a circular failure surface, v_c is the average of v_{ch} and v_{cm} .

(b) When the membrane stress f_h or f_m is tensile, the peripheral or punching shear stress taken by the

Page 65

concrete on the assumed failure surface at loaded areas that are circular, square, or rectangular with an aspect ratio β_c less than 2, shall not exceed v_c as obtained in (a) above.

For $f_h/\rho'_h f_y \geq (-0.9)$

$$v_{cm} = \sqrt{f_c} (4 + k_p f_h/\rho'_h f_y)$$

For $f_h/\rho'_h f_y < (-0.9)$

$$v_{cm} = 0.5\sqrt{f_c}$$

and

For $f_m/\rho'_m f_y \geq (-0.9)$

$$v_{ch} = \sqrt{f_c} (4 + k_p f_m/\rho'_m f_y)$$

For $f_m/\rho'_m f_y < (-0.9)$

$$v_{ch} = 0.5\sqrt{f_c}$$

where

f_m	= concrete membrane stress in meridional direction, compression positive, psi
f_h	= concrete membrane stress in hoop direction, compression positive, psi
β_c	= ratio of long side to short side of loaded rectangular area
ρ'_h	= hoop direction reinforcing ratio based on wall thickness t
ρ'_m	= meridional direction reinforcing ratio based on wall thickness t
k_p	= adjustment factor for penetrations = $1 + 2.9d_p/t$ (not to exceed 3.9)
d_p	= average outside diameter of penetration in containment wall
t	= containment wall thickness

When the aspect ratio β_c of the loaded rectangular area is greater than 2, and when v_{cm} or v_{ch} is greater than $0.5\sqrt{f_c}$, the values of v_{cm} or v_{ch} shall be reduced by the factor $(1/2 + 1/\beta_c)$.

(c) Where the membrane stress f_h or f_m is compressive but less than 125 psi, v_{cm} or v_{ch} shall be taken equal to $4\sqrt{f_c}$.

(d) For load conditions where the membrane stress f_h or f_m , as defined above, is at least 125 psi compression, the peripheral or punching shear taken by the concrete on the assumed failure surface shall not exceed v_c as obtained in (a) above:

$$v = 3.5\sqrt{f_c} + 0.3f$$

$$cm \quad c \quad h$$

$$v_{ch} = 3.5\sqrt{f'_c} + 0.3f_m$$

where f'_c shall not be taken as greater than 5000 psi and neither f_h nor f_m shall be taken greater than 500 psi.

CC-3421.6.1 Critical Section.

The failure surface for peripheral shear shall be perpendicular to the surface of the containment and located so that its periphery is at a distance $d/2$ from the periphery of the concentrated load or reaction area, except for impact loads where the critical section is defined in CC-3931.

CC-3421.7 Torsion.

Torsional shear stress is a local, in-plane shear stress produced in the containment wall by a direct external torsional loading applied about an axis normal to the containment wall. In the case of piping penetrations normal to and anchored in the containment wall, the applicable loading is the torsional moment in the penetration. When the penetration is on a skew from the containment wall, the applicable loading is the sum of the components, along an axis normal to the containment, of the internal moments (torsion and bending) in the penetration. Such a loading and anchorage will produce in-plane shear stress in the concrete normal to a radius from the center line of the penetration.

(a) The shear stress carried by the concrete v_{ct} resulting from a torsional loading shall not exceed v_{ct} as calculated from the following equation:

$$v_{ct} = 6\sqrt{f'_c} \sqrt{1 + \frac{f_h + f_m}{6\sqrt{f'_c}} + \frac{f_m f_h}{(6\sqrt{f'_c})^2}} \quad (11)$$

(11)

but need not be taken less than $4\sqrt{f'_c}$.

(b) The torsional shear failure surface shall be a cylindrical surface perpendicular to the surface of the containment and located at a distance r from the center line of the penetration or embedment plate.

Failure surfaces located nearer to the center line than $r_{\min}$ need not be evaluated.

(c) The following definitions shall be used:

r

= the distance measured along a radial line from the center of a containment piping penetration or embedded plate to the failure surface, in.

$r_{\min}$

= the distance measured along a radial line from the center of a containment penetration to the end of penetration anchors attached normal to the penetration wall, or the radial distance from the center line of containment penetration or embedded plate to the center line of the furthest

CC-3421.8 Brackets and Corbels

CC-3421.8.1 General.

These provisions shall apply to brackets and corbels with a shear span-to-depth ratio a/d not greater than unity, and subject to a horizontal tensile force N_{uc} not larger than V_u . Distance d shall be measured at face of support.

CC-3421.8.2 Depth.

Depth at outside edge of bearing area shall not be less than $0.5d$.

CC-3421.8.3 Design.

Section at face of support shall be designed to resist simultaneously a shear V_u , a moment $[V_u a + N_{uc}(h-d)]$, and a horizontal tensile force N_{uc} .

(a) In all design calculations in accordance with these provisions, the nominal shear stress v_u shall be computed as

$$v_u = \frac{V_u}{0.85bd}$$

where V_u is the factored shear force at the section.

(b)(1) Design of shear-friction reinforcement A_{vf} to resist shear V_u shall be in accordance with CC-3424.

(2) The nominal shear stress v_u shall not exceed $0.2f_c$ nor 800 psi (5520 kPa).

(c) Reinforcement A_f to resist moment $[V_u a + N_{uc}(h-d)]$ shall be computed in accordance with CC-3500.

(d) Reinforcement A_n to resist tensile force N_{uc} shall be determined from $N_{uc} \leq 0.85A_n f_y$. Tensile force N_{uc} shall not be taken less than $0.2V_u$ unless special provisions are made to avoid tensile forces. Tensile force N_{uc} shall be regarded as a live load even when tension results from creep, shrinkage, or temperature change.

(e) Area of primary tension reinforcement A_3 shall be made equal to the greater of $(A_f + A_n)$ or $(2A_{vf}/3 + A_n)$.

CC-3421.8.4 Stirrups.

Closed stirrups or ties parallel to A_3 , with a total area A_h not less than $0.5(A_3 - A_n)$, shall be uniformly distributed within two-thirds of the effective depth adjacent to A_3 .

CC-3421.8.5 Reinforcement Ratio.

Ratio $\rho = A_3/bd$ shall not be less than $0.04(f_c/f_y)$.

CC-3421.8.6 Anchorage.

At front face of bracket or corbel, primary tension reinforcement A_3 shall be anchored by one of the following:

- (a) by a structural weld to a transverse bar of at least equal size; weld to be designed to develop specified yield strength f_y of A_3 bars;
- (b) by bending primary tension bars A_3 back to form a horizontal loop; or
- (c) by some other means of positive anchorage.

CC-3421.8.7 Bearing Area.

Bearing area of load on bracket or corbel shall not project beyond straight portion of primary tension bars A_3 , nor project beyond interior face of transverse anchor bar (if one is provided).

CC-3421.9 Bearing.

Bearing stresses shall not exceed $0.6f_c$ except as provided below.

(a) When the supporting surface is wider on all sides than the loaded area or otherwise confined, the permissible bearing stress on the loaded area may be multiplied by $\sqrt{A_2/A_1}$ but not by more than 2.

(b) When the supporting surface is sloped or stepped, A_2 may be taken as the area of the lower base of the largest frustum of a right pyramid or cone contained wholly within the support and having for its upper base the loaded area, and having side slopes of one vertical to two horizontal.

(c) This Subsection does not apply to post-tensioning anchorages.

CC-3422 Reinforcing Steel

CC-3422.1 Tension

(a) The design yield strength of reinforcement shall not exceed 60,000 psi (410 MPa).

(b) The allowable stress for load resisting purposes shall not exceed $0.9f_y$.

(c) Under the primary forces only, the tensile strain in reinforcement resisting membrane and flexural components of the local section forces (but not the strain in reinforcement resisting local section shear forces) may exceed $0.9\epsilon_y$, provided a sufficient number of reinforcement bars remains below $0.9\epsilon_y$, such that attainment of a general yield state is precluded with respect to any components of curvature. Reinforcement may be permitted to exceed $0.9\epsilon_y$ under the effects of primary forces for the following conditions only.

(1) *Primary Bending Moment.* If more than one layer of reinforcement is provided to resist primary bending moments, one or more layers of reinforcement may be permitted to exceed $0.9\epsilon_y$, provided the strain at the centroid of all bars more than $h/6$ from the center of the concrete section on the maximum tension side of the section shall not exceed $0.9\epsilon_y$.

(2) *Tension Diagonal Reinforcement.* The strain in a tension diagonal reinforcement of a four-way

Page 67

reinforcement system to primary forces may exceed $0.9\epsilon_y$. To avoid the possible buckling of compression diagonal reinforcement, either the diagonal reinforcement shall be enclosed by at least one layer of hoop reinforcement or the tension and compression diagonal reinforcement shall be tied at their intersections.

(3) *Adjacent to Large Openings.* The maximum strain in reinforcement adjacent to large openings may exceed $0.9\epsilon_y$, provided that, when a section of width one-half nominal containment shell thickness h extending from the opening or 25% of the opening diameter, whichever is smaller, is analyzed for the total forces and moments assumed uniformly distributed over the section width, no reinforcement strain shall exceed $0.9\epsilon_y$.

distributed over the section width, no reinforcement strain shall exceed $0.9\epsilon_y$.

(d) Under combined primary and secondary forces, the tensile strain in reinforcement may exceed $0.9\epsilon_y$.

(e) Calculated tensile strains in any reinforcement due to primary forces and the major principal membrane strain due to primary forces shall not exceed $2\epsilon_y$. For analysis purposes, ϵ_y is defined as the yield stress divided by Young's modulus.

CC-3422.2 Compression

(a) For load resisting purposes, the stress shall not exceed $0.9f_y$.

(b) The strains may exceed yield when acting in conjunction with the concrete if the concrete requires strains larger than the reinforcing yield to develop its capacity.

CC-3423 Tendon System Stresses

The axial tensile capacity of the tendon shall not be taken as greater than $0.9f_{py}$.

CC-3424 Shear Friction

CC-3424.1 General.

The provisions of CC-3424 shall apply to brackets and corbels designed in accordance with CC-3421.8.

CC-3424.2 Crack Location.

A crack shall be assumed to occur along the shear plane considered. Required area of shear-friction reinforcement A_{vf} across the shear plane may be designed using either CC-3424.3 or any other shear transfer design methods that result in prediction of strength in substantial agreement with results of comprehensive tests.

CC-3424.3 Shear-Friction Design Method

CC-3424.3.1

When shear-friction reinforcement is perpendicular to shear plane, the area of reinforcement required shall be computed by

$$A_{vf} = \frac{V_u}{0.85\mu f_y}$$

where μ is the coefficient of friction in accordance with CC-3424.3.3 and V is the factored shear force at section.

CC-3424.3.2

When shear-friction reinforcement is inclined to shear plane, such that the shear force produces tension in shear-friction reinforcement, the area of reinforcement required shall be computed by

$$A_{vf} = \frac{V_u}{0.85 f_y (\mu \sin \alpha_f + \cos \alpha_f)}$$

where α_f is the angle between shear-friction reinforcement and shear plane. This equation is not valid if α_f is greater than 90 deg.

CC-3424.3.3

Coefficient of friction μ in CC-3424.3.1 and CC-3424.3.2 shall be:

- (a) 1.4 for concrete placed monolithically;
- (b) 1.0 for concrete placed against hardened concrete with surface intentionally roughened as specified in CC-3424.8;
- (c) 0.6 for concrete placed against hardened concrete not intentionally roughened;
- (d) 0.7 for concrete anchored to as-rolled structural steel by headed studs or by reinforcing bars (see CC-3424.9).

CC-3424.4 Maximum Shear.

The shear friction provisions of CC-3424 are not applicable if the nominal shear stress v_u exceeds $0.2f_c$ or 800 psi (5520 kPa).

CC-3424.5 Strength of Reinforcement.

Design yield strength of shear-friction reinforcement shall not exceed 60,000 psi (410 MPa).

CC-3424.6 Tension.

Net tension across shear plane shall be resisted by additional reinforcement. Permanent net compression across shear plane may be taken as additive to the force in the shear-friction reinforcement A_{vf} when calculating required A_{vf} .

CC-3424.7 Anchorage.

Shear-friction reinforcement shall be appropriately placed along the shear plane and shall be anchored to develop the specified yield strength on both sides by embedment, hooks, or welding to special devices.

CC-3424.8 Concrete-to-Concrete Interface.

For the purpose of CC-3424, when concrete is placed against previously hardened concrete, the interface for shear transfer shall be clean and free of laitance. If μ is

assumed equal to 1.0, the construction specification shall include requirements for roughening and cleaning the hardened surface.

CC-3424.9 Concrete-to-Steel Interface.

When shear is transferred between as-rolled steel and concrete using headed studs or welded reinforcing bars, steel shall be clean and free of paint.

CC-3430 ALLOWABLE STRESSES FOR SERVICE LOADS

CC-3431 Concrete Stresses

CC-3431.1 Compression.

The allowable stresses for service compression loads are summarized in Table CC-3431-1. Compression under the tendon end anchor bearing plates shall not exceed $0.6f_{ci}(A_2/A_1)^{1/3}$. The compression stress shall be calculated by dividing the initial tendon force at anchoring by the net area of the bearing plate, but shall not be greater than f_{ci} . These allowables shall be reduced, if necessary, to maintain the structural stability.

CC-3431.2 Tension.

Concrete tensile strength (membrane and flexure) shall not be relied upon to resist the external loads and moments or the forces and moments resulting from internal self-constraint.

CC-3431.3 Shear, Torsion, and Bearing

(a) The allowable concrete stresses and the limiting maximum stresses for shear, torsion, and bearing shall be 50% of the values given for factored loads in CC-3421.3 through CC-3421.9, except as follows.

(1) In CC-3421.4.1(c) and CC-3421.6(b), the allowable concrete stress need not be reduced below $0.5\sqrt{f_c}$.

(2) The allowable concrete stress shall be 67% of the values given for factored loads in load combinations that include the temporary pressure loads during the test condition or the temporary loads from prestressing which will decrease at completion of prestressing.

(3) The allowable concrete stress shall be 67% of the values given for factored loads when secondary forces, defined in Table CC-3136.6-1, are combined with other forces, provided the section thus required is not less than that required for the combination of other loads in the loading combination.

(b) The computed membrane stress on the gross section resulting from service loads shall be multiplied by 2 and substituted for N_u/A_g , f_m , F_p , or f_{pc} in invoking the provisions of CC-3421.4.1, CC-3421.4.2, CC-3421.6, and CC-3421.7, except in those instances listed in (a) above, where 67% of the values given for factored loads is specified, in which case a 1.5 multiplier shall be used.

(c) Reinforcement requirements for brackets and corbels shall be computed using a factor of $0.5f_y$ instead of the $0.85f_y$ given in CC-3421.8 and CC-3424.

CC-3432 Reinforcing Steel Stresses and Strains

CC-3432.1 Bar Tension

(a) The average tensile stress shall not exceed $0.5f_y$.

(b) The calculated average stress for the reinforcing in zones which have predicted concrete tension due to prestressing loads shall not exceed $0.5f_y$. The maximum load considered need not exceed the initial force at tendon anchoring. The values given in (a) above may be increased by $33\frac{1}{3}\%$ when the following loads are combined with other loads in the load combination:

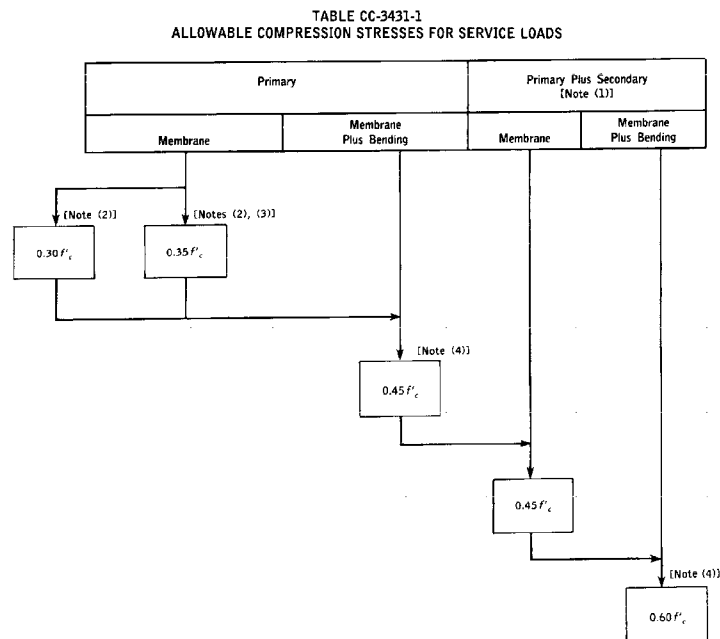
- (1) the temporary loads from prestressing which will reduce at completion of prestressing;
- (2) when secondary forces, defined in Table CC-3136.6-1, are combined with other forces, provided the section thus required is not less than that required for the combination of other loads in the loading combination.
- (c) The values given in (a) above may be increased by 50% when the temporary pressure loads during the test condition are combined with other loads in the load combination.

CC-3432.2 Bar Compression

- (a) For load resisting purposes, the stress shall not exceed $0.5f_y$.
- (b) The stress may exceed that given in (a) above for compatibility with the concrete but this stress may not be used for load resistance.
- (c) The values given in (a) above may be increased by $33\frac{1}{3}\%$ when the following loads are combined with other loads in the load combination:
- (1) the temporary loads from prestressing which will be reduced at completion of prestressing;
- (2) the temporary pressure loads during the test condition;
- (3) when secondary forces, defined in Table CC-3136.6-1, are combined with other forces, provided the section thus required is not less than that required for the combination of other loads in the loading combination.

CC-3433 Tendon System Stresses

The tendon stresses during stressing and anchoring, and the tendon stresses used for design shall not exceed the following allowables.



- NOTES:
- (1) The primary portion of this calculated stress shall not exceed the allowable stress applicable when primary stress acts alone.
- (2) These allowable stresses may be increased by $0.05f'_c$ for sections with radial tension reinforcement.
- (3) At initial prestress.
- (4) The membrane portion of this calculated stress shall not exceed the allowable stress applicable when membrane stress acts alone.

TABLE CC-3431-1 ALLOWABLE COMPRESSION STRESSES FOR SERVICE LOADS

- (a) During stressing, the tension stress at the anchor point shall not exceed $0.80f_{pu}$ or $0.94f_{py}$, whichever is less.
- (b) Immediately after anchoring, the tension stress at the anchor point shall not exceed $0.73f_{pu}$ and the calculated average tension stress over the length of the tendon shall not exceed $0.70f_{pu}$.
- (c) For the purpose of design, the effective prestress shall be based on tendon stresses not exceeding those calculated to occur immediately after anchoring minus all applicable losses defined in CC-3542.

CC-3440 CONCRETE TEMPERATURES

- (a) The following temperature limitations are for normal operation or any other long-term period. The temperatures shall not exceed 150°F (66°C) except for

Page 70

local areas, such as around a penetration, which are allowed to have increased temperatures not to exceed 200°F (93°C).

- (b) The following temperature limitations are for accident or any other short-term period. The temperatures shall not exceed 350°F (177°C) for the interior surface. However, local areas are allowed to reach 650°F (343°C) from steam or water jets in the event of a pipe failure.

- (c) Higher temperatures than given in (a) and (b) above may be allowed in the concrete if tests are provided to evaluate the reduction in strength and this reduction is applied to the design allowables. Also, evidence shall be provided which verifies that the increased temperatures do not cause deterioration of the concrete either with or without load.

CC-3500 CONTAINMENT DESIGN DETAILS

CC-3510 DESIGN FOR FLEXURE AND AXIAL LOADS

CC-3511 Assumptions

CC-3511.1 Factored Load Design

- (a) The design of sections for flexure and membrane loads shall be based on the assumptions given in this paragraph and on satisfaction of the applicable conditions of equilibrium and compatibility of strains.

- (b) Strain in the reinforcing steel and concrete shall be assumed directly proportional to the distance from the neutral axis.

- (c) Stress in reinforcement below 0.9 of the specified yield strength for the grade of steel used shall be taken as E_s times the steel strain. For strains greater than that corresponding to $0.9f_y$, the stress in the reinforcement shall be considered independent of strain and equal to $0.9f_y$.

- (d) Tensile strength of the concrete shall be neglected in flexural calculations of reinforced concrete.

- (e) The relationship between the concrete compressive stress distribution and the concrete strain used in the analysis of sections may be assumed to be a triangle, parabola, or any other shape which results in prediction of stress and strains in substantial agreement with the results of comprehensive tests. The stresses determined shall be compared to the stress limits of CC-3420 to ensure design adequacy.

CC-3511.2 Service Load Design.

The straight line theory of stress and strain shall be used and the following assumptions shall be made.

- (a) A section plane before bending remains plane after bending; strains vary as the distance from the neutral axis.
- (b) The stress-strain relation for concrete is a straight line under service loads within the allowable stresses; stresses vary as the distance from the neutral axis.
- (c)

(c) Tensile stress of the concrete shall be neglected in flexural calculations of reinforced concrete.

(d) The modular ratio, $n = E_s / E_c$, may be taken as the nearest whole number but not less than 6. In doubly reinforced members, an effective modular ratio of $2E_s / E_c$ may be used to transform the compression reinforcement for stress computations.

CC-3520 DESIGN OF SHEAR REINFORCEMENT

CC-3521 Factored Load Design

CC-3521.1 Tangential Shear and Membrane Forces

CC-3521.1.1 Reinforced Concrete

(a) Required area of orthogonal (hoop and meridional) reinforcement, with or without inclined reinforcement, provided for combined tangential shear and membrane strength shall be computed by:

$$A_{sh} + A_{si} = \frac{N_h + (N_h \ell^2 + V_u^2)^{1/2}}{0.9f_y} \quad (12)$$

$$A_{sm} + A_{si} = \frac{N_m + (N_m \ell^2 + V_u^2)^{1/2}}{0.9f_y} \quad (13)$$

(12-13)

(b) Any combination of orthogonal and inclined reinforcement as required for strength according to Eqs. (12) and (13), and as required to control shear deformations may be used with the following limits on maximum shear force.

(1) Tangential shear strength provided by orthogonal reinforcement V_{so} and computed by

$$(14) V_{so} = V_u - 0.9f_y A_{si}$$

shall not be greater than $0.2f_c b \ell$.

(2) Tangential shear force V_u shall not exceed $(0.4f_c b \ell - V_{so})$ where V_{so} is computed according to Eq. (14)

where

A_{sh}	= area of bonded reinforcement in the hoop direction (in. ² /ft)
A_{sm}	= area of bonded reinforcement in the meridional direction (in. ² /ft)
A_{si}	= area of bonded reinforcement in one direction of inclined bars at 45 deg. to horizontal (in. ² /ft along a line perpendicular to the direction of the bars). Inclined reinforcement shall be provided in both directions.

Page 71

N_h and N_m

= membrane force in the hoop and meridional direction respectively due to pressure, prestress, and dead load. The prestress force shall be the effective value. N_h and N_m are positive when tension and negative when compression.

N_h and $N_{m,ell}$

= membrane force in the hoop and meridional direction, respectively, from lateral load such as earthquake, wind, or tornado loading. When considering earthquake loading, this force is based on the square root of the sum of the squares of the components of the two horizontal and vertical earthquakes. The force is always considered as positive.

V_c

= tangential shear strength provided by concrete

V_{si}

= tangential shear strength provided by inclined reinforcement

V_{so}

= tangential shear strength provided by orthogonal reinforcement

V_u

= the peak membrane tangential shear force resulting from lateral load such as earthquake, wind, or tornado loading. When considering earthquake loading, this force is based on the square root of the sum of the squares of the components of the two horizontal and vertical earthquakes. The shear force shall be considered as positive.

All forces and strengths are expressed in kips/ft.

The strain compatibility of the concrete and reinforcement shall be checked to ensure that the strain allowables in CC-3422 are not exceeded for orthogonal and inclined reinforcement.

CC-3521.1.2 Prestressed Concrete

(a) A sufficient amount of effective prestress shall be provided so that N_h and N_m are either negative (compression) or zero. Thermal membrane forces shall be included in N_h and N_m for the calculation of effective prestress.

(b) No additional reinforcement is required for tangential shear forces if

$$(15) V_u \leq 0.85 V_c$$

where V_c is calculated according to CC-3421.5.2.

(c) When the section under consideration does not meet the requirements of either CC-3521.1.2 (a) or (b), additional reinforcement shall be provided according to requirements of CC-3521.1.1.

CC-3521.2 Radial Shear

CC-3521.2.1 Nominal Shear Stress.

The nominal shear stress v_u shall be computed by

$$(16) v_u = V_u / 0.85bd$$

where d need not be less than $0.85h$ for prestressed members.

CC-3521.2.2 Applied Shear Stress.

When the reaction, in the direction of applied shear, introduces compression into the end region of the containment, sections located less than a distance d from the face of the support may be designed for the same v_u as that computed at a distance d . For prestressed concrete, sections located at a distance less than $t/2$ may be designed for the shear computed at $t/2$.

CC-3521.2.3 Shear Reinforcement

(a) When shear reinforcement perpendicular to the containment surface is used, the required area of shear reinforcement shall not be less than

$$(17) A_v = (v_u - v_c)bs/f_y$$

The perpendicular shear reinforcement shall not be spaced further apart than $0.50d$.

(b) When inclined stirrups or bent bars are used as shear reinforcement in reinforced concrete members, the following provisions apply.

(1) When inclined stirrups are used, the required area shall not be less than

$$A_v = \frac{(v_u - v_c)bs}{f_y(\sin \alpha + \cos \alpha)} \quad (18)$$

(18)

(2) When shear reinforcement consists of a single bar or a single group of parallel bars, all bent at the same distance from the support, the required area shall be not less than

Page 72

$$A_v = \frac{(v_u - v_c)bd}{f_y \sin \alpha} \quad (19)$$

(19)

in which $(v_u - v_c)$ shall not exceed $3\sqrt{f'_c}$.

(3) When shear reinforcement consists of a series of parallel bent bars or groups of parallel bent bars at different distances from the support, the required area shall be not less than that computed by Eq. (19).

(c) Only the center three-fourths of the inclined portion of any bar that is bent shall be considered effective for shear reinforcement.

(d) Where more than one type of shear reinforcement is used to reinforce the same portion of the section, the required area shall be computed as the sum for the various types separately. In such computations, v_c shall be included only once.

(e) Inclined stirrups and bent bars shall be so spaced that every 45 deg. line extending toward the reaction from the

mid-depth of the section, $0.50d$, to the tension bars shall be crossed by at least one line of shear reinforcement. (f) The value of $(v_u - v_c)$ shall not exceed $8\sqrt{f'_c}$.

CC-3521.3 Peripheral Shear.

Shear stress shall be investigated at the critical section and at successive sections more distant from the critical section in accordance with the following rules.

(a) The nominal shear stress v_u shall be calculated by

$$v_u = V_u / 0.85bd$$

where V_u and b are taken at the critical section specified in CC-3421.6.1.

(b) Shear stress v_c shall be calculated in accordance with CC-3421.6. When v_u is less than v_c and membrane steel stresses are not greater than $0.6f_y$, no additional reinforcing is required.

(c) When v_u is less than v_c and either of the membrane steel stresses exceeds $0.6f_y$, the corresponding meridional or hoop reinforcement shall be designed to resist 1.0 times the shear force corresponding to v_u in addition to any membrane forces and in-plane shear forces. These forces shall be considered as additional membrane forces.

(d) When v_u is greater than v_c , the excess shear force corresponding to $(v_u - v_c)$ shall be resisted by shear reinforcement designed in accordance with CC-3521.2.3. $(v_u - v_c)$ shall be determined as follows.

(1) v_u shall not exceed the greater of $6\sqrt{f'_c}$ or $1.5v_c$ where v_c is calculated in accordance with CC-3421.6.

(2) The shear stress v_c carried by the concrete at any section shall not exceed the greater of $\sqrt{f'_c}$ or $1/2v_c$ when v_c calculated in accordance with CC-3421.6, is greater than or equal to $\sqrt{f'_c}$. When v_c is less than $\sqrt{f'_c}$, the value of v_c calculated in accordance with CC-3421.6, shall be used.

CC-3521.4 Torsional Shear.

Torsional shear stress shall be investigated at the section where $r = r_{\min}$ and at successive surfaces more distant until v_{ut} , as defined below, is equal to or less than v_{ct} as defined in CC-3421.7(a).

(a) The nominal torsional shear stress shall be calculated by:

$$v_{ut} = \frac{T_u}{0.85t(2\pi r^2)} \quad (20)$$

(20)

where T_u = the maximum factored torsional loading applied to the containment wall.

(b) When v_{ut} is less than or equal to v_{ct} no reinforcing is required.

(c) Where v_{ut} is greater than v_{ct} the entire shear stress shall be resisted by reinforcing that which is within the plane of the wall and normal to the failure surface. Such reinforcing shall be designed by the following equation:

$$A_{vt} = \frac{v_{ut}(2\pi\tau)t}{(f_y)\mu} \quad (21)$$

(21)

where

t

= concrete thickness

μ

= a coefficient of friction that shall be taken equal to 1.0 when the failure surface is concrete to concrete and 0.7 when the failure surface is concrete to steel

(d) A_{vt} (in.²) shall be distributed uniformly around the failure surface and shall be fully developed by embedment or mechanical means on either side of the failure surface. Uniformly distributed shall be taken as requiring at least eight approximately equally spaced bars crossing the failure surface.

(e) v_{ut} shall not exceed $0.2f_c$ nor 800 psi (5520 kPa).

CC-3522 Service Load Design

The same requirements stated in CC-3521 shall be used in designing shear reinforcement for service loads with the following modifications.

(a) Equation (17) shall be replaced by $v = V/bd$.

Page 73

(b) The reinforcement steel stress allowable from CC-3432.1 shall replace f_y in Eqs. (18) to (20).

(c) The reinforcing steel stress allowable from CC-3432.1 shall replace $0.9f_y$ in Eqs. (12) to (14).

(d) V_u in Eqs. (12) to (14) shall be replaced by V .

(e) The maximum tangential shear stress provided by orthogonal reinforcement and limiting maximum tangential shear stresses shall be 50% of the values given for factored loads in CC-3521.1.1(b).

(f) Equation (15) in CC-3521.1.2(b) shall be replaced by $V\sqrt{0.5V_c}$.

(g) The requirements of CC-3521.3 shall be used for peripheral shear design for service loads with the following modifications.

(1) The nominal shear stress shall be calculated by $v = V/bd$.

(2) Shear stress v_c shall be calculated in accordance with CC-3431.3.

(3) When v is greater than v_c , the excess shear force corresponding to $(v - v_c)$ shall be resisted by shear reinforcement designed in accordance with (b) above. $(v - v_c)$ shall be determined as follows.

- (a) v shall not exceed the greater of $3\sqrt{f'_c}$ or $1.5v_c$ when v_c is calculated in accordance with CC-3431.3.
- (b) The shear stress v_c carried by the concrete at any section shall not exceed the greater of $\sqrt{f'_c}$ or $1/2v_c$ when v_c calculated in accordance with CC-3431.3, is greater than or equal to $\sqrt{f'_c}$. When v_c is less than $\sqrt{f'_c}$, the value of v_c calculated in accordance with CC-3431.3, shall be used.
- (h) Torsional shear provisions for Service Load Design shall be as follows.
 - (1) In Eq. (21), v_t and T shall be substituted for v_{ut} and T_u , respectively.
 - (2) In Eq. (22), v_t shall be substituted for v_{ut} .
 - (3) v_{ct} shall be calculated in accordance with CC-3431.3.
 - (4) The reinforcement steel stress allowable from CC-3432.1 shall replace f_y in Eq. (22).
 - (5) The limits on v_t shall be calculated in accordance with CC-3431.3 with the values for factored loads being those given in CC-3521.4.

CC-3530 REINFORCING STEEL REQUIREMENTS

CC-3531 General

The following requirements shall govern design of the reinforcing steel.

- (a) The reinforcing steel shall be designed with consideration of placement tolerances specified herein and in the Construction Specification.
- (b) The following paragraphs relate to all load combinations in Table CC-3230-1.

CC-3532 Reinforcing Steel Splicing and Development

- (a) Splices of reinforcement shall be made only as required or permitted on the Design Drawings or in the Construction Specification.
- (b) Lap splices shall not be used for bars larger than No. 11. Lap splices of bundled bars shall be based on the lap splice length required for individual bars of the same size as the bars spliced. The length of lap, as prescribed in CC-3532.1 and CC-3532.2, shall be increased 20% for a 3-bar bundle and 33% for a 4-bar bundle. Bars spliced by noncontact lap splices in flexural members shall not be spaced transversely farther apart than one-fifth the required length of lap nor more than 6 in.
- (c) Where a non-prestressed reinforcement bar splice must be located in a region where tension is predicted in a direction perpendicular to the bar to be spliced, only a positive mechanical splice or a welded butt splice shall be used, unless calculations or tests of the selected splice detail are made to demonstrate that there is an adequate transfer of force. These provisions do not apply to nominal temperature reinforcement.
- (d) Butt splices may be welded or mechanical and shall develop a tensile strength of at least 125% of the specified minimum yield strength of the bar.

CC-3532.1 Tension Splices

CC-3532.1.1 Classification of Tension Lap Splices

- (a) The minimum length of lap for tension lap splices shall be as follows:

Class A splices $1.0l_d$

Class B splices $1.3l_d$

Class C splices $1.7l_d$

The tensile development length l_d for full f_y is as given in CC-3532.1.2.

CC-3532.1.2 Development Length

(a) Reinforcing steel which must terminate in a location where biaxial tension is predicted, such as at penetrations, shall be anchored by hooks, bends, or by positive mechanical anchorage in such a manner that the force in the terminated bar is adequately transferred to other reinforcement. Bar development lengths at such locations shall be increased by at least 25% over those

Page 74

permitted for uniaxial tension. Mechanical devices for end anchorage shall be capable of developing at least 125% of the specified minimum yield strength of the bar. These special precautions are not required for nominal temperature reinforcement.

(b) Where bars no longer required to carry load are terminated in areas of biaxial tension, the bar development lengths shall be increased at least 25% over that required for areas of uniaxial tension, provided that biaxial tension forces are carried by other reinforcement. This requirement does not apply to nominal temperature reinforcement.

(c) The calculated tension in the reinforcement at each section shall be developed on each side of that section by embedment length or end anchorage or a combination thereof. For bars in tension, hooks may be used in developing the bars. If mechanical devices are used in whole or in part for end anchorage, the system shall be capable of developing at least 125% the specified minimum yield strength of the bar.

(d) Tension reinforcement may be anchored by bending it across the section and either making it continuous with the reinforcement on the opposite face of the section, or anchoring it there by any mechanical device capable of developing the required strength of reinforcement.

(e) The critical sections for development of reinforcement are at points of maximum stress and at points where adjacent reinforcement terminates or is bent.

(f) Reinforcement shall extend beyond the point at which it is no longer required to resist flexure for a distance equal to the effective depth of the section or 12 bar diameters, whichever is greater. The extension need not exceed 5 ft (1.5 m) if shear reinforcement is provided in the same area.

(g) Continuing reinforcement shall have an embedment length not less than the development length l_d beyond the point where bent or terminated reinforcement is no longer required to resist flexure or tension.

(h) Reinforcement shall not be terminated in a tension zone unless one of the following conditions is satisfied.

(1) The shear at the cutoff point shall not exceed two-thirds that permitted, including the shear strength of furnished radial reinforcement.

(2) Stirrup area in excess of that required for shear and torsion is provided along each terminated bar over a distance from the termination point equal to three-fourths the effective depth of the member. The excess stirrups shall be proportioned such that $(A_v/b_w s)f_y$ is not less than 60 psi (414 kPa). The resulting spacings shall not exceed $d/(8\beta_p)$, where β_p is the ratio of the area of bars cut off to the total area of bars at the section.

(3) For No. 11 and smaller bars, the continuing bars provide double the area required for flexure at the cutoff point and the shear does not exceed three-fourths that permitted.

(i) The development length l_d in inches, shall be computed as the product of the basic development length of (1) below and the applicable modification factor or factors of (2) below, but l_d shall be not less than 12 in.

(1) The basic development length shall be as follows:

For No. 11 or smaller bars

$$0.04 A_b f_y / \sqrt{f'_c}$$

but not less than

$$0.0004 d_b f_y$$

For No. 14 bars

-

$$0.085f_y/\sqrt{f'_c}$$

For No. 18 bars

$$0.11f_y/\sqrt{f'_c}$$

(2) For horizontal reinforcement, the basic development length shall be multiplied by the factor specified herein if more than 12 in. (305 mm) of concrete is placed below the reinforcement during the concrete placement that embeds the reinforcement in the section. For the purpose of these requirements, reinforcement is considered to be horizontal if the angle the reinforcement makes with the horizontal plane is 30 deg. or less. The multiplying factor shall be equal to 1.4 if more than 36 in. (914 mm) of concrete is placed below the reinforcement. A multiplying factor may be used which decreases linearly from 1.2 to 1.0 as the height of the concrete placed below the reinforcement decreases from 36 in. to 12 in. (914 mm to 305 mm).

(3) The basic development length, modified by the requirements of (2) above, may be multiplied by 0.8 for reinforcement being developed in length under consideration and spaced laterally at least 6 in. (152 mm) on center with at least 3 in. (76 mm) clear from face of member to edge bar measured in the direction of spacing.

(4) The basic development length may be reduced by the ratio of (area required)/(area provided).

Page 75

CC-3532.1.3 Splices in Region of Maximum Tensile Stress.

Splices in regions of maximum tensile stress should be avoided. Where such splices must be used, they shall be butt spliced in accordance with CC-3532(d) or lap spliced in accordance with CC-3532.1.1, as follows:

- (a) if no more than one-half of the bars are lap spliced within a required lap length - Class B;
- (b) if more than one-half of the bars are lap spliced within a required lap length - Class C.

CC-3532.1.4 Splices Away From Regions of Maximum Tensile Stress.

Splices away from regions of maximum tensile stress (maximum computed stress less than $0.5f_y$) shall be butt spliced in accordance with CC-3532(d) or lap spliced in accordance with CC-3532.1 as follows:

- (a) if no more than three-fourths of the bars are lap spliced within a required lap length - Class A;
- (b) if more than three-fourths of the bars are lap spliced within a required lap length - Class B.

CC-3532.1.5 Splices in Tension Tie Members.

Splices shall be made with a welded butt splice or a positive mechanical connection in accordance with CC-3532(d) and be staggered at least $1.7l_d$.

CC-3532.2 Compression Splices

CC-3532.2.1 General.

Splices in compression may be lap or butt spliced. Lap splices shall meet the requirements of CC-3532.2.2 and butt splices shall meet the requirements of CC-3532(d).

CC-3532.2.2 Lap Splices.

The minimum length of a lap splice in compression shall be the development length in compression l_d in accordance with CC-3532.2.3 but not less, in inches, than $0.0005f_y d_b$ for f_y of 60.0 ksi or less.

CC-3532.2.3 Development Length for Bars in Compression

(a) The calculated compression in the reinforcement at each section shall be developed on each side of that section by embedment length or end anchorage or a combination thereof.

(b) The development length l_d for bars in compression shall be computed as $0.02f_y d_b / \sqrt{f_c}$ but shall be not less than $0.0003f_y d_b$ or 8 in. l_d may be modified by a reduction factor equal to (as required)/(as provided).

(c) Hooks shall not be considered effective in developing bars in compression.

CC-3532.3 Development of Standard Hooks in Tension

(a) Development length.. $_{dl}$ in inches, for deformed bars in tension terminating in a standard hook (CC-4321) shall be computed as the product of the basic development length.. $_{hb}$ of (b) below and the applicable modification factor or factors of (c) below, but.. $_{dh}$ shall not be less than $8d_b$ or 6 in. (152 mm), whichever is greater.

(b) Basic development length; $_{ell_{hb}}$ for a hooked bar with f_y equal to 60,000 psi (410 MPa) shall be $1200 d_b / \sqrt{f_c}$ constant carries unit of lb/in.²

(c) Basic development length.. $_{hb}$ shall be multiplied by applicable factor or factors for:

(1) *Bar Yield Strength.* Bars with f_y other than 60,000 psi - $f_y/60,000$;

(2) *Concrete Cover.* For #11 bar and smaller, side cover (normal to plane of hook) not less than $2\frac{1}{2}$ in. (64 mm), and for 90 deg. hook, cover on bar extension beyond hook not less than 2 in. (51 mm) - 0.7;

(3) *Ties or Stirrups.* For #11 bar and smaller, hook enclosed vertically or horizontally within ties or stirrup ties spaced along the full development length.. $_{dh}$ not greater than $3d_b$ where d_b is diameter of hooked bar - 0.8;

(4) *Excess Reinforcement.* Where anchorage or development for f_y is not specifically required, reinforcement in excess of that required by analysis - (A_s required) (A_s provided).

(d) For bars being developed by a standard hook at discontinuous ends of members with both side cover and top (or bottom) cover over hook less than $2\frac{1}{2}$ in., hooked bar shall be enclosed within ties or stirrup ties spaced along the full development length.. $_{dh}$ not greater than $3d_b$ where d_b is diameter of hooked bar. For this case, factor of (c)(3) above shall not apply.

(e) *Notation*

d_b

= nominal diameter of bar, in.

.. $_{dh}$

= development length of standard hook in tension, measured from critical section to outside end of hook [straight embedment length between critical section and start of hook (point of tangency) plus radius of bend and one bar diameter], in.

=.. $_{hb}$ × applicable modification factors

.. $_{hb}$

= basic development length of standard hook in tension, in.

CC-3533 Reinforcing Steel Anchorage

CC-3533.1 Anchorage of Radial Shear Reinforcement

(a) Radial shear reinforcement shall be carried as close to the compression and tension surfaces of the

Page 76

section as cover requirements and the proximity of other steel will permit. The ends shall be anchored by one of the following means:

(1) a standard hook plus an effective embedment of $0.5l_d$; the effective embedment of a stirrup leg shall be taken as the distance between the mid-depth of the member $d/2$ and the start of the hook (point of tangency);

(2) embedment on the compression side of mid-depth $d/2$ for a full-development length l_d but not less than 24 bar diameters;

(3) bending around the membrane reinforcement through at least 135 deg.; hooking or bending stirrups around the membrane reinforcement shall be considered effective anchorage;

(4) any mechanical device capable of developing the required strength of reinforcement.

(b) Between the anchored ends, each bend in the continuous portion of a transverse simple U- or multiple U-stirrup shall enclose a longitudinal bar.

(c) Bars bent to act as section reinforcement shall, in a region of tension, be continuous with the main reinforcement and in a compression zone shall be anchored on the compression side of mid-depth as specified for development length in CC-3532.2.3 for that part of f_y which is needed to satisfy Eq. (19).

(d) Pairs of U-stirrups so placed as to form a closed tie shall be considered properly spliced when the laps are each $1.7l_d$.

CC-3534 Reinforcing Steel Cover and Spacing Requirements

CC-3534.1 Cover

(a) The following minimum concrete cover shall be provided for reinforcing bars, prestressing tendons, or ducts:

	Minimum Cover, in.
Cast against and permanently exposed to earth	3
Exposed to earth or weather:	
No. 6 through No. 18 bars	2
No. 5 bars, $\frac{5}{8}$ in. wire and smaller	$1\frac{1}{2}$
Not exposed to weather or in contact with the ground:	
Principal reinforcement, ties, and stirrups	$1\frac{1}{2}$
Other reinforcement	1

For bar bundles, the minimum cover shall equal the equivalent diameter of the bundle but need not be more than 2 in. (51 mm) or the tabulated minimum, whichever is greater.

(b) The concrete cover shall be established by considering the placing tolerances of the formwork and reinforcement. The minimum concrete cover specified in (a) above shall not be reduced by the placing tolerances of the formwork and reinforcement.

CC-3534.2 Spacing.

The clear distance between parallel bars in a layer shall not be less than the nominal diameter of the bars, nor $1\frac{1}{3}$ times the maximum size of the coarse aggregate, nor 1 in. (25 mm). The clear distance between parallel layers shall not be less than $1\frac{3}{8}$ in. (35 mm). The clear distance limitation between bars shall also apply to the clear distance between a contact (lap) splice and adjacent splices or bars.

CC-3535 Concrete Crack Control

(a) When an expected crack formation is so located that critical elements of the containment, such as anchor zone concrete, buttresses, ring girders, and large opening edges, may be weakened, bonded nonprestressed reinforcement shall be provided to carry the total tensile force in the concrete.

(b) Nonprestressed reinforcement shall be provided in the containment shell to control surface and membrane cracking from the effects of shrinkage, temperature, and membrane tension. The area of such reinforcement in each direction at each face of the concrete shall be a minimum of 0.0020 times the gross cross-sectional area of the section. This requirement may be met in whole or in part by reinforcement otherwise required to resist calculated loads. An integral steel liner, if provided, may be included to satisfy the requirement for inside face reinforcement. Reinforcing bars considered as face reinforcement shall not be more than one-fifth of the total section thickness from the concrete face.

considered as face reinforcement shall not be more than one-fifth of the total section thickness from the concrete face.

CC-3536 Curved Reinforcement

All forces imposed by curved reinforcement shall be considered in the design of local areas such as around penetrations.

CC-3540 PRESTRESSED CONCRETE

CC-3541 General

(a) Provisions in this Subarticle apply to structural members prestressed with high strength steel meeting the requirements for prestressing material in CC-2400.

(b) The following assumptions shall be made for purposes of design.

Page 77

(1) Strains vary linearly with depth through the entire load range.

(2) At cracked sections, the ability of the concrete to resist tension is neglected.

(3) In calculations of section properties prior to bonding of tendons, areas of the open ducts shall be deducted. The transformed area of reinforcing steel and bonded tendons may be included.

(c) The effects on the adjoining structure of elastic and plastic deformations, deflections, changes in length, and rotations caused by the prestressing shall be provided for.

CC-3542 Loss of Prestress

(a) To determine the effective prestress, allowance for the following sources of loss of prestress shall be considered:

(1) slip at anchorage;

(2) elastic shortening of concrete;

(3) creep of concrete;

(4) shrinkage of concrete;

(5) stress relaxation;

(6) frictional loss due to intended or unintended curvature in the tendons.

(b) Friction losses in post-tensioned steel shall be based on experimentally determined wobble and curvature coefficients and shall be verified during stressing operations. The values of coefficients assumed for design and the acceptable ranges of jacking forces and steel elongations shall be specified. These friction losses shall be calculated as follows:

$$(22) P_s = P_x e^{(Kl + \mu\alpha)}$$

When $(Kl + \mu\alpha)$ is not greater than 0.3, Eq. (24) may be used:

$$(23) P_s = P_x (1 + Kl + \mu\alpha)$$

(c) When prestress in a member may be reduced through its connection with adjoining elements, such reduction shall be allowed for in the design.

CC-3543 Tendon End Anchor Reinforcement

Reinforcement oriented perpendicular to the direction of applied force shall be provided to control cracking in the end anchor zone.

(a) Reinforcement shall be sized to resist a load of at least 10% of the applied permanent prestressing force. This reinforcement shall be located starting not more than 2 in. (51 mm) from the bearing plate and extending not more than twice the minimum bearing plate width when measured in the direction of the load.

(b) In lieu of the provisions of (a) above, reinforcement may be based on the result of tests which show that the end anchor zone can adequately resist a force equivalent to the design ultimate force of the prestressing tendon.

CC-3544 Curved Tendons

All forces imposed by curved tendons shall be considered in the design of local areas, such as around penetrations.

CC-3545 Radial Tension Reinforcement

For portions of prestressed containments with curvature, consideration shall be given to the radial forces. Radial reinforcement shall be provided to resist radial tensile forces from curved tendons in portions of the containment with double curvature.

The spacing of reinforcement shall not be greater than the shell thickness or 3 ft (0.9 m), whichever is smaller. The radial reinforcement shall be developed on either side of the centroid of the curved tendons in accordance with CC-3530.

CC-3550 SEPARATION OF STRUCTURES

Since the containment will deform under the design loadings and temperature effects, such deformations and interaction with integral, adjacent, and internal structures and components shall be considered in the design of the containment; otherwise, the containment shall be sufficiently separated from adjacent and internal structures to ensure no contact during deformation.

CC-3560 FOUNDATION REQUIREMENTS

CC-3561 General

(a) The foundation properties used in the design shall be supported by analysis made from information provided by laboratory or field tests of specimens taken from the subsurface strata supporting the containment.

(b) The bottom of the foundation shall be placed at a sufficient distance below finished grade to preclude the possibility of undermining due to flood or possible future adjacent construction.

(c) The short-term as well as the long-term foundation soil properties shall be considered. In order to

Page 78

ensure use of the maximum loading conditions, a range of values of soil constants shall be used which bracket the expected values.

CC-3564 Water Table

The design analysis shall include the effect of possible significant changes in the groundwater table. The effect of moisture changes upon the soils being loaded shall be included in the settlement analysis.

CC-3565 Deterioration of Material

The design shall provide due protection against possible deterioration of the foundation material.

CC-3566 Containment Displacement

Containment movements shall be considered in determining potential interaction with adjacent or attached piping or equipment. Long-term settlements, such as consolidation of clay or silt layers, shall be given full consideration. An investigation shall be made to preclude the founding of a containment on strata subject to liquefaction under the specified design conditions.

The load combinations shown in Table CC-3230-1 are applicable to containment displacement considerations, except that load factors for all load cases shall be taken equal to 1.0.

CC-3570 CONTAINMENT EXTERNAL ANCHORS

CC-3571 General

The effects of anchors, embedments, or other attachment details not attached to the steel liner or a load carrying steel element, that provide anchorage into the containment concrete from the external surface, shall be considered. The anchors are, however, not under the jurisdiction of the Code. The induced effects on the containment shall be considered in accordance with this Section.

CC-3572 Loads and Displacements

The resulting loads on the containment shall be considered in the appropriate load categories and load combinations as described in Section CC-3200 of the Code. Containment displacements and their effects shall be considered in accordance with Section CC-3550 and Section CC-3566 of the Code.

CC-3573 Analysis Methods

The analysis necessary to predict the effects of such anchors shall be consistent with Section CC-3300 of the Code.

CC-3574 Design Allowables

The effects of the anchors shall not cause stresses or strains, in combination with the other loads on the containment as determined by Sections CC-3572 and CC-3573, that exceed the allowables of Section CC-3400 of the Code.

CC-3575 Additional Design Requirements

The Design Specification shall contain requirements that the external anchors are designed to preclude structural damage to the containment.

CC-3600 LINER DESIGN ANALYSIS PROCEDURES

CC-3610 GENERAL

(a) An analysis shall be prepared in sufficient detail to show that each of the design allowables of CC-3700 is satisfied when the liner, penetrations, brackets, and attachments are subjected to the loadings of CC-3200.

(b) Experimental results may be used to evaluate the capacity of components to withstand static or cyclic loading.

CC-3620 LINER

The liner analysis shall consider deviations in liner geometry due to the fabrication and erection tolerances, which are stated in CC-4522, and any additional tolerances stated in the Construction Specification. Since the liner will be anchored at relatively close intervals compared to its diameter, the analysis may be based on plate or beam theory, provided all assumptions made in the analysis are conservative.

CC-3630 LINER ANCHORS

The anchors may be analyzed assuming the liner remains elastic under all conditions; for example, the liner strains shall be converted to stress using Hooke's law with the modulus of elasticity and Poisson's ratio below yield. If the liner stress and resulting membrane

Page 79

forces are substantially higher than the uniaxial yield strength, then biaxial tests may be performed to determine the biaxial yield. If biaxial yield tests are performed, the anchor loads may be determined considering the liner in a plastic state when justified by the design.

CC-3640 PENETRATION ASSEMBLIES

The penetration assemblies shall be analyzed using the same techniques and procedures used for metal containments in Division 1, where applicable. The analysis shall consider the concrete confinement for penetration sleeves embedded in the

concrete containment. Local thickening of the liner at an opening is allowed.

CC-3650 BRACKETS AND ATTACHMENTS

Brackets and attachments connected to the liner shall be designed and analyzed using accepted techniques applicable to beams, columns, and weldments such as those illustrated in AISC, Manual for Steel Construction, Part 5, Specification for Design, Fabrication, and Erection of Structural Steel for Buildings.

CC-3700 LINER DESIGN

CC-3710 GENERAL

Due to the nature of the loads and other effects, together with the types of components, the allowable capacities of the components will be specified in terms of stress, strain, force or displacement, whichever is applicable. Since many of the allowable capacities are based on ultimate capacities, testing of a prototype may be necessary to verify the ultimate capacity of a particular part.

CC-3720 LINER

The calculated strains and stresses for the liner shall not exceed the values given in Table CC-3720-1. The load combinations shown in Table CC-3230-1 are applicable to the liner, except that load factors for all load cases may be taken equal to 1.0. Strains associated with construction-related liner deformations may be excluded when calculating liner strains for the Service and factored load combinations.

**TABLE CC-3720-1
LINER PLATE ALLOWABLES**

Stress-Strain Allowable [Note (1)]		
Category	Membrane	Combined Membrane and Bending
Construction	$f_{st} = f_{sc} = \frac{2}{3} f_{py}$	$f_{st} = f_{sc} = \frac{2}{3} f_{py}$
Service	$\epsilon_{st} = \epsilon_{sc} =$ 0.002 in./in.	$\epsilon_{st} = \epsilon_{sc} =$ 0.004 in./in.
Factored	$\epsilon_{sc} = 0.005$ in./in. $\epsilon_{st} = 0.003$ in./in.	$\epsilon_{sc} = 0.014$ in./in. $\epsilon_{st} = 0.010$ in./in.

NOTE:

(1) The types of strains limited by this Table are strains induced by other than construction-related liner deformations.

TABLE CC-3720-1 LINER PLATE ALLOWABLES

CC-3730 LINER ANCHORS

(a) The liner shall be anchored to the concrete so that the liner strains do not exceed the strain allowable given in CC-3720. The anchor size and spacing shall be chosen so that the response of the liner is predictable for all the loads and load combinations given in CC-3200. The anchorage system shall be designed so that it can accommodate the design in-plane (shear) loads or deformations exerted by the liner and loads applied normal to the liner surface.

(b) The allowable force and displacement capacity are given in Table CC-3730-1. The load combinations shown in Table CC-3230-1 are applicable to the liner anchors, except that load factors for all load cases may be taken equal to 1.0. Mechanical loads are those which are not self-limiting or self-relieving with load application. Displacement limited loads are those resulting from constraint of the structure or constraint of adjacent material and are self-limiting or self-relieving.

(c) The anchorage forces to be transferred to the concrete shall be established in the Design Specification.

CC-3740 PENETRATION ASSEMBLIES

(a) Each penetration shall be provided with an anchorage system capable of transferring loads and thermal effects to the concrete. The anchorage design shall be in accordance with liner anchor requirements.

(b) The design allowables for the penetration nozzles shall be the same as those used for Division 1. A nozzle is a part of the assembly not backed up by concrete.

Page 80

**TABLE CC-3730-1
LINER ANCHOR ALLOWABLES**

Category	Force and Displacement Allowables	
	Mechanical Loads, Lesser of:	Displacement Limited Loads
Test, normal, severe environmental, extreme environmental	$F_a = 0.67 F_y$ $F_a = 0.33 F_u$	$\delta_a = 0.25 \delta_u$
Abnormal, abnormal/severe environmental, abnormal/extreme environmental	$F_a = 0.9 F_y$ $F_a = 0.5 F_u$	$\delta_a = 0.50 \delta_u$

CC-3730-1 LINER ANCHOR ALLOWABLES

(c) The design allowables for the liner in the vicinity of the penetration shall be the same as those given in AISC, Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings, for resisting mechanical loads² in service load category. For factored load categories, the allowables may be increased by a factor of 1.5, except for impulse loads and impact effects.

(d) The portion of the penetration sleeve backed by concrete shall be designed to meet the requirements of CC-3700 and CC-3800.

(e) The anchorage forces to be transferred to the concrete shall be established in the Design Specification.

CC-3750 BRACKETS AND ATTACHMENTS

(a) The design allowables for brackets, attachments, and the liner in their vicinity shall be the same as those given in AISC, Manual for Steel Construction, Part 5, Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings, for resisting mechanical loads² in the construction, test, and normal categories. For all other categories, the

allowables may be increased by a factor of 1.5, except for impulse loads and impact effects.

- (b) The anchorage forces to be transferred to the concrete shall be established in the Design Specification.

2 Mechanical loads are those loads which are not self-limiting.

CC-3760 FATIGUE

In general, the design of liners is not fatigue controlled since most stress and strain changes will occur only a small number of times and produce only minor stress-strain fluctuations. The occurrence of earthquake and design basis accident full-design strains occurs too infrequently and with too few cycles to generally be controlling. Nevertheless, because of the critical nature of the liner, the Designer shall ensure the suitability of the liner for the specific operating conditions involving cyclic application of loads and thermal conditions that have been established in the Design Specification. The fatigue methods and limits established by Division 1 shall apply.

CC-3800 LINER DESIGN DETAILS

CC-3810 LINER ANCHORS

The anchor design and analysis shall consider the effects of the following.

- (a) The unbalanced loads resulting from the variation of liner curvature. Some areas of the liner may have inward curvature between the anchors, whereas other areas will have outward curvature. The variation will result in shear load and displacement at the anchor.

- (b) Liner thicker than nominal due to the rolling tolerances given in SA-20. The thicker plate will impose greater forces and displacements on the anchorage system than a nominal thickness liner.

- (c) Yield strength higher than the minimum specified due to the rolling processes and biaxial loading. Adequate consideration of yield strength in excess of the minimums may be provided by the following:

- (1) converting liner strains to stress and membrane forces assuming the material remains elastic;

- (2) conducting biaxial yield strength tests to establish the biaxial yield strength of materials used for the liner. Biaxial yield strength tests are required only when anchor designs rely on liner yielding to limit the forces applied to the anchors.

- (d) weld offset, structural discontinuities, and concrete voids behind the liner;

Page 81

- (e) variation in anchor spacing;

- (f) variation in anchor stiffness due to a variation of the concrete modulus;

- (g) local concrete crushing in the anchor zone;

- (h) Stud anchors shall be designed to fail before tearing the liner.

CC-3820 PENETRATION LINERS

For penetration assemblies designed for pipe rupture loads, the design shall consider one of the following:

- (a) the moment, axial, torque, and shear loadings that the piping is capable of producing;

- (b) penetration loads based on a dynamic analysis considering pipe rupture thrust as a function of time.

CC-3830 TRANSITIONS FROM CONCRETE TO STEEL

CC-3831 Transition Details

When containments use a combination of concrete and metal (Fig. CC-3831-1), the design rules below shall govern. Transition sections shall be divided into two categories.

(a) Category One: full-containment diameter transitions, penetration with nozzles embedded in the concrete containment wall for attachment of piping, hatches, and locks;

(b) Category Two: local zones backed up by compressible materials.

CC-3831.1 Category One: Transition Section

(a) Metal sections not backed by concrete shall meet all the design requirements of Division 1 and shall consider the concrete confinement.

(b) Metal sections may be attached to the concrete portion of the containment with anchor rods, anchor bolts, attachment to the primary reinforcement or prestressing system, or any anchorage method capable of transferring the design loads.

CC-3831.2 Category Two: Transition Sections.

Metal sections backed up by compressible material to provide local flexibility shall meet all design requirements of Division 1 in the region where compressible material is present. Where the sections attach to concrete backed or embedded members, only the requirements of CC-3000 apply.

CC-3840 WELDED CONSTRUCTION

CC-3841 Joint Category

The term *category* as used herein defines the location of a joint in a liner and illustrates some acceptable details. The joints included in each category are designated A, B, C, D, E, F, G, H, and J. Figure CC-3831-1 illustrates typical joint locations.

(a) *Category A*: longitudinal welded joints within the liner or penetration nozzles

(b) *Category B*: circumferential welded joints within the liner or penetration nozzles

(c) *Category C*: detailed descriptions and requirements for this category are covered in Division 1

(d) *Category D*: welded joints connecting penetration nozzles in the liner

(e) *Category E*: welded joints connecting flat liner bottom sections to elements of spherical, cylindrical, or conical liner sections or for intersection of liner sides to sides, or sides to bottoms

(f) *Category F*: welded joints connecting liner floor plates together and to liner transition sections and joints connecting liner sides and bottom plates together

(g) *Category G*: welded joints connecting the sides of liner side plates to liner floor plates

(h) *Category H*: welded joints connecting attachments to liner and embedment anchors to attachments to liners or other embedment anchors

(i) *Category J*: welded joints connecting liner plates to embedments that are continuous throughout liners

CC-3842 Permissible Types of Welded Joints

Joints of any category shall meet the requirements of CC-3830 for transition zones from concrete to steel when compressible material is present between the liner and the concrete.

CC-3842.1 Category A.

All welded joints of Category A shall meet the fabrication requirements of CC-4542 and shall be capable of being examined in accordance with CC-5520.

CC-3842.2 Category B.

All welded joints of Category B shall meet the fabrication requirements of CC-4542 and shall be capable of being examined in accordance with CC-5520.

CC-3842.3 Category C.

Rules for joints of Category C are included in Division 1.

Page 82

Page 83

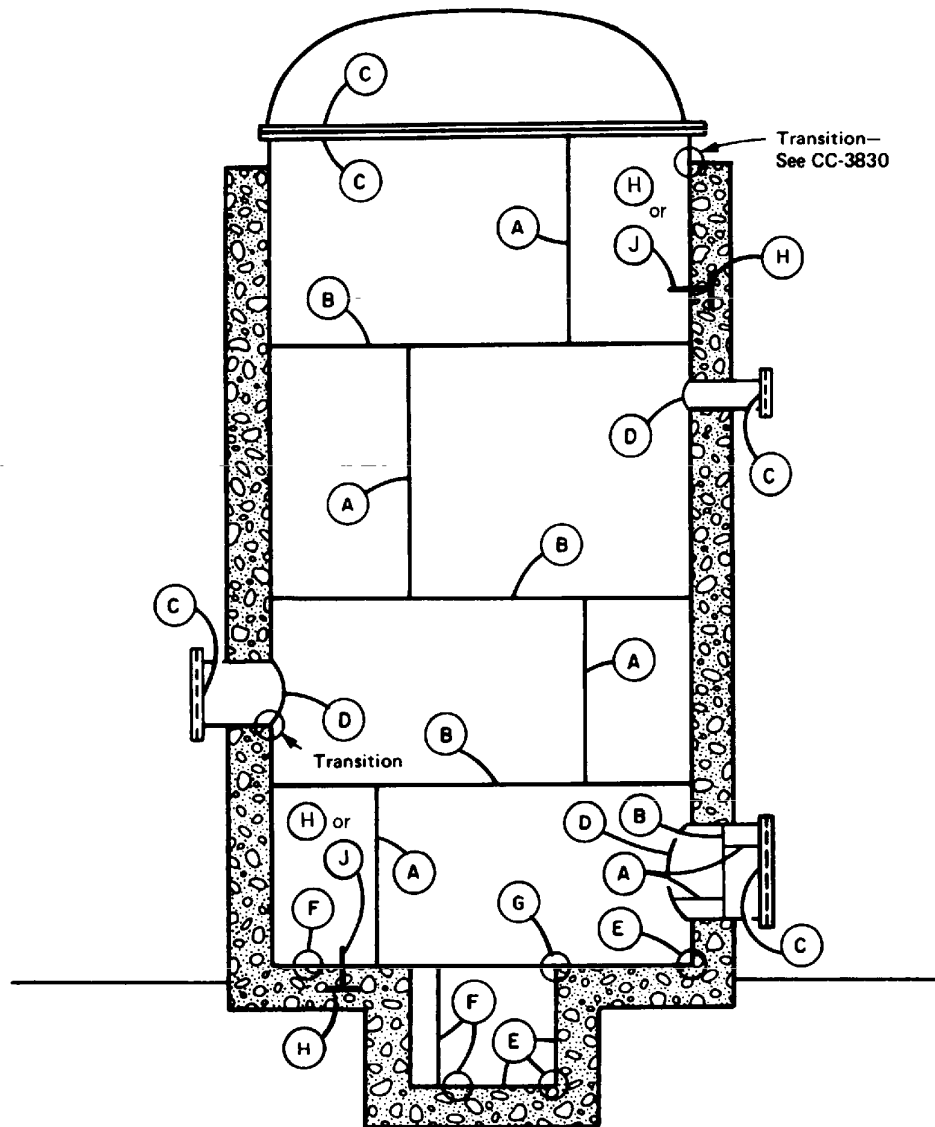


FIG. CC-3831-1 ILLUSTRATION OF WELDED JOINT LOCATIONS TYPICAL OF ALL CATEGORIES
(For Definitions of Categories see CC-3841)

FIG. CC-3831-1 ILLUSTRATION OF WELDED JOINT LOCATIONS TYPICAL OF ALL CATEGORIES

CC-3842.4 Category D

(a) Joints of Category D shall meet the requirements of Fig. CC-4542.2-1 for nozzles over 3 in. diameter.

(b) Joints of Category D shall meet the requirements of Fig. CC-4542.2-2 for nozzles 3 in. diameter and under.

CC-3842.5 Category E.

Joints shall be of the type shown in Fig. CC-4542.2-3.

CC-3842.6 Category F.

Joints shall be of the type shown in Fig. CC-4542.2-4.

CC-3842.7 Category G.

Joints shall be of the type shown in Fig. CC-4542.2-5.

CC-3842.8 Category H.

Welded joints shall be of the type shown in Fig. CC-4542.2-6.

CC-3842.9 Category J.

Welded joints shall be of the type shown in Fig. CC-4542.2-7.

CC-3842.10 Minimum Dimensions.

The minimum dimensions of Fig. CC-4542.2-1 through Fig. CC-4542.2-7 shall be met where:

t	= nominal thickness of liner
t_a	= nominal thickness of attachments to liner
t_c	= $0.7t_r$, $0.7t_1$, $0.7t_a$ or $\frac{1}{4}$ in. (6 mm), whichever is less
$t_{\min}$	= the smaller of $\frac{3}{4}$ in. (19 mm) or the thickness of the thinner of the parts joined
t_n	= nominal thickness of penetrating part
t_w	= $0.7t_{\min}$
t_1, t_2	= not less than the smaller or $\frac{1}{4}$ in. (6 mm) or $0.7t_{\min}$
$t_1, t_2 \geq \frac{1}{4}t_{\min}$	
r_1	= $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2	= $\frac{1}{4}$ in. min.

CC-3843 Unequal Thickness Transitions

A tapered transition section having a length not less than three times the offset between the adjacent section surfaces as shown in Fig. CC-3840-1 shall be provided at joints of Categories A and B between sections that differ in thickness by more than one-fourth of the thickness of the thinner section. The transition section may be formed by any process that will provide a uniform taper.

CC-3900 DESIGN CRITERIA FOR IMPULSE LOADINGS AND MISSILE IMPACT

CC-3910 GENERAL

Containment and liner shall be designed to resist the effects of impulse loadings from pipe rupture and the impact of missiles resulting from pipe rupture, tornadoes, or any other missile specified in the Design Specification in accordance with CC-3200. Load classifications are given in CC-3240.

CC-3920 DESIGN ALLOWABLES

CC-3921 General

CC-3921.1 Normal and Severe Environmental Load Categories.

Structural members designed to resist loads in the normal and severe environmental load categories are not allowed to exceed yield.

CC-3921.2 Abnormal, Extreme Environmental, Abnormal and Extreme Environmental Load Categories.

Structural members designed to resist impulse loads and dynamic effects in the abnormal, extreme environmental, and abnormal and extreme environmental categories are allowed to exceed yield strain and displacement values. Design adequacy is controlled by limiting the ductility³ assumed in evaluating the energy absorption capability or resistance function of the structure.

CC-3922 Stress Allowables

The allowables applicable to the determination of section strength are given in CC-3400 and CC-3700. In determining f_y values, the dynamic effect of the loading may be considered.

CC-3923 Ductility Limits

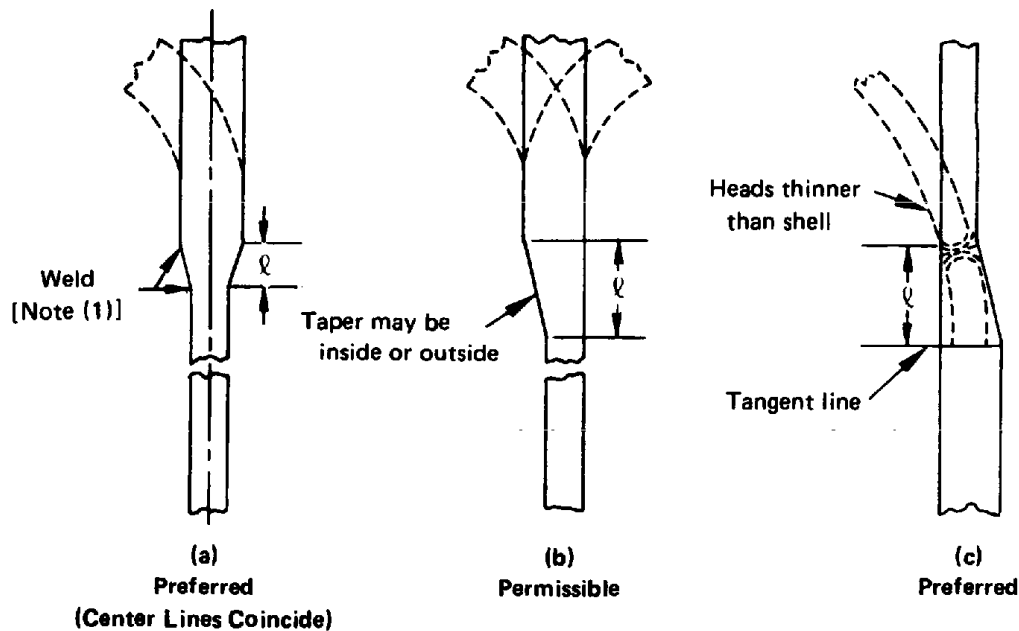
CC-3923.1 Impulse Loads.

The ductility limits used in design for impulse load shall not exceed one-third the ductility determined at failure.

CC-3923.2 Impact Effects.

The ductility limits used in design for impact load shall not exceed two-thirds the ductility determined at failure.

³ Ductility μ is defined as the ratio of maximum deformation or strain of the member at the point of collapse to the maximum elastic deformation or strain.



NOTE:
(1) Length of taper may include the width of the weld.

FIG. CC-3840-1 TAPERED TRANSITION SECTIONS

FIG. CC-3840-1 TAPERED TRANSITION SECTIONS

CC-3930 DESIGN ASSUMPTIONS

CC-3931 Penetration Formulas and Impulse or Impact Effects

Empirical penetration formulas are assumed to govern design local to the missile impact area. Missile penetration shall be limited to 75% of total section thickness. Local areas for missile impact are defined as having a maximum diameter equal to 10 times the mean diameter of the impacting missiles, or $5\sqrt{t}$ plus the mean diameter of the impacting missile where t is defined as the total section thickness in feet, whichever is smaller. The effect of damage in the local missile impact area shall be considered in the overall structural integrity of the section.

CC-3932 Effective Mass During Impact

For a concrete section, the effective diameter of the section to be used in determining the kinetic energy transferred on missile impact or the dynamic characteristics of the structural response shall be equal to the mean diameter of the missile plus one section thickness t . Larger values of effective mass may be used if a test or analytical verification is available to substantiate the use of larger values.

July 1, 1998
American Society Of Mechanical Engineers

CC-4100 GENERAL REQUIREMENTS

CC-4110 INTRODUCTION

Concrete containments shall be fabricated and constructed in accordance with the requirements of this Article. The requirements apply whether performed in a shop or at the field site. Unless otherwise indicated, throughout this Article the term *component* shall be understood to include parts and appurtenances. The fabrication of parts and appurtenances designated to meet the requirements for Class MC and which are not backed up by concrete for load carrying purposes shall meet the requirements of NE-4000 and Subsection NCA. Attachments to parts fabricated to the requirements of Division 1 shall meet the requirements of this Article.

CC-4120 CERTIFICATION OF MATERIAL AND FABRICATION OR CONSTRUCTION BY COMPONENT FABRICATOR OR CONSTRUCTOR

CC-4121 Means of Certification

The Fabricator or Constructor of a concrete containment or component shall certify, by application of the appropriate Code symbol and completion of the appropriate Data Report in accordance with Article NCA-8000, that the materials used comply with the requirements of CC-2000 and that the fabrication and construction complies with the requirements of CC-4000.

CC-4121.1 Certification of Treatments, Tests, and Examinations.

If the Fabricator or Constructor performs treatments, tests, repairs, or examinations required by other Articles of this Division, he shall certify that he has fulfilled those requirements. Reports of all required treatments and of the results of all required tests, repairs, and examinations shall be available to the Authorized Inspector.

CC-4121.2 Repeat of Tests.

If, during the fabrication or construction of the component, the material is subjected to conditions which cause a change in principal characteristics that has not been accounted for in the Design Report and that may change properties from the specified values, the tests shall be repeated or additional tests made by the Fabricator or Constructor for verification of acceptability.

CC-4122 Material Identification

CC-4122.1 Concrete.

Each *concrete placement* (defined as a placement made continuously between construction joints) shall be identified on the as-built sketch, and records maintained of the date, concrete batch tickets with traceability to the information required in CC-4220, and testing performed in accordance with CC-5230.

CC-4122.2 Reinforcing Material.

Reinforcing steel, by groups of bars or shipments, shall be identifiable by documentation, tags, or other means of control to a specific heat number or heat code until review of the CMTR has been performed. After acceptance of the reinforcing steel, adequate documentation, tags, or other means shall be provided to ensure traceability to an accepted shipment or to groups of accepted shipments of reinforcing steel.

CC-4122.3 Prestressing System Material.

Material for prestressing systems shall carry identification markings or tags which shall remain distinguishable until

the tendon assembly is completed. If the original identification markings are cut out or the material is divided into two or more pieces, the markings shall be accurately transferred to the pieces prior to cutting, or a coded marking or other means of control shall be used to ensure identification of each piece of material during the subsequent assembly. A tabulation shall be made of the CMTR for the materials used in an assembly or group of assemblies.

Page 90

CC-4122.4 Liner Material.

Material for liners (excluding leak-chase system materials, embedments, and attachment material) shall carry identification markings which will remain distinguishable until the liner is assembled. If the original identification markings are cut out or the material is divided into two or more pieces, the marks shall either be accurately transferred to all pieces prior to cutting or a coded marking shall be used to ensure identification of each piece of material during subsequent fabrication or installation. In either case, an as-built sketch or a tabulation of materials shall be made identifying each piece of material with the CMTR and the coded marking. Welding and brazing materials shall be identified and controlled so that they can be traced to each liner, or else a control procedure shall be employed which ensures that the specified materials are used.

CC-4122.5 Control of Material.

Material shall be controlled, marked, and identification maintained in accordance with NCA-4134.7 and NCA-4134.8.

CC-4123 Examinations

Visual examination activities that are not referenced for examination by CC-5000 and are performed solely to verify compliance with requirements of CC-4000 are not required to be performed by personnel and procedures qualified to CC-5000 unless so specified.

CC-4200 CONCRETE

CC-4210 GENERAL

The Construction Specification shall specify the requirements for stockpiling, batching, mixing of concrete constituents, conveying, depositing, consolidating, and curing of concrete and construction joint preparation. The Construction Specification shall specify any requirements or special procedures to be followed to limit concrete temperature.

CC-4220 STORING, BATCHING, MIXING, AND PLACING

CC-4221 Stockpiling and Storing

CC-4221.1 Aggregates.

Aggregates shall be handled, transported, and stockpiled in a manner that will minimize segregation and ensure that the fineness moduli and gradation are maintained within the range specified. Intermixing between stockpiles shall be prevented. Suitable storage facilities shall be provided to ensure that the above requirements are met. Aggregates shall be sampled and tested in accordance with the requirements of CC-5223.

CC-4221.2 Moisture Control.

Cement, admixtures, and other concrete and grout constituents that are adversely affected by moisture before mixing shall be stored, handled, and transported in a manner that will prevent the introduction of moisture. If the above materials are exposed to moisture after testing, they shall be resampled and tested before use in accordance with the requirements of CC-5220.

CC-4222 Batching

CC-4222.1 General.

The Construction Specification for batching of constituents for concrete manufacture shall be based on ACI 304. Only constituents from stockpiles or storage containers which have been accepted shall be used. Constituents shall be removed from storage in a manner such that the distribution of particle sizes remains within the ranges specified. Aggregate shall be rescreened if necessary to maintain specified gradation.

CC-4222.2 Measuring.

Aggregates, cements, ice, and mineral admixtures shall be measured by weight. Liquids may be measured by volume or weight. Free moisture content of aggregates and admixtures shall be determined and accounted for as corrections to the amount of added mixing water as differentiated from total mixing water requirements. The measurement accuracy and precision shall be such that the proportion of constituents stays within the ranges established in ASTM C 94, Specification for Ready-Mixed Concrete. The $\pm 1\%$ tolerance for water specified in ASTM C 94 may be modified to $\pm 2\%$ if permitted in the Construction Specification and if the plant can demonstrate a standard deviation less than 400 psi (2800 kPa) as determined by ACI 214. Records shall be maintained of the constituent quantities in each batch. Recording paper divisions or digital printout records shall be capable of verifying conformance to $\pm 1\%$ for the measurements of cement, total aggregates, mineral admixtures and water, and to $\pm 3\%$ for liquid admixture.

CC-4223 Mixing

CC-4223.1 General.

All concrete shall be mixed in accordance with the requirements set forth in ASTM C 94 and any additional requirements of the Construction Specification.

Page 91

CC-4223.2 Operation of Mixers.

The range of mixing capacities and corresponding mixing times for all mixers shall be determined by the performance of mixer uniformity tests as specified in ASTM C 94. Mixers shall be used only within the range of capacities and mixing times qualified by mixer uniformity tests.

CC-4224 Conveying

CC-4224.1 General.

Concrete shall be conveyed from the mixer to final placement by methods which will prevent the separation or loss of materials.

CC-4224.2 Conveying Equipment.

Conveying equipment shall be capable of providing a supply of concrete at the site of placement without separation of constituents and without interruptions that cause loss of plasticity between successive increments. The delivery rate shall be such that unconsolidated material is not covered by newly deposited concrete, and new material is not placed on concrete which has hardened unless the surface of the hardened material has been properly prepared as a construction joint. Performance of all conveying equipment including hoppers, buckets, conveyors, pumps, and chutes shall be selected and employed so that the concrete shall meet the specified characteristics. Concrete, during conveyance, shall not come in contact with aluminum.

CC-4225 Depositing

CC-4225.1 General.

Concrete shall be deposited as near as practicable to its final position to avoid segregation due to rehandling or flowing. The placing operation shall be conducted at such a rate that the concrete is at all times plastic and flows readily into forms and around reinforcement and embedments. Concrete that is partially hardened or contaminated shall not be deposited in the structure. Pretempered concrete or concrete which has been remixed after initial set shall not be used.

CC-4225.2 Continuity.

Concreting shall be a continuous operation until the placement is completed. The top surfaces of vertically formed lifts shall be generally level. Location and preparation of construction joints shall be in accordance with CB-4252.

CC-4226 Consolidation

CC-4226.1 General.

Concrete shall be thoroughly worked around the reinforcement and embedments and into corners of the forms. ACI 309, Recommended Practice for Consolidation of Concrete, shall be used as a guide to develop suitable consolidation techniques.

CC-4226.2 Use of Mortar.

Where placement and consolidation conditions are difficult, or where reinforcement is congested, batches of mortar containing the same proportions of cement and sand as used in the concrete shall first be deposited in the forms to the depth specified. Sufficient water shall be added to the mortar to provide necessary workability, but the water-cement ratio shall not exceed the water-cement ratio of the specified concrete design mix.

CC-4226.3 Placeability Tests.

When required by the Construction Specification, one or more mockups shall be prepared and filled with the specified concrete to demonstrate that the concrete can be properly placed and consolidated under field conditions. The mockup shall contain representative amounts of reinforcing steel, tendon tubes, and embedments. Vibrators, equipment, and procedures used in the tests shall be representative of those that will be used in the actual construction.

CC-4230 PREPLACED AGGREGATE CONCRETE

CC-4231 General

The Construction Specification shall prescribe complete specifications for materials, locating and placing grout pipes, preplacing and compacting coarse aggregates, grout pumps and equipment, preparation for grouting, completing the top surface, and the grout mix design, fluidity, and temperature. Specifications and procedures shall be based on ACI 304.

CC-4240 CURING

(a) The concrete shall be cured and protected against thermal and physical damage from the time of placement until the end of the minimum curing period specified in the Construction Specification.

(b) Special requirements on the type and duration of the curing process shall be established in the Construction Specification together with the details of any special conditions to be maintained during the curing period.

(c) During cold weather, the surfaces of the concrete placement shall be maintained above 40°F (4°C) for a minimum period of the first three days. Cold weather is defined as a period when for more than three successive days, the average daily outdoor temperature drops below 40°F (4°C). The average daily temperature

Page 92

is the average of the highest and lowest temperature during the period from midnight to midnight. When temperatures above 50°F occur for more than half of any 24 hr duration, the period should no longer be regarded as cold weather.

(d) The period for protection against freezing may be reduced if it can be demonstrated that the compressive strength of the concrete is at least 500 psi (3.4 MPa) and the structure has no early strength requirements.

CC-4250 FORMWORK AND CONSTRUCTION JOINTS

CC-4251 Formwork Design

CC-4251.1 General.

Forms shall result in a final structure which conforms to the shape, lines, and dimensions required by the Design Drawings and shall be substantial and sufficiently tight to prevent leakage of mortar. They shall be properly braced, tied, or supported to maintain position and shape within the limits prescribed by the Construction Specification.

CC-4251.2 Design of Formwork.

The Construction Specification for the design of formwork shall be based on ACI 347, Recommended Practice for Concrete Formwork, and shall include consideration of the following factors:

- (a) rate and method of placing concrete;
- (b) density of concrete;
- (c) construction loads, including vertical, horizontal, and impact loads.

CC-4251.3 Use of the Liner as Formwork.

In using the steel containment liner as formwork, special attention shall be given to liner supports and the height of lifts to prevent exceeding the tolerance requirements of CC-4522.

CC-4252 Construction Joints

Construction joints shall be located only as shown on the Design Drawings. The Construction Specification shall specify the method of their preparation. Specific attention shall be given to ensure that before concrete is placed, all debris, water, and ice are removed from the space to be occupied by the concrete. Joint preparation shall include removal of all laitance and other unsound material from hardened concrete surface, roughening of the surface to uniformly expose the aggregate, and saturating of the surface before additional concrete is placed.

CC-4253 Precast Concrete Segments

Where precast concrete segments will be used as forms, the Construction Specification shall specify the alignment tolerance, the type of joints between elements, the surface preparation, and ties required to ensure attachment to the containment concrete. Precast concrete segments shall be supported adequately to prevent displacement during concreting.

CC-4260 COLD AND HOT WEATHER CONDITIONS

Cold and hot weather procedures shall be in accordance with the Construction Specification. The Construction Specification shall establish a permissible range of as-placed temperatures for the concrete and may specify the preheating or precooling of the concrete constituents, or the use of ice or other means to control the temperature of the concrete, including maximum rate of cooling to prevent thermal shock. Such procedures shall be based on the information provided in ACI 305R, Hot Weather Concreting and ACI 306R, Cold Weather Concreting.

CC-4270 REPAIRS TO CONCRETE

Honeycombed or defective concrete shall be repaired or removed and replaced as directed by the Designer. Adjoining surfaces shall be prepared as specified for construction joints (CC-4252).

CC-4280 CEMENT GROUT FOR GROUTED TENDON SYSTEMS

CC-4281 Equipment for Grouting

- (a) Equipment for measuring and batching grout constituents shall be accurate within $\pm 3\%$.
- (b) Material shall be mixed in equipment that will produce grout of uniform consistency, free from lumps and undispersed cement. The grout shall be continuously agitated until pumped.
- (c) The pump shall be of the positive displacement type and shall be capable of exerting the required maximum pressure.

A safety device shall be provided to guard against exerting a pump discharge pressure in excess of 300 psi (2070 kPa). The pump shall not draw air in with the grout.

(d) A screen shall be provided between the mixer and the pump to ensure that the grout does not contain lumps.

Page 93

(e) The equipment shall be designed to prevent leakage and segregation of grout.

CC-4282 Grouting

(a) Grouting shall be carried out as promptly as possible after tensioning. The total time of exposure of the tendon steel to other than a controlled environment prior to grouting shall be specified in the Construction Specification and shall not exceed 30 days, nor shall the period between tensioning and grouting exceed 7 days unless special precautions are taken to protect the tendon against corrosion. The methods or products used in that case shall not jeopardize either the effectiveness of the grout as a corrosion inhibitor or the bond between the prestressing element and the grout. The Designer shall evaluate the potential corrosive effects of the local atmospheric conditions to determine if additional restrictions on the above limits must be established in the Construction Specification.

(b) Flushing before grouting is not recommended. When flushing has to precede the grouting, appropriate measures shall be taken and specified in the Construction Specification to ensure that:

(1) the level of harmful substances in the in-place grout does not increase above that of the designed grout;

(2) the properties of the injected grout satisfy the requirements of CC-2243.

(c) The maximum time after mixing within which the grout can be used shall be specified in the Construction Specification and established by tests that verify:

(1) that the intended reaction of the admixtures, such as expansive agents, continues when such a grout is injected in the duct; and

(2) that this time is 2 hr less than that required for the initial set of the grout as determined in accordance with ASTM C 191.

(d) The temperature at any point in the tendon duct during grouting shall be above 40°F (4°C). The end anchorages and the tendon duct shall be maintained above 40°F (4°C) for a period of 48 hr after grouting or until the grout reaches a minimum of 800 psi (5.5 MPa) compressive strength. The grout temperature shall not exceed 100°F (38°C) during mixing and pumping.

(e) The development of the grouting procedure shall consider the extremes of anticipated environmental conditions. The procedure will ensure that the ducts will be filled.

(f) All openings, air vents, and drains shall be hermetically sealed after grouting to prevent the ingress of water or any corrosive agents. When an expansive grout is used, all high point openings shall remain open to permit free expansion until grout sets.

CC-4300 FABRICATION OF REINFORCING SYSTEMS

CC-4310 GENERAL

This Subarticle covers the fabrication requirements for the reinforcing systems of concrete containments.

CC-4320 BENDING OF REINFORCING BAR

CC-4321 Standard Hooks

CC-4321.1 Definition.

The term *standard hook* as used herein shall mean either:

(a) a semicircular turn plus an extension of at least 4 bar diameters, but not less than $2\frac{1}{2}$ in. (64 mm) at the free end of the bar; or

(b) a 90 deg. turn plus an extension of at least 12 bar diameters at the free end of the bar; or

(c) for stirrup and tie anchorages:

(1) for No. 5 bar and smaller, a 90 deg. turn plus an extension of 6 bar diameters;

(2) for Nos. 6 through 8 bar, a 90 deg. turn plus an extension of 12 bar diameters;

(3) for No. 8 bar and smaller, a 135 deg. turn plus an extension of 6 bar diameters.

CC-4321.2 Diameter.

The diameter of bend measured on the inside of the bar for standard hooks shall not be less than the values of Table CC-4322-1, except for stirrups and ties in sizes Nos. 3 through 5.

CC-4322 Stirrups, Tie Hooks, and Bends Other Than Standard Hooks

(a) Inside diameter of bends for stirrups and ties shall not be less than 4 bar diameters for No. 5 bar and smaller.

(b) Bends for all other bars shall have diameters on the inside of the bar not less than allowed by Table CC-4322-1.

CC-4323 Bending

CC-4323.1 Fabrication of Bars.

When bending is required, it shall be performed prior to embedding the bars in the concrete except as permitted in CC-4323.2. All bars to be bent shall be cold bent prior to embedment in concrete, except as permitted in CC-4323.2.

Page 94

**TABLE CC-4322-1
MINIMUM DIAMETER OF BEND**

Bar Size	Minimum Diameter, bars
No. 3–No. 8	6
No. 9–No. 11	8
No. 14, No. 18	10

TABLE CC-4322-1 MINIMUM DIAMETER OF BEND

CC-4323.2 Bending of Bars Partially Embedded in Set Concrete.

Bending or straightening of bars partially embedded in set concrete shall not be permitted, except in isolated cases where corrective action or a field change is required and is specifically approved by the Designer. The bend diameters shall conform to the requirements of Table CC-4322-1. In addition, the beginning of the bend shall not be closer to the

shall conform to the requirements of Table CC-4322-1. In addition, the beginning of the bend shall not be closer to the existing concrete surface than is shown in Fig. CC-4323-1. The following requirements shall be adhered to for individual bar sizes.

(a) Bar Nos. 3 through 5 may be cold bent once. Preheating in accordance with CC-4323.3 is required for subsequent straightening or bending.

(b) Bar No. 6 and larger shall be preheated in accordance with CC-4323.3

(c) Examination of all bends shall be in accordance with CC-5340.

CC-4323.3 Preheating.

Preheating prior to bending or straightening, when required, shall be in accordance with the following rules.

(a) Preheating may be applied by any method which does not harm the bar material or cause damage to the concrete.

(b) The preheat shall be applied to a length of bar equal to 5 bar diameters each way from the center of the bend, except that preheat shall not extend below the surface of the concrete. The temperature of the bar at the concrete interface shall not exceed 500°F (260°C).

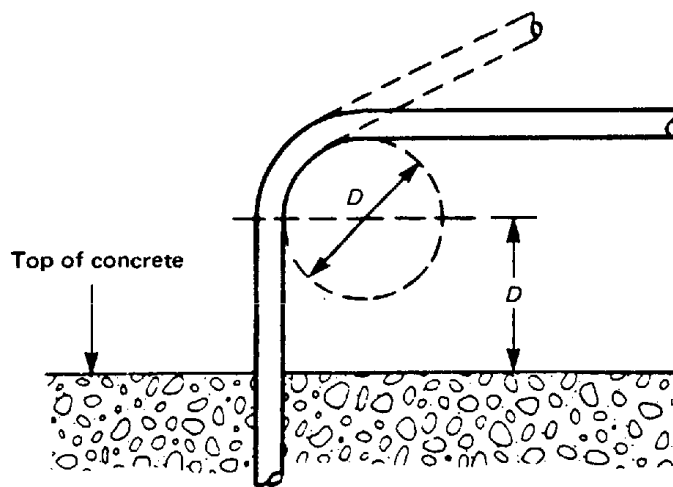
(c) The preheat temperature shall be 1100°F to 1200°F (593°C to 649°C).

(d) The preheat temperature shall be maintained until bending or straightening is complete.

(e) The preheat temperature shall be measured by temperature measurement crayons or contact pyrometer.

CC-4323.4 Tolerances.

Bars used for concrete reinforcement shall meet fabricating tolerance requirements specified in the Construction Specification.



D = minimum diameter of bend from Table CC-4322-1

FIG. CC-4323-1 ALLOWABLE BEND CONFIGURATION

CC-4330 SPLICING OF REINFORCING BARS

CC-4331 Introduction

CC-4331.1 General.

Splicing of reinforcing bars shall be made only as required or permitted by the Designer.

CC-4331.2 Permitted Types of Splices and Joints.

The types of splices and joints listed in (a), (b), and (c) below are permitted within the limitations described in the following subparagraphs:

- (a) lap splices
- (b) mechanical splices of the following types:
 - (1) sleeve with ferrous filler metal splices
 - (2) taper threaded splices
 - (3) swaged splices
 - (4) threaded splices in thread deformed reinforcing bars
 - (5) sleeve with cementitious grout
- (c) arc-welded joints

CC-4332 Lap Splices

Lap splice requirements are stated in CC-3532.

CC-4333 Mechanical Splices

CC-4333.1 Qualifications, Records, and Identifying Stamps

CC-4333.1.1 Required Qualifications.

Each Constructor or Fabricator is responsible for the splicing made by his organization and he shall conduct the tests required by this Subarticle in order to qualify the splicing procedure and the splicers.

CC-4333.1.2 Maintenance and Certification of Records.

The Constructor or Fabricator shall maintain a record of the splicing procedure and the splicers qualified and employed by him, showing the date and results of tests, and the identification mark or marks assigned to each splicer. These records shall be reviewed, verified, and signed by an authorized individual assigned by the Constructor. The records shall be accessible to the Owner and to the Authorized Inspector.

CC-4333.1.3 Splicing Prior to Qualification.

No splicing shall be undertaken until a splicer has been qualified. Only splicers who are qualified in accordance with CC-4333.4 shall be used.

CC-4333.2 Splice System Qualification Requirements

CC-4333.2.1 General Requirements.

Each splice system Manufacturer shall conduct a series of performance tests in order to qualify his splice system for use.

CC-4333.2.2 Materials to Be Used for Performance Tests.

The types of materials to be used for the performance test splices shall be the same as those intended for use in production splices. The actual materials used and the necessary dimensions of all test specimens shall be documented.

CC-4333.2.3 Type and Number of Performance Tests

(a) *Static Tensile Tests.* Six splice specimens for each bar size and splice type to be used in construction shall be tensile tested to failure using the loading rate set forth in SA-370. For swaged or sleeve with cementitious grout splices, three different deformation patterns shall be used for each bar size tested. The static tensile tests shall be repeated for each bar grade to be used in construction for taper threaded splices and threaded splices in thread deformed reinforcing bars. For taper threaded splices, one of the six specimens shall be tested at 20°F (-7°C) or less. A tensile test on an unspliced specimen from the same bar used for the spliced specimens shall be performed to establish actual tensile strength. The average tensile strength of the splices shall not be less than 90% of the actual tensile strength of the reinforcing bar being tested, nor less than 100% of the specified minimum tensile strength. The tensile strength of an individual splice system shall not be less than 125% of the specified minimum yield strength of the spliced bar. Each individual test report on both the spliced and unspliced specimens shall include at least the following information:

- (1) tensile strength;
- (2) total elongation;
- (3) load-extension curve to a minimum of 2% strain.

The gage length for each pair of spliced and unspliced specimens shall be the same, and equal to the length of splice sleeve, plus not less than 1 bar diameter nor more than 3 bar diameters at each end. For taper threaded splices, one of the splice specimens shall be cold soaked for a minimum of 24 hr prior to testing at a temperature equal to or less than the temperature required for this test. The test temperature at the root of the critical thread shall be 20°F (-7°C) or less and maintained until the specimen reaches yield level load.

(b) *Cyclic Tensile Tests.* Three specimens of the bar-to-bar splice for each reinforcing bar size (and grade for taper threaded splices and threaded splices in thread deformed reinforcing bar) and splice type to be used in construction shall be subjected to a low cycle tensile test. Each specimen shall withstand 100 cycles of stress variation from 5% to 90% of the specified minimum yield strength of the reinforcing bar. One cycle is defined as an increase from the lower load to the higher load and return.

CC-4333.2.4 Essential Variables.

The performance tests must be completely reconducted when any of the applicable changes listed below are made. Changes other than those listed may be made without the necessity for repeating the performance tests.

- (a) for all splice systems:
 - (1) a change in splice sleeve material or grade
 - (2) a reduction in the cross-sectional area of the splice sleeve
 - (3) a reduction in the bar engagement length
 - (4) an increase in reinforcing bar grade
- (b) for sleeve with ferrous filler metal splices, a change in the filler metal;
- (c) for taper threaded splices:

- (1) a change in thread geometry
 - (2) a change in torque
 - (d) for swaged splices:
 - (1) a change in swaging pressure
 - (2) a change in die geometry
 - (3) a change in stud material
 - (4) a change in outside or inside diameter
-

Page 96

- (5) for heated splices, a change in the required minimum temperature of the sleeve at the time of swaging and maximum time and temperature that sleeves may be held in the heating oven
- (e) for threaded splices in thread deformed bar:
 - (1) a change in thread geometry
 - (2) a change in torque
- (f) for sleeve with cementitious grout splices:
 - (1) a change in the cementitious grout formulation
 - (2) a change in the deformation pattern inside the sleeve
 - (3) a change in the reinforcing steel deformation pattern
 - (4) a change in temperature limits for the splice system (bar, sleeve, grout) during placement and curing of grout.

CC-4333.3 Requirements for Production Splicing Procedures.

All production splicing shall be performed in accordance with a written procedure which shall include, as a minimum, the procedures used for the performance tests in CC-4333.2.3, with the following additional information:

- (a) for sleeve with ferrous filler metal splices:
 - (1) bar end preparation
 - (2) cleanliness requirements
 - (3) bar end location tolerances
 - (4) permissible gap between reinforcing bar ends
 - (5) allowable voidage in the filler metal
- (b) for taper threaded splices:
 - (1) type of equipment and methods used to verify bar thread acceptability
 - (2) cleanliness requirements
 - (3) type of equipment and methods used for torquing
 - (4) required force and method of measurement
 - (5) method of mechanically locking the position splices
 - (6) method used to verify the final alignment and engagement of the splice on both bars
- (c) for swaged splices:

- (1) cleanliness requirements
- (2) type of equipment and methods used for swaging
- (3) required swaging pressure, method of measurement, pressure tolerance, and frequency of calibration of the hydraulic system
- (4) method used to verify final alignment and engagement of the splice on both bars
- (5) bar end preparation
- (6) minimum and maximum number of swaging operations per sleeve
- (7) method used to ensure sleeve is swaged along full length
- (8) limits of die wear and frequency of checking
- (9) for heated sleeves, limits and methods used to measure duration and temperature of heating cycle and temperature of sleeve at time of swaging
- (10) method used to ensure that stud is locked to swaged sleeve
- (d) for threaded splices in thread deformed bar:
 - (1) type of equipment and methods used to verify bar thread acceptability
 - (2) cleanliness requirements
 - (3) type of equipment and methods used for torquing
 - (4) required torque, tolerance on required torque, and method of measurement
 - (5) method used to verify the final alignment and engagement of the splice coupler on both bars
 - (6) method used to lock the coupling in position to prevent loosening of the splice
- (e) for sleeve with cementitious grout splices:
 - (1) bar end preparation
 - (2) cleanliness requirements
 - (3) bar end location tolerances
 - (4) bar and sleeve centering tolerances
 - (5) permissible gap between reinforcing bar ends
 - (6) allowable voidage in the grout
 - (7) procedures for storing, mixing, placing, and curing the grout
 - (8) maximum and minimum temperature of the splice system during placement and curing of grout
 - (9) restriction to prevent relative bar movement during setting and strength development of the grout

CC-4333.4 Initial Qualification Tests.

Each splicer shall prepare two qualification splices on the largest bar size to be used. In addition, for ferrous filler metal splices, cementitious grouted splices, and swaged splices only, each of the splice positions to be used (e.g., horizontal, vertical, diagonal) shall be qualified. The qualification splices shall be made using reinforcing bar identical to that to be used in the structure. The completed qualification splices shall be tensile tested using the loading rates set forth in SA-370 and the tensile results shall meet those specified in Table CC-4334-1.

CC-4333.5 Continuing Splice Performance Tests

CC-4333.5.1 Introduction.

A continuing series of tests shall be made to ensure that production splices meet the tensile requirements. Nondestructive examination requirements are specified in CC-5320.

Page 97

CC-4333.5.2 Splice Samples.

Splice samples may be production splices (cut directly from in-place reinforcement) or straight sister splices (removable splices made in place next to production splices and under the same conditions), in accordance with the schedule established in CC-4333.5.3.

CC-4333.5.3 Testing Frequency.

Splice samples shall be tensile tested in accordance with the following schedule for the appropriate splice system.

(a) Separate test cycles shall be established for sleeve with ferrous filler metal splices, sleeve with cementitious grout splices, and swaged splices in horizontal, vertical, and diagonal bars. Straight sister splices may be substituted for production test samples on radius bent bars and for splicing sleeves arc welded to structural steel elements or the liner.

(1) For sleeve with ferrous filler metal splices, one splice shall be tested for each unit of 100 production splices.

(2) For swaged splices and sleeve with cementitious grout splices, test cycles shall be established as follows.

(a) If only production splices are tested, the sample frequency shall be as follows:

(1) 1 of the first 10 production splices;

(2) 1 of the next 90 production splices;

(3) 2 of the next units and each subsequent unit of 100 production splices.

(b) If production and sister splices are tested, the sample frequency shall be as follows:

(1) 1 production splice of the first 10 production splices;

(2) 1 production and 3 sister splices for the next 90 production splices;

(3) 3 splices, either production or sister splices, for the next and each subsequent unit of 100 production splices.

At least one-fourth of the total number of splices tested shall be production splices.

(b) Taper threaded splices and threaded splices in thread deformed reinforcing bar. Separate test cycles shall be established for each bar size and grade, using straight sister splices as follows:

(1) 1 of the first 10 splices;

(2) 1 of the next 90 splices;

(3) 2 of the next and subsequent units of 100 splices.

In addition, for taper threaded splices, a minimum of three tests shall be made for each bar heat.

CC-4333.5.4 Tensile Testing Requirements.

Splice samples shall be tensile tested using the loading rates set forth in SA-370. All taper threaded sample splices shall be tensile tested at 20°F (-7°C) or less. The following shall constitute the acceptance standards.

(a) The tensile strength of each sample shall equal or exceed 125% of the specified yield strength as shown in Table CC-4334-1.

(b) The average tensile strength of each group of 15 consecutive samples shall equal or exceed the specified

minimum tensile strength as shown in Table CC-4334-1.

If any sample tested fails to meet the provisions of (a) or (b) above, the requirements of CC-4333.5.5 shall be followed.

CC-4333.5.5 Substandard Tensile Test Results

(a) If any splice used for testing fails to meet the strength requirement of Table CC-4333-1 and failure occurs in the bar, the cause of the bar break shall be investigated by the Constructor or Fabricator. Any necessary corrective action affecting splice samples shall be implemented prior to continuing the testing frequency of CC-4333.5.3.

(b) If any splice used for testing fails to meet the strength requirement of Table CC-4333-1 and failure does not occur in the bar, two additional splices shall be tested. If either of these retests fails to meet the strength requirement of Table CC-4333-1, splicing shall be halted. Splicing shall not be resumed until the cause of failures has been corrected and resolved.

(c) If the running average tensile strength of 15 consecutive samples fails to meet the tensile requirement of Table CC-4333-1, splicing shall be halted. The Constructor or Fabricator shall investigate the cause and make the necessary corrective action.

(d) When splicing is resumed, the testing frequency shall be started anew.

CC-4333.6 Recording of Tensile Test Results.

The results of all tensile tests obtained from the tests prescribed by CC-4333.4 and CC-4333.5, along with all other pertinent data, shall be recorded.

CC-4333.7 Welding.

Welding of splice sleeves to parts shall be performed using welding procedures and welders qualified in accordance with AWS D1.1 or Section IX.

CC-4333.8 Impact Requirements.

When reinforcing bar or mechanical splices are to be welded to material that requires impact testing, the following shall apply.

(a) The weld filler metal shall be impact tested in accordance with the requirements of the material that the reinforcing bar is attached to.

(b) The acceptance criteria of the material requiring impact testing shall be met.

**TABLE CC-4333-1
TENSILE REQUIREMENTS FOR MECHANICAL REINFORCING BAR SPLICES AND WELDED JOINTS**

Specification	Reinforcing Bar Properties		Splice or Joint Strength Requirements		
	Bar Grade	Minimum Yield Strength, psi	Minimum Tensile Strength, psi	Minimum Average Mechanical Splice or Welded Joint Tensile Strength, psi [Note (1)]	Minimum Single Mechanical Splice or Welded Joint Tensile Strength, psi [Note (2)]
ASTM A 615	Grade 40	40,000	70,000	70,000	50,000
ASTM A 615	Grade 60	60,000	90,000	90,000	75,000
ASTM A 706		60,000	80,000	80,000	75,000

NOTES:

(1) See CC-4333 and Appendix XI.

(2) These values are equivalent to 125% of the yield strength of each bar grade.

TABLE CC-4333-1 TENSILE REQUIREMENTS FOR MECHANICAL REINFORCING BAR SPLICES AND WELDED JOINTS

CC-4334 Arc Welded Joints

Refer to Appendix XI for qualification requirements.

CC-4340 PLACING REINFORCEMENT

CC-4341 General

The placement of reinforcing steel shall comply with the Design and Construction Drawings and the placing tolerances specified in the Construction Specification.

CC-4342 Supports

Reinforcement shall be accurately placed and adequately supported before concrete is placed and shall be secured against displacement beyond permitted tolerances. Welding of crossing bars shall not be permitted.

CC-4343 Tolerances

The tolerances for the placement of reinforcement shall be specified in the Construction Specification.

CC-4350 SPACING OF REINFORCEMENT

CC-4351 Layers

The clear distance between parallel bars in a layer and the clear distance between parallel layers of reinforcement shall not be less than that required by the Construction Specification to properly place and consolidate concrete.

CC-4352 Splices

The clear distance limitation between bars shall also apply to the clear distance between a contact (lap) splice and adjacent splices or bars.

CC-4360 SURFACE CONDITION

(a) Reinforcing bars at the time concrete is placed shall be free from mud, oil, ice, snow, or other coatings that adversely affect bonding.

(b) Reinforcing bars with rust, mill scale, or a combination of both shall be considered satisfactory provided the minimum dimensions, including height of deformations and weight of a hand wire brushed test specimen, are not less than ASTM A 615 requirements.

CC-4400 FABRICATION AND INSTALLATION OF PRESTRESSING SYSTEMS

CC-4410 GENERAL

This Subarticle covers the requirements for the fabrication, installation, tensioning, and protection of prestressing tendons.

CC-4420 RECEIVING, STORING, AND HANDLING OF MATERIAL

The construction procedures shall specify the manner in which material is to be received, stored, and handled in the Fabricator's plant and at the construction site.

Page 99

The Constructor's, Fabricator's, or Material Supplier's Quality Assurance Program shall provide for material identification and segregation in accordance with CC-2152. The handling shall not cause detrimental mechanical damage to the material. The Construction Specification shall establish requirements for storage of all material to ensure that it is protected from detrimental corrosion. Limits of detrimental corrosion shall be specified in the Construction Specification.

CC-4430 TENDON FABRICATION

CC-4431 Anchorage Components

CC-4431.1 Bearing Plate - Trumpet Assembly.

All welding shall be performed using welding procedures and welders qualified in accordance with Section IX. The suggested preheat schedules of Appendix D of this Division shall be taken into account.

CC-4431.2 Anchor Assemblies, Couplings, Wedge Blocks, Shims, Wedges, and Anchor Nuts.

The construction procedures shall set forth the manufacturing limits and tolerances applicable to these items.

CC-4432 Tendon Assembly

CC-4432.1 Introduction.

The following subparagraphs apply to both shop and field assembly operations.

CC-4432.2 Cutting.

The construction procedures shall specify the methods and procedures for cutting and cutting tolerances of prestressing elements.

CC-4432.3 Assembly Procedures.

A detailed fabrication procedure, including a checklist of work and information as required by the construction procedures, shall be prepared before tendon fabrication. The checklist information for each tendon shall include traceability data such as heat number or element coil number, anchorage component serial numbers, etc. It shall also include length, location, numerical designations of the tendons, and the temporary corrosion protection of the tendon.

CC-4432.4 Details.

Attention shall be given to specific aspects such as dimensions, geometry, concentricity, alignment, angularity, and surface conditions. Limits and tolerances of these aspects shall be specified in the construction procedures.

CC-4432.5 Twisting and Coiling.

Prestressing tendons comprised of multiple elements shall be twisted, as necessary, to minimize differential length of the individual prestressing steel elements. Twisting is mandatory for all horizontal circumferential tendons comprised of multiple elements stressed simultaneously as a group. The amount of twist shall be specified in the construction procedure. Coiling, when required for transportation, shall be performed in a manner not to cause damage to the tendon. Coil diameter shall be specified in the construction procedures.

CC-4432.6 Corrosion Protection Applied During Fabrication.

The type of corrosion protection, the detailed procedure for its application, and the pertinent time limitations shall be specified in the construction procedures.

CC-4440 TENDON IDENTIFICATION

Upon completion of fabrication into a whole or partial tendon, the tendon shall be identified with a tendon number. The materials in the tendon shall be recorded so that they can be traced to the tests which have determined their quality.

CC-4450 TENDON INSTALLATION

CC-4451 Installation Procedure

A detailed installation procedure, including a checklist of work and information as required by the construction procedures, shall be prepared before the tendon installation. The checklist shall include lengths, locations, and numerical designations of the tendons; inspection and preparation of the tendon ducts; method and materials for the corrosion protection of the tendons; requirements for welding or burning where tendons are handled and installed; and sequencing of installation. Prestressing system components shall not be installed, or shall be removed and replaced, if handling or storage causes their characteristics to change beyond the tolerances established in the Construction Specification.

CC-4452 Tendon Ducts and Channels

The Construction Specification shall specify the tolerances for position and alignment. Tendon ducts and channels shall be adequately supported against displacement during concreting. Open ducts shall be protected by capping or plugging to prevent entry of concrete or other deleterious material. All joints shall be made tight against the inleakage of mortar or appreciable water from the fresh concrete. The Construction Specification shall specify the temporary corrosion protection system, if any, and the construction procedures shall define the method for its application. All water and

Page 100

debris shall be removed from ducts prior to installation of tendons.

CC-4460 POST-TENSIONING

CC-4461 Supervision

Prestressing operations shall be under the direction of an experienced supervisor and shall be carried out only by trained operators.

CC-4462 Stressing Sequence

The required sequence of prestressing shall be specified in the Construction Specification.

CC-4463 Alignment

Components of the tensioning equipment shall be accurately set and supported in line with the axis of the tendon to which they are fitted, and they shall be squarely seated on each other and on the anchorage before stressing is commenced. All anchorages, temporary connections, and jacks shall be checked for alignment before transmitting any significant load to the tendon.

CC-4464 Load and Extension Measurement

CC-4464.1 Procedure.

Tendon extension shall be measured during the application of the jacking force. The measurement of extension shall commence at a specified load of approximately 10% of the ultimate load of the tendon. The calculated elongation due to the initial force applied prior to commencing measurement shall be added to the measured elongation. In addition, proper allowance shall be made for any significant elongations within the stressing equipment if they are included in the measured elongation. The load applied to any tendon immediately prior to anchoring shall not exceed the limits prescribed in the Construction Specification. The tensioning load shall be measured by load cells or equivalent means having an accuracy not less than $\pm 2\%$ of the required tensioning force. Hydraulic pressure gages or dynamometers shall be calibrated against standards traceable to the National Standards before their use in the prestressing operation. Pressure gages and jacks shall be calibrated as a unit and shall always be used together. During stressing, records shall be made of elongations as well as forces obtained. Dynamometer or gage readings shall be checked against elongation of the tendons. The cause of any discrepancy exceeding $\pm 10\%$ for individual tendons and $\pm 5\%$ for the average of all tendons of one family (configuration; for example, hoop, dome, inverted U-shaped) of tendons of that predicted by calculations, using average load elongation curves, shall be resolved in consultation with the Designer. Final elongation and stress shall be recorded.

CC-4464.2 Lubricants.

If lubricants are used to reduce friction, they shall comply with the requirements of CC-2442.

CC-4465 Loss of Prestressing Force

The loss of prestressing force due to unreplaced, broken, or damaged prestressing elements shall not exceed the percentage of the total prestressing force specified in the Construction Specification.

CC-4470 PERMANENT CORROSION PROTECTION

CC-4471 General

The Construction Specification shall specify the permanent corrosion protection system, if any, and the construction procedures shall define the method for its application. Material shall conform to the requirements of CC-2442.3 or CC-2240.

CC-4472 Cement Grout for Grouted Tendon Systems

The sequence and specific procedures for batching, mixing, pumping, and placing of cement grout for bonded tendon systems shall be specified in the Construction Specification and conform to the requirements of CC-4280.

CC-4500 FABRICATION OF LINERS

CC-4510 GENERAL REQUIREMENTS

CC-4511 Introduction

(a) The rules in the following paragraphs apply specifically to the fabrication and construction of metal liners.

(b) Each Fabricator or Constructor shall be responsible for the quality of the welding done by his organization and he shall conduct tests not only of the welding procedure to determine its suitability to ensure welds which will meet the required tests, but also of the

Page 101

welders and welding operators to determine their ability to apply the procedure properly.

(c) No production work shall be undertaken until both the welding procedure and the welders or welding operators have been qualified in accordance with Section IX.

CC-4512 Elimination and Repair of Defects

Defects in materials may be eliminated or repaired by the Constructor or Fabricator by welding provided the defects are removed, repaired, and examined in accordance with the requirements of CC-2530 for the applicable product form.

CC-4520 FORMING, FITTING, AND ALIGNING

CC-4521 Cutting, Forming, and Bending

CC-4521.1 Cutting.

Liner material, edges of heads, and other parts may be cut to shape and size by mechanical means, such as machining, shearing, grinding, or by oxygen or arc cutting. After oxygen cutting, all slag, dross, or other foreign material shall be removed by mechanical means prior to further fabrication or use.

CC-4521.1.1 Preheating Prior to Thermal Cutting.

When thermal cutting is performed to prepare weld joints or edges, to remove attachments or defective material, or for any other purpose, consideration shall be given to preheating the material using preheat schedules such as suggested in Appendix D.

CC-4521.2 Forming and Bending Processes.

Any process may be used to hot or cold form or bend liner plate materials, including weld metal, provided the notch toughness properties of the materials, where required, are not reduced below the minimum specified values, or they are effectively restored by heat treatment following the forming operation. *Hot forming* is defined as forming with the material temperature higher than 100°F below the lower critical temperature of the material.

CC-4521.2.1 Required Postweld Heat Treatment.

Cold-formed shell sections and heads of P-No. 1 materials shall be postweld heat treated when the resulting maximum extreme fiber elongation is more than 5%.

CC-4521.3 Qualifications of Forming and Bending Processes.

A procedure qualification test shall be conducted on specimens taken from coupons of the same material specification, grade or class, heat treatment, and similar impact requirements as employed for the material of the component involved. These coupons shall be subjected to the equivalent forming or bending process and heat treatment as the material of the component involved. Applicable tests shall be conducted to determine that the required impact properties are met after straining.

CC-4521.3.1 Exemptions.

Procedure qualification tests are not required for the following:

- (a) hot-formed material, such as forgings, in which the hot forming is completed by the Material Manufacturer prior to removal of the impact test specimens;
- (b) hot-formed material represented by test coupons which have been subjected to heat treatment representing the hot-forming procedure and the heat treatments to be applied to the parts;
- (c) material which does not require impact testing in accordance with CC-2500;
- (d) material which has a final strain after forming of less than 0.5%;
- (e) material where the final strain is less than that of a previously qualified procedure for the material;
- (f) material from which the impact testing is required by CC-2522 to be performed on each heat and lot, as applicable, after forming.

CC-4521.3.2 Procedure Qualification Test.

The Procedure qualification test shall be performed in the following manner.

- (a) The tests shall be performed on three different heats of material both before and after straining to establish the effects of the forming and subsequent heat treatment operations.
- (b) Specimens shall be taken in accordance with the requirements of this Division and shall be taken from the tension side of the strained material.
- (c) The percent strain shall be established by the following formulas.

For cylinders

$$\% \text{ strain} = \frac{50t}{R_f} \left(1 - \frac{R_f}{R_o} \right)$$

For spherical or dished surfaces

$$\% \text{ strain} = \frac{75t}{R_f} \left(1 - \frac{R_f}{R_o} \right)$$

For pipe

$$\% \text{ strain} = \frac{100r}{R}$$

where

t	= nominal thickness
R_f	= final radius to center line of shell
R_o	= original radius (equal to infinity for a flat part)
R	= nominal bending radius to the center line of the pipe
r	= nominal radius of the pipe

(d) The procedure qualification shall simulate the maximum percent surface strain employing a bending process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient Charpy V-notch impact test specimens shall be taken from each of the three heats of material to establish a transition curve showing both the upper and lower shelves. Tests consisting of three impact specimens taken from each of three heats shall be conducted at a minimum of five different temperature distributions throughout the transition range. The upper and lower shelves may be established by the use of individual test specimens. As an alternative to the transition curve, drop weight tests may be used, or one set of Charpy V-notch impact test specimens tested after forming at the specified temperature may be used if performed on each heat or lot, as applicable, of formed material.

(f) From the impact test transition curves or drop weight tests from each of the three heats, both before and after straining, determine either:

(1) the maximum change in temperature considering various energy levels when transition curves are used, or the change in nil-ductility transition (NDT) temperature as determined by the drop weight tests; or

(2) the maximum loss of impact energy for the material considering each temperature increment of 10°F.

CC-4521.3.3 Acceptance Standards.

To be acceptable, the material used in the liner must have impact properties sufficient to compensate for the maximum change in temperature or energy levels established by the qualification procedures for all material subjected to the equivalent strain used in the liner.

CC-4521.3.4 Requalification.

A new procedure qualification test is required when any of the following changes are made:

- (a) where the postweld heat treatment time at temperature is greater than previously qualified (If the material is not postweld heat treated, the procedure must qualify without postweld heat treatment.);
- (b) where the maximum calculated strain of the material exceeds the previously qualified strain by more than 0.5%;
- (c) where preheat over 250°F (121°C) is used in the forming or bending operation but not followed by a subsequent postweld heat treatment.

CC-4521.4 Minimum Thickness of Fabricated Material.

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of CC-3000, the material may be repaired in accordance with CC-2530.

CC-4522 Forming Tolerances

CC-4522.1 Tolerances for Liner Shells and Heads.

The following Subarticles define the requirements for liner tolerances. The Construction Specification shall state any additional requirements. A guide for dimensional tolerances for liners is provided in Appendix F.

CC-4522.1.1 Tolerances for Liner Shells.

At the specified increments of elevation, the difference between the maximum diameter and the minimum shall not exceed $\frac{1}{2}$ of 1%. This requirement will be satisfied by measuring diameters spaced approximately 30 deg. apart for each 12 ft (3.7 m) of height. The overall containment plumbness of the liner cylinder between the springline (start of dome) and the bottom shall be 1 in 200 based on the total height of the cylinder.

CC-4522.1.2 Tolerance for Liner Heads.

The inner surface of the liner head shall not deviate from the specified shape by more than $1\frac{1}{4}\%$ of the inside diameter of the liner shell.

CC-4522.2 Localized Thin Areas.

Forgings are permitted to have small areas thinner than required if the adjacent areas surrounding each has sufficient thickness to provide the necessary reinforcement.

CC-4522.3 Tolerance Deviations for Liner Parts Fabricated From Pipe.

Liner parts fabricated from pipe meeting all other requirements of this Subarticle may have variations of diameter and deviations from circularity permitted by the material specification for such pipe.

CC-4523 Fitting and Aligning

CC-4523.1 Fitting and Aligning Methods.

Parts that are to be joined by welding may be fitted, aligned, and retained in position during the welding operation by the use of bars, jacks, clamps, tack welds, or temporary attachments.

CC-4523.1.1 Tack Welds.

Tack welds shall be made by qualified welders using qualified welding procedures. Tack welds used to secure alignment shall

either be removed completely when they have served their purpose; or when the tack welds are to become part of the finished weld, their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the finished weld.

**TABLE CC-4523-1
MAXIMUM ALLOWABLE OFFSET
IN FINAL WELDED JOINTS**

Section Thickness, in.	Offset
Up to $\frac{3}{4}$, incl.	$\frac{1}{4}t$
Over $\frac{3}{4}$ to $1\frac{1}{2}$, incl.	$\frac{3}{16}$ in.
Over $1\frac{1}{2}$	$\frac{1}{8}t$ to $\frac{1}{4}$ in. max.

TABLE CC-4523-1 MAXIMUM ALLOWABLE OFFSET IN FINAL WELDED JOINTS

CC-4523.2 Maximum Offset of Aligned Sections

(a) Alignment of sections shall be such that the maximum offset of the finished weld will not be greater than the applicable amount listed in Table CC-4523-1, where t is the nominal thickness of the thinner section of the joint.

(b) Joints in spherical liners and within heads and joints between cylindrical shells and hemispherical heads shall meet the requirements of Table CC-4523-1.

CC-4523.2.1 Fairing of Offsets.

Any offset within the allowable tolerance provided above shall be faired to at least a three to one taper over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld.

CC-4523.3 Support During Concreting.

The liner shall be adequately supported, braced, and tied to prevent displacement beyond the tolerances set forth in CC-4522.

CC-4530 WELDING QUALIFICATIONS

CC-4531 General Requirements

CC-4531.1 Types of Processes Permitted.

Only those welding processes which are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Division may be used for welding liners or attachments thereto, except as otherwise permitted by CC-4333.7. Any process used shall be such that the records required by CC-4532.2 can be made.

CC-4531.1.1 Capacitor Discharge Welding.

The capacitor discharge method of welding may be used for temporary attachments directly to the liner, provided any surface defects found upon removal are eliminated in accordance with CC-4545.2.

CC-4531.1.2 Low Energy Capacitor Discharge Welding.

The low energy capacitor discharge method of welding may be used for permanent nonstructural attachments such as strain gages and thermocouples, provided:

(a) the power output is limited to less than 125 W/sec;

(b) a Welding Procedure Specification describing the capacitor discharge equipment, the combination of materials to be joined, and the techniques of application is prepared; qualification of the welding procedure is not required;

(c) the minimum thickness of the material to which the attachment is made exceeds 0.09 in. (2.3 mm).

CC-4532 Welding Qualifications, Records, and Identifying Stamp

CC-4532.1 Required Qualifications

(a) Each Fabricator or Constructor is responsible for the welding done by his organization and he shall establish procedures and conduct the tests required by this Subarticle and by Section IX in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures.

(b) Procedures, welders, and welding operators used to join permanent or temporary attachments to liners and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Subarticle.

(c) When making procedure test plates for butt welds, it is recommended that consideration be given to the effect of angular, lateral, and end restraint on the weldment. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

CC-4532.2 Maintenance and Certification of Records.

The Fabricator or Constructor shall maintain a record of his qualified welding procedures and of the welders and welding operators qualified and employed by him, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and signed by any authorized individual assigned by the Fabricator or Constructor and shall be accessible to the Owner or his agent and to the Authorized Inspector.

Page 104

CC-4532.2.1 Identification of Joints by Welder or Welding Operator.

The welder or welding operator making permanent welded joints shall be identified by one of the following methods:

(a) The welder or welding operator making a joint shall apply the identification mark assigned by the Fabricator or Constructor on or adjacent to all permanent welded joints. The marking shall be at intervals of 3 ft or less and shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps.

(b) The Fabricator or Constructor shall keep a record of permanent welded joints in a component and of the welders and welding operators making each joint.

(c) When a multiple number of permanent welded joints are made, the Fabricator or Constructor need not maintain a record to identify the welder or welding operator who welded each individual joint provided:

(1) The Fabricator or Constructor maintains a system that will identify the welders or welding operators who made such welds so that the Inspector can verify that the welders or welding operators were properly qualified.

(2) The welds in each category are all of the same type and configuration and are welded using the same welding procedure specification.

(d) The identification of welders or welding operators making tack welds that become part of a permanent weld is not required provided the Fabricator or Constructor maintain a system to permit the Inspector to verify that such tack welds were made by qualified welders or welding operators.

(e) The identification of welders or welding operators is not required for attachment welds provided the Fabricator or Constructor maintains a system to permit the Inspector to verify that all such attachment welds were made by qualified welders or welding operators.

CC-4532.3 Welding Prior to Qualifications.

No welding shall be started until after the welding procedures which are to be used have been qualified. All welders and welding operators shall be qualified in accordance with CC-4534 and Section IX.

CC-4532.4 Transferring Qualifications.

The performance qualification tests for welders and welding operators conducted by one Fabricator or Constructor shall not qualify welders or welding operators to weld for any other Fabricator or Constructor.

CC-4533 General Requirements for Welding Procedure Qualification Tests

CC-4533.1 Conformance to Section IX Requirements.

All welding procedure qualification tests, including stud welding, shall be in accordance with the requirements of Section IX as supplemented by the requirements of this Article.

CC-4533.2 Base Material to Be Employed.

Welding procedure qualifications for materials which have specified impact test requirements shall be made using base materials in accordance with the applicable requirements of QW-403.4 and QW-403.5 of Section IX.

CC-4533.3 Heat Treatment of Qualification Welds for Ferritic Materials.

Postweld heat treatment of procedure qualification welds shall conform to the applicable requirements of CC-4550 and Section IX. The postweld heat treatment time at temperature shall be at least 80% of the maximum time to be applied to the weld material. The postweld heat treatment total time may be applied in one heating cycle.

CC-4533.4 Preparation of Test Coupons and Specimens

(a) Removal of test coupons from the test weld and the dimensions of specimens made from them shall conform to the requirements of Section IX, except the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with CC-4533.4.1, CC-4533.4.2, and (b) below.

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test specimens. When each process cannot be included in the full-size impact test specimen at the $\frac{1}{4}t$ location required by this Section, additional full-size specimens shall be obtained from locations in the test weld that will assure that at least a portion of each process has been included in full-size test specimens. As an alternative, additional test welds can be made with each process so that full-size specimens can be tested for each process.

CC-4533.4.1 Coupons Representing the Weld Deposits.

Impact test specimens and testing shall conform to the applicable requirements of CC-2522.1. The impact specimen shall be located so that the longitudinal axis of the specimen is at least $\frac{1}{4}t$, and where the thickness of the test assembly permits, not less than $\frac{3}{8}$ in. (10 mm) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified in CC-4552 and the test assembly is cooled at an accelerated rate, the longitudinal axis of the specimen shall be a minimum of t from the edge of the

test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the weld. The length of the notch of the Charpy V-notch specimen shall be normal to the surface

Page 105

of the weld. Where drop weight specimens are required, the tension surface of the specimen shall be oriented parallel to the surface of the test weld assembly.

CC-4533.4.2 Coupons Representing the Heat Affected Zone.

Where impact tests of the heat affected zone are required by CC-4533.5.2, specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through (c) below.

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented either parallel to or perpendicular to the principal direction of rolling or forging.

(b) The heat affected zone impact test specimens and testing methods shall conform to the requirements of CC-2522.1.2. The specimens shall be removed from a location as near as practical to a depth midway between the surface and center thicknesses. The coupons for heat affected zone impact specimens shall be taken transverse to the axis of the weld and etched to define the heat affected zone. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much heat affected zone as possible in the resulting fracture. Where the material thickness permits, the axis of a specimen may be inclined to allow the root of the notch to align parallel to the fusion line. When a grain refining heat treatment is not performed on welds made by the electroslag or electrogas welding process, the notch for the impact specimens shall be located in the grain coarsened region.

(c) For the comparison of heat affected zone values with base material values [CC-4533.5.2(b)], Charpy V-notch specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the heat affected zone specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the heat affected zone specimens and the axis of the notch shall be normal to the surface of the base material.

CC-4533.5 Impact Test Requirements.

Impact tests of the weld metal and the heat affected zone are required when impact tests are required for either of the base materials being joined (CC-2521). Exemption from impact testing under CC-2521.1(h) does not apply to weld metal unless the specific weld metal used is included in Table CC-2521.1-1. Exemption from impact testing of the heat affected zone of those base materials exempted by CC-2521.1(h) is not permitted. The welding procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of CC-2524 and CC-4533.4. Acceptance standards and exceptions to test requirements shall be in accordance with the following subparagraphs. Retests in accordance with the provisions of CC-2527 are permitted.

CC-4533.5.1 Impact Tests of Weld Metal

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding $\frac{5}{8}$ in. (16 mm) in thickness when the weld will be made on the surface or will penetrate the base material that requires impact testing in accordance with CC-2521. In addition, such testing of the weld metal is required for the welding procedure qualification tests for any weld repair to base material that requires impact testing in accordance with CC-2521, regardless of the depth of the repair. Exemption from impact testing under CC-2521.1(h) does not apply for weld metal of welding procedure qualification tests for either production weld joints or base material repairs, unless the specific weld metal used is included in Table CC-2521.1-1.

(b) The impact test requirements and acceptance standards for welding procedure qualification weld metal shall be the same as specified in CC-2524 for the base material to be welded or repaired. When two materials having different fracture toughness requirements are to be joined by welding, the test requirements and acceptance standards of either material may be used for the weld metal except where otherwise specified by NCA-2143 or other parts of this Section.

(c) Impact tests are not required for austenitic weld metal.

(d) A Welding Procedure Specification qualified to the impact testing requirements of Subsection NB, NC, or NE may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection.

CC-4533.5.2 Impact Tests of Heat Affected Zone

(a) Charpy V-notch tests of the heat affected zone of the welding procedure qualification test assembly are required whenever the thickness of the weld exceeds $\frac{5}{8}$ in., and the base materials require impact testing in accordance with the rules of CC-2521. Exemption of base materials by CC-2521.1(h) does not apply to the welding procedure qualification heat affected zone or unaffected base material for such materials. The only exceptions to the requirements are the following:

(1) the qualification for welds in P-No. 1 materials that are postweld heat treated and are made by any process other than electroslag, electrogas, or thermit;

(2) the qualification for weld deposit cladding on any base material.

(b) Impact testing of the procedure qualification test heat affected zone, where required by CC-4533.5.2,

Page 106

shall be conducted in accordance with (b)(1) through (3), or (b)(4) through (6) and (c) below, if applicable.

(1) For tests of welding procedure qualifications for materials that require tests in accordance with CC-2524.2.1 and CC-2524.4.1, when applicable, three Charpy V-notch heat affected zone specimens and three Charpy V-notch unaffected base material specimens shall be tested at a temperature in accordance with CC-2524.1(a)(1). The Charpy V-notch test of the unaffected base material shall meet the requirements of Table CC-2524.2-1 or Table CC-2524.2-2, and Table CC-2524.4-1, if applicable. If the average toughness value of the three heat affected zone specimens is equal to or greater than the average value of the unaffected base material Charpy V-notch specimen, the qualification test shall be considered acceptable and the values and testing temperature shall be recorded on the Welding Procedure Qualification Record. The production base material impact tests may be conducted at temperatures in accordance with CC-2524.1.

(2) If the heat affected zone Charpy V-notch average toughness value of (b)(1) above is less than the unaffected base material value, and the qualification test meets the other criteria of acceptance, the Charpy V-notch test results may be recorded on the Welding Procedure Qualification Record. In this case, either production base material impact tests shall be conducted 30°F lower than required by CC-2524.1; or data which will provide a testing temperature reduction for the production base material below that of CC-2524.1, or an increase in the permissible lowest service metal temperature for the base material for which the welding procedure is being qualified, shall be obtained in accordance with (b)(3) below and included. Alternatively, the welding procedure qualification may be rewelded and retested.

(3) The data for use in (b)(2) above shall be developed by performing additional Charpy V-notch tests on either or both of the welding procedure qualification test heat affected zone and the unaffected base material at temperatures which provide toughness values that meet or exceed those required for the thickness or thickness-strength combination of the material to be welded in production. The average toughness values for the heat affected zone and unaffected base material shall be plotted on a property-temperature chart. The temperature at which these two sets of data exhibit a common acceptable value of toughness for the production thickness or thickness-strength combination involved shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the heat affected zone. This difference, if a positive number, shall be used in (b)(2) above as the adjustment temperature. The welding procedure adjustment temperature shall be added to the highest lowest service metal temperature (LSMT) established by the tests of CC-2524.2.1 for all of the base material to be welded by this procedure in production. If the temperature difference is zero or a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by the tests for CC-2524.2.1 will still apply as stated in (b)(1) above. Where the actual lowest service metal temperature is not required for the production material to be welded (for example, where a testing temperature is established by the Design Specification to determine that the material has adequate toughness to meet the requirements at the specified test temperature) the adjustment temperature determined by the curve shall be used to establish a reduction in the specified testing temperature for the production material. The adjustment temperature shall be used to lower

the specified testing temperature for any production material upon which the procedure will be used.

(4) For tests of welding procedure qualifications for materials that require tests in accordance with CC-2524.2.2, three Charpy V-notch heat affected zone specimens and three Charpy V-notch unaffected base material specimens shall be tested at a temperature lower than or equal to the lowest service metal temperature. The Charpy V-notch impact tests of the unaffected base material shall each meet or exceed the applicable Over $2\frac{1}{2}$ in. (64 mm) thickness requirements of Table CC-2524.2-1 or Table CC-2524.2-2, and Table CC-2524.4-1, if applicable. If the average toughness value of the three heat affected zone specimens is equal to or greater than the average value for the unaffected base material Charpy V-notch specimens, the qualification test shall be considered acceptable. The values and testing temperature shall be recorded on the Welding Procedure Qualification Record.

(5) If the heat affected zone Charpy V-notch average toughness value of (b)(4) above is less than the unaffected base material value, and the qualification test meets the other criteria of acceptance, the Charpy V-notch test results may be recorded on the Welding Procedure Qualification Record. In this case, either production base material impact tests shall be conducted 30°F lower than required by CC-2524.1; or data which will provide a testing temperature reduction for the production base material below that of CC-2524.1, or an increase in the permissible lowest service metal temperature for the base material for which the welding procedure is being qualified, shall be obtained in accordance with (b)(6) below and included. Alternatively, the

Page 107

welding procedure qualification may be rewelded and retested.

(6) The data for use in (b)(5) above shall be developed by performing additional Charpy V-notch tests on either or both of the welding procedure qualification heat affected zone or unaffected base material at temperatures which provide values equal to or greater than the applicable Over $2\frac{1}{2}$ in. (64 mm) thickness requirements of Table CC-2524.2-1 or Table CC-2524.2-2, and Table CC-2524.4-1, if applicable. The average toughness values for the heat affected zone and the unaffected base material shall be plotted on a property-temperature chart. The temperature at which these two sets of data exhibit a common toughness value equal to or greater than the applicable Over $2\frac{1}{2}$ in. (64 mm) thickness requirements of Table CC-2524.2-1 or Table CC-2524.2-2, and Table CC-2524.4-1, if applicable, shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the heat affected zone. This difference, if a positive number, shall be used in (b)(5) above as the adjustment temperature. The adjustment temperature shall be added to the highest T_{NDT} established by the tests of CC-2524.2.2 for all of the base material to be welded by this procedure in production. If the temperature difference is zero or a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by the tests for CC-2524.2.2 will still apply as stated in (b)(4) above. Where the actual T_{NDT} is not required for the production material to be welded (for example, where a testing temperature is established by the Design Specification to determine that the T_{NDT} is at or below the specified temperature) the adjustment temperature determined by the curves shall be used to establish a reduction in the specified testing temperature for the production material. The adjustment temperature shall be used to lower the specified testing temperature for any production material upon which the procedure will be used.

(c) Should the unaffected base material Charpy V-notch impact test results fail to meet the applicable requirements referenced in (b)(1) or (b)(4) above, additional unaffected base material Charpy V-notch impact tests shall be tested at higher temperatures until the applicable requirements are met. Charpy V-notch impact tests of the heat affected zone shall be tested at the same temperature at which acceptable unaffected base material properties were achieved. The rules governing the average toughness of the heat affected zone relative to the average toughness of the unaffected base material shall be followed as in (b)(1) through (b)(3) or (b)(4) through (b)(6) above, as applicable, to determine the data to be recorded on the Welding Procedure Qualification Record.

(d) A Welding Procedure Specification qualified to the impact testing requirements of Subsection NB, NC, or NE may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection.

CC-4533.6 Qualification Requirements for Built-Up Weld Deposits.

Built-up weld deposits for base metal compensation shall be qualified in accordance with the requirements of CC-4533.1 to CC-4533.5, inclusive.

CC-4534 Continuing Performance Test for Stud Welding

(a) For each operator, one stud in every 100 production studs shall be tested as follows.

(1) *Unthreaded Studs.* The test studs shall be tested by bending to an angle of 15 deg. by striking with a hammer. The test studs may be welded to a plate attached to the liner adjacent to a stud from the lot under consideration. The plate shall be of the same type and thickness as the liner with dimensions equal to at least four times the diameter of the stud. The temporarily attached plate shall be adequately supported during testing so as to develop the 15 deg. bend in the stud.

(2) *Threaded Studs.* The test studs shall be torque tested with a calibrated torque wrench to the value shown in Table CC-4534-1 for the corresponding diameter and thread of the stud in a device similar to that shown in Fig. CC-4534-1.

(b) If the studs fail, two more of the existing studs from 100 shall be bent or torque tested. If either of these two studs fails, all of the studs represented by the tests shall be torque tested, bend tested, or rejected.

CC-4540 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS

CC-4541 Precautions to Be Taken Before Welding

CC-4541.1 Identification, Storage, and Handling of Welding Materials.

The Fabricator or Constructor is responsible for control of the welding electrodes and other materials which are used in the fabrication and installation of components (CC-4120). Suitable identification, storage, and handling of electrodes, flux, and other welding materials shall be maintained. Precautions

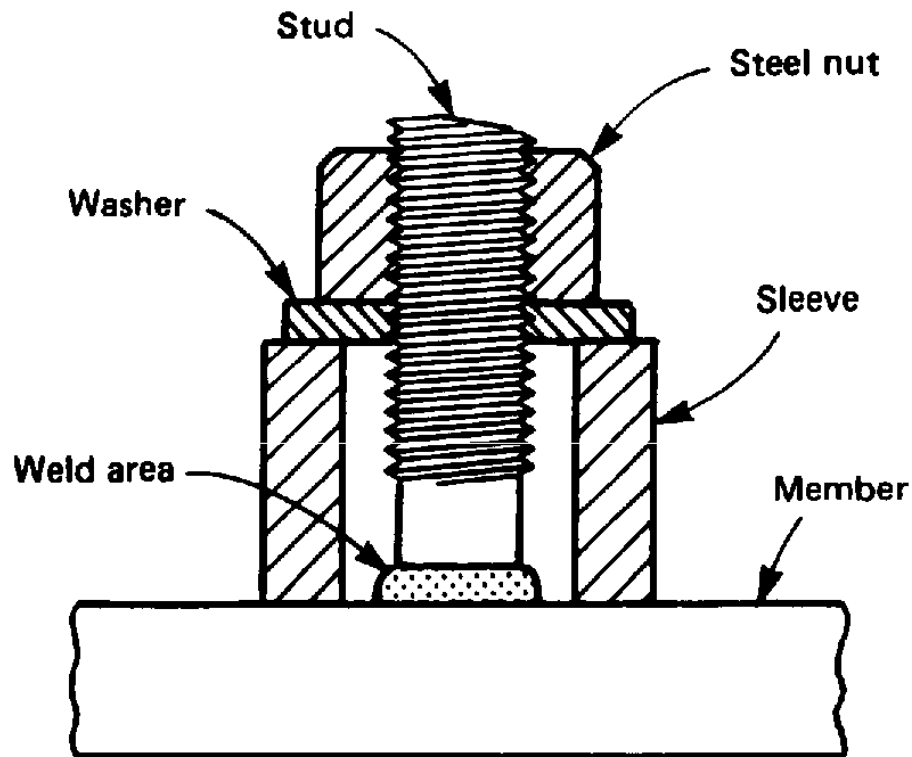
Page 108

**TABLE CC-4534-1
REQUIRED TORQUE FOR TESTING STUDS**

Nominal Stud Diameter, in.	Thread/in. and Series Designated	Testing Torque, ft-lb
$\frac{1}{4}$	28 UNF	5.0
$\frac{1}{4}$	20 UNC	4.2
$\frac{5}{16}$	24 UNF	9.5
$\frac{5}{16}$	18 UNC	8.6
$\frac{3}{8}$	24 UNF	17.0
$\frac{3}{8}$	10 UNC	15.0
$\frac{7}{16}$	20 UNF	27.0
$\frac{7}{16}$	14 UNC	24.0
$\frac{1}{2}$	20 UNF	42.0
$\frac{1}{2}$	13 UNC	37.0
$\frac{9}{16}$	18 UNF	60.0
$\frac{9}{16}$	12 UNC	54.0
$\frac{5}{8}$	18 UNF	84.0
$\frac{5}{8}$	11 UNC	74.0
$\frac{3}{4}$	10 UNF	147.0
$\frac{3}{4}$	10 UNC	132.0
$\frac{7}{8}$	14 UNF	234.0
$\frac{7}{8}$	9 UNC	212.0
1	12 UNF	348.0
1	8 UNC	218.0

TABLE CC-4534-1 REQUIRED TORQUE FOR TESTING STUDS

shall be taken to minimize absorption of moisture by electrodes and flux.



GENERAL NOTES:

- (a) Dimensions are appropriate to the size of the stud.
- (b) Threads of the stud shall be clean and free of lubricant other than residual cutting oil.

**FIG. CC-4534-1 TYPICAL TORQUE
TESTING DEVICE**

FIG. CC-4534-1 TYPICAL TORQUE TESTING DEVICE

CC-4541.2 Cleanliness and Protection of Welding Surfaces.

The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

CC-4542 Rules for Making Welded Joints

CC-4542.1 Category A and B Joints

(a) All welded joints of Category A and B shall be butt joints. The joints may be single or double welded, but backup bars are not allowed except for the first liner plate course and the transition section at the bottom. The first liner plate course shall not exceed 10 ft (3.0 m) in height. However, when reinforced concrete design without prestressing is used, backup bars may be used for the first four liner plate courses up to a maximum height of 35 ft (10.6 m).

(b) Backup bars, when allowed, shall be continuous and any joints shall be made with full penetration welds. When structural shapes are used as backups, these requirements shall apply.

(c) For repairs to the liner after concrete placement, backups may be used.

CC-4542.2 Other Category Joints.

Welded joints of Category D, E, F, G, H, and J shall be single or double welded. Backup bars are permitted except when the weld is to be radiographed. Backup bars, when allowed, shall be continuous and any joints shall be made with full penetration welds. When structural shapes are used as backups, these requirements shall apply. See Fig. CC-4542.2-1 through Fig. CC-4542.2-7 for typical joint details.

CC-4542.3 Double-Welded Joints.

Before applying weld metal on the second side to be welded, the root of double-welded joints shall be prepared by suitable methods such as chipping, grinding, or thermal gouging, except for those processes of welding by which proper fusion and penetration are otherwise obtained and demonstrated to be satisfactory by welding procedure qualification.

CC-4542.4 Single-Welded Joints.

Where single-welded joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joint for its full length.

Page 109

Page 111

Pages 110-110

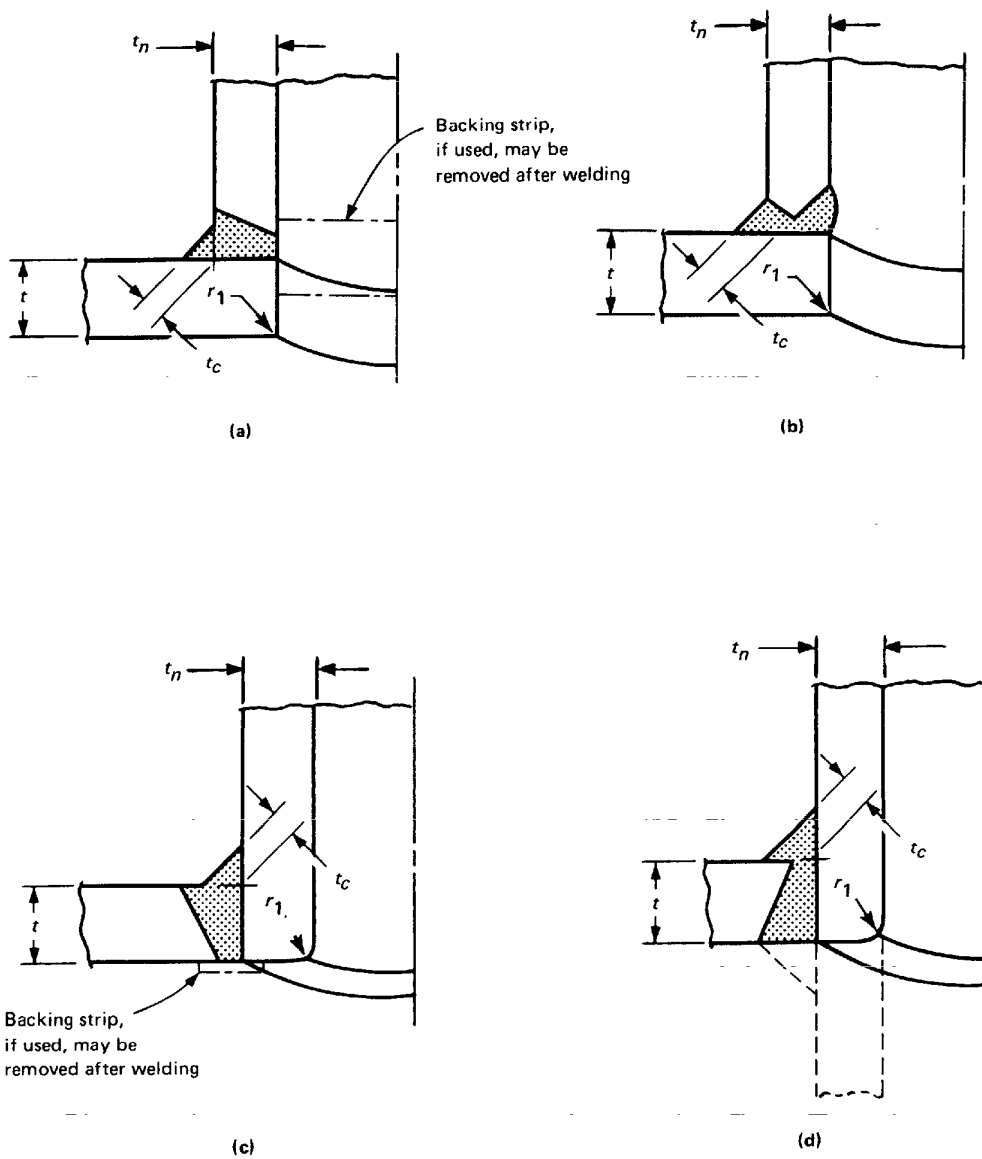
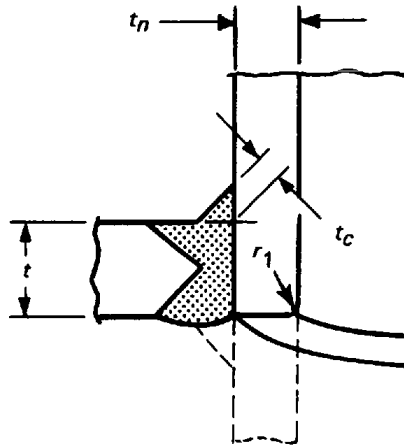
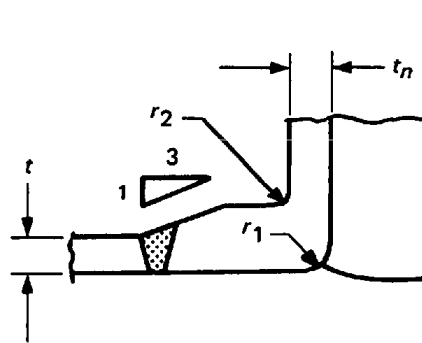


FIG. CC-4542.2-1 TYPICAL CATEGORY D JOINTS FOR NOZZLE DIAMETERS OVER 3 in. NPS
(For Definition of Symbols, See CC-3842.10)

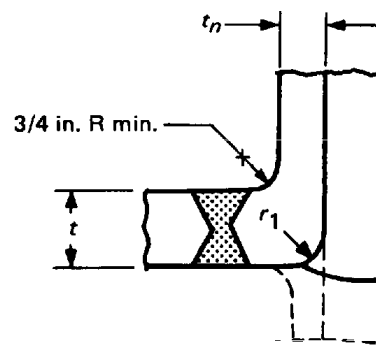
FIG. CC-4542.2-1 TYPICAL CATEGORY D JOINTS FOR NOZZLE DIAMETERS OVER 3 in. NPS



(e)



(f)



(g)

**FIG. CC-4542.2-1 TYPICAL CATEGORY D JOINTS FOR NOZZLE
DIAMETERS OVER 3 in. NPS (CONT'D)
(For Definition of Symbols, See CC-3842.10)**

FIG. CC-4542.2-1 TYPICAL CATEGORY D JOINTS FOR NOZZLE DIAMETERS OVER 3 in. NPS (CONT'D)

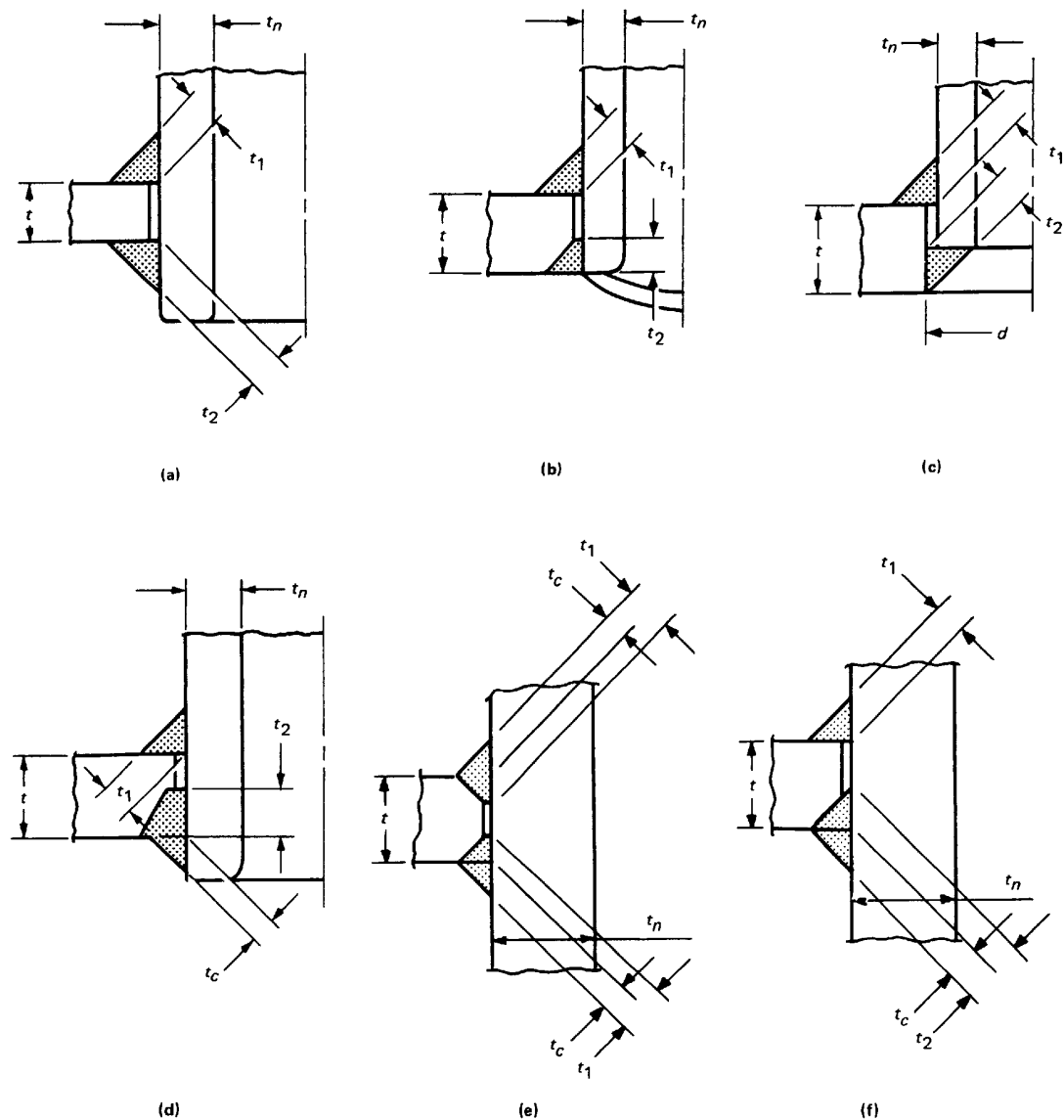


FIG. CC-4542.2-2 TYPICAL CATEGORY D JOINTS FOR NOZZLE DIAMETERS 3 in. NPS AND LESS
(For Definition of Symbols, See CC-3842.10)

FIG. CC-4542.2-2 TYPICAL CATEGORY D JOINTS FOR NOZZLE DIAMETERS 3 in. NPS AND LESS

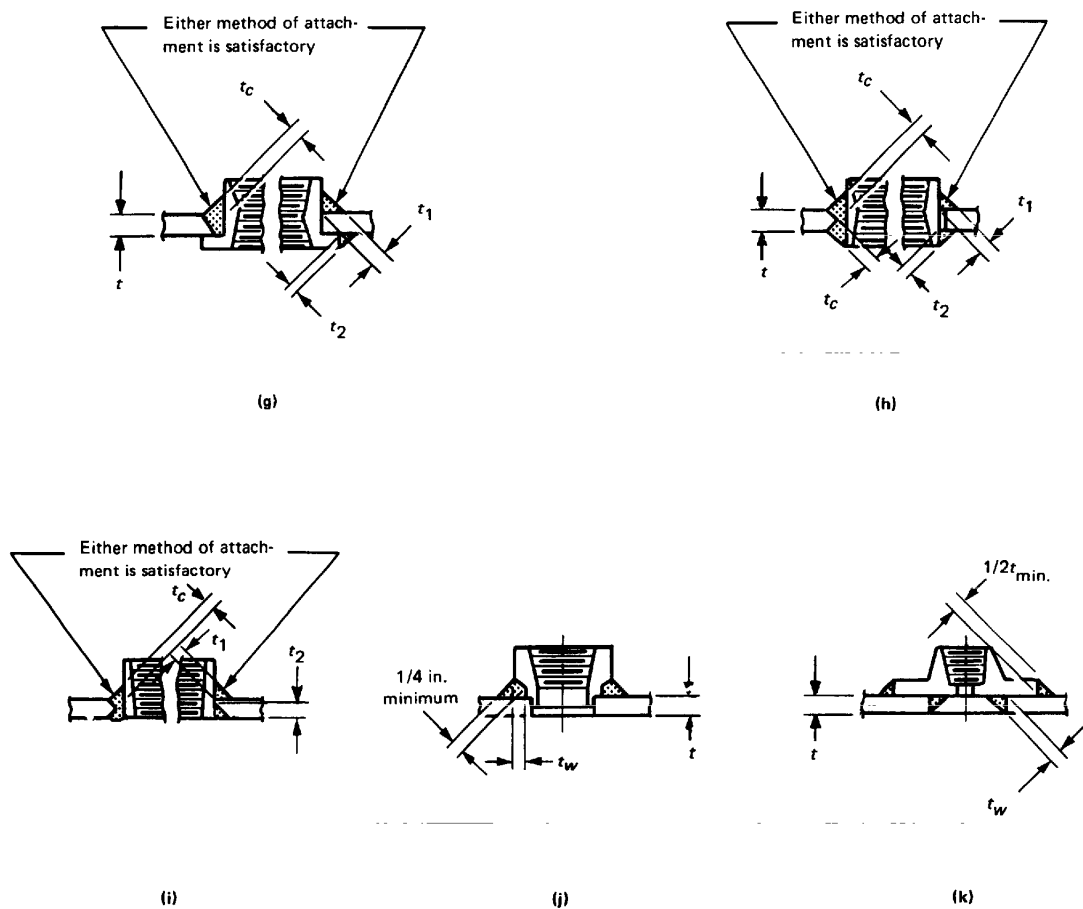
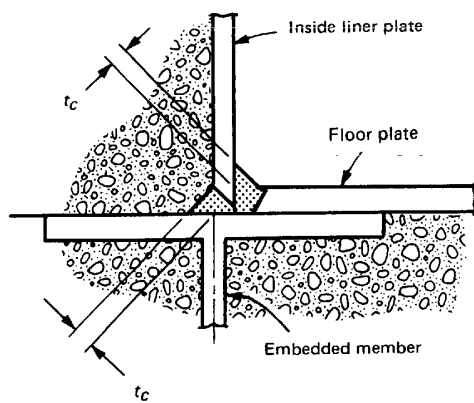
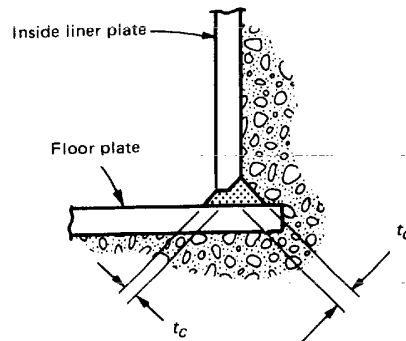


FIG. CC-4542.2-2 TYPICAL CATEGORY D JOINTS FOR NOZZLE DIAMETERS 3 in. NPS AND LESS (CONT'D)
(For Definition of Symbols, See CC-3842.10)

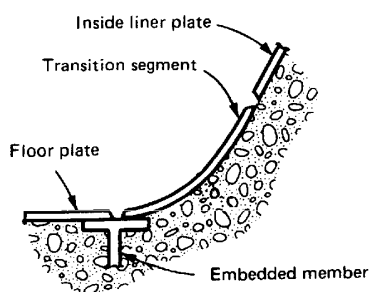
FIG. CC-4542.2-2 TYPICAL CATEGORY D JOINTS FOR NOZZLE DIAMETERS 3 in. NPS AND LESS (CONT'D)



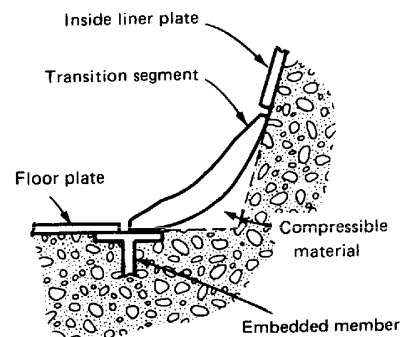
(a)



(b)



(c)



(d)

FIG. CC-4542.2-3 TYPICAL CATEGORY E JOINTS
(For Definition of Symbols, See CC-3842.10)

FIG. CC-4542.2-3 TYPICAL CATEGORY E JOINTS

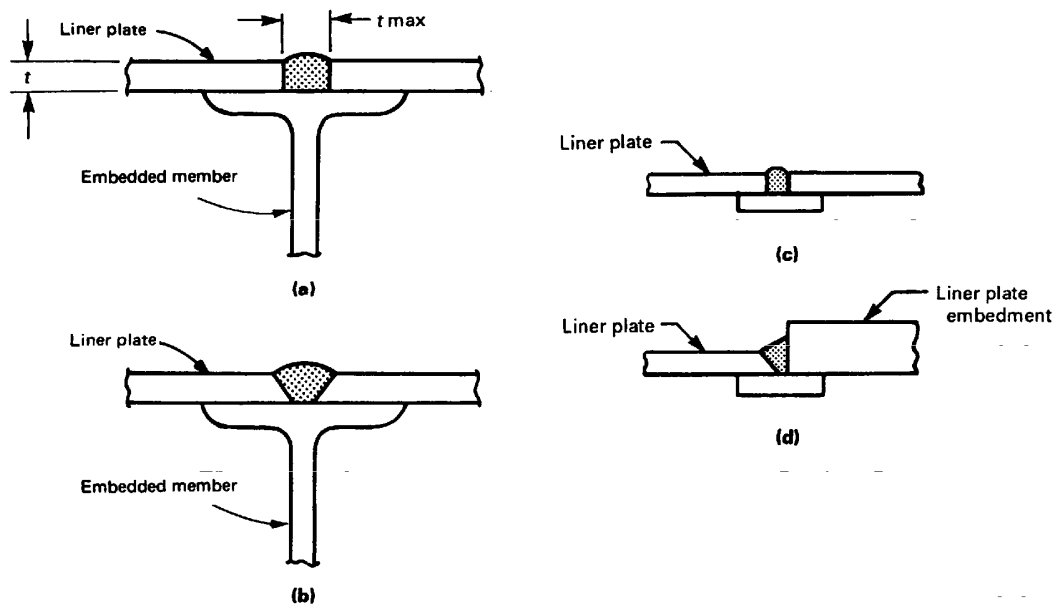


FIG. CC-4542.2-4 TYPICAL CATEGORY F JOINTS
(For Definition of Symbols, See CC-3842.10)

FIG. CC-4542.2-4 TYPICAL CATEGORY F JOINTS

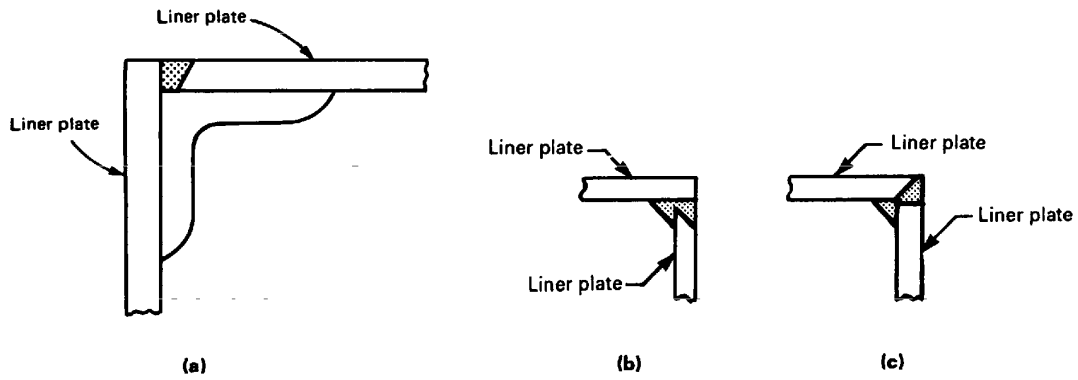


FIG. CC-4542.2-5 TYPICAL CATEGORY G JOINTS
(For Definition of Symbols, See CC-3842.10)

FIG. CC-4542.2-5 TYPICAL CATEGORY G JOINTS

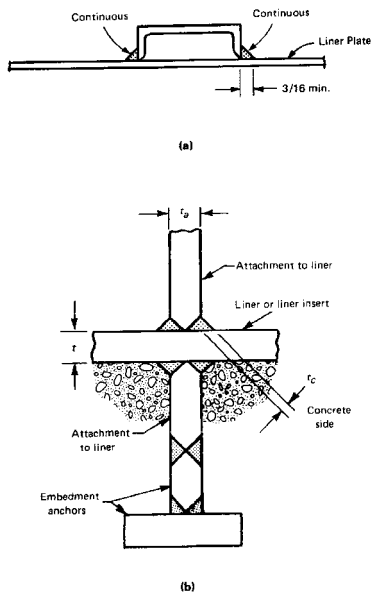


FIG. CC-4542.2-6 TYPICAL CATEGORY H JOINTS
(For Definition of Symbols, See CC-3842.10)

FIG. CC-4542.2-6 TYPICAL CATEGORY H JOINTS

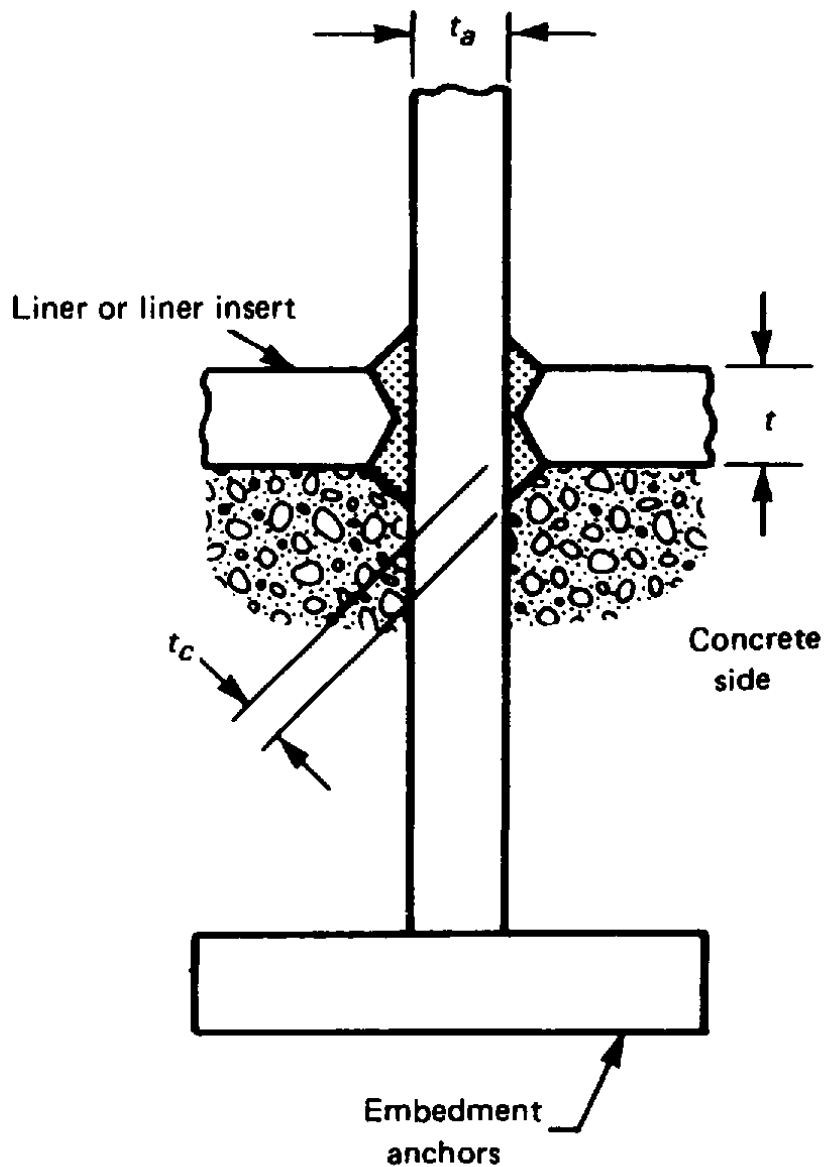


FIG. CC-4542.2-7 TYPICAL CATEGORY J JOINTS
(For Definition of Symbols, See CC-3842.10)

FIG. CC-4542.2-7 TYPICAL CATEGORY J JOINTS

CC-4542.5 Surfaces of Welds.

The surface of welds shall be free from coarse ripples or grooves, overlaps, and abrupt ridges or valleys. Abrupt changes in section thickness, such as undercuts which do not exceed $\frac{1}{32}$ in. (0.8 mm) for liner plate $\frac{1}{4}$ in. (6 mm) nominal thickness and greater, are permitted. The surface condition of the finished weld shall be suitable for the proper interpretation of nondestructive examinations of the weld. If the surface of the weld requires grinding, care shall be taken to avoid reducing the weld or base material below the required thickness.

CC-4542.6 Welding Components of Different Thicknesses.

When materials or parts of different thicknesses are welded together, there shall be a gradual transition between the two surfaces. The length of the transition may include the weld. The slope of the transition shall be such that the length-offset ratio shall not be less than 3:1.

CC-4542.7 Peening.

Controlled peening may be performed to minimize distortion. Peening shall not be used on the initial layer (root) of the weld nor on the final layer unless the weld is postweld heat treated.

CC-4542.8 Reinforcement of Welds

CC-4542.8.1 Finished Surfaces of Welds and Thickness of Weld Reinforcement.

Welds which are to be radiographed shall be prepared as follows.

(a) The weld ripples or weld surface irregularities on both the inside and outside shall be removed by any suitable mechanical process to such a degree that the resulting radiographic image, due to any irregularities, cannot mask or be confused with the image of any unacceptable discontinuity.

(b) The finished surface of the reinforcement of all butt welded joints may be flush with the base material or may have reasonably uniform crowns, the maximum on each side not to exceed the thicknesses of Table CC-4542-1.

CC-4542.9 Fillet Welds.

Fillet welds may vary from convex to concave. The size of the weld shall be determined in accordance with Fig. CC-4542-1.

CC-4543 Welding of Attachments

CC-4543.1 Material for Permanent Structural Attachments.

Material for lugs, brackets, stiffeners, and

Page 117

other permanent structural attachments which are permanently welded to liners shall meet the requirements of liner material (CC-2500 except CC-2530). If the welds are exempt from postweld heat treatment (CC-4522), the attachments shall meet the fracture toughness requirements of CC-2520 if required by CC-2521.1.

**TABLE CC-4542-1
MAXIMUM THICKNESSES PERMITTED**

Material Nominal Thicknesses, in.	Maximum Reinforcement on Each Side, in.
Up to $\frac{1}{2}$, incl.	$\frac{3}{32}$
Over $\frac{1}{2}$ to 1	$\frac{1}{8}$
Over 1 to 2	$\frac{3}{16}$

TABLE CC-4542-1 MAXIMUM THICKNESSES PERMITTED

CC-4543.2 Welding of Permanent Structural Attachments.

The rules of CC-4532.1 governing welding qualifications shall apply to the welding of both internal and external permanent structural attachments to liner material. Welds shall meet the postweld heat treatment requirements of CC-4552.

CC-4543.3 Lugs and Fitting Attachments.

All lugs, brackets, saddle type nozzles, manhole frames, reinforcement around openings, and other appurtenances shall conform reasonably to the curvature of the shell or surface to which they are attached.

CC-4543.4 Welding of Nonstructural and Temporary Attachments.

Nonstructural attachments, such as lifting lugs, insulation supports, nameplates, locating lugs, and temporary attachments may be noncertified material and may be welded directly to the liner with continuous or intermittent fillet or partial penetration welds, provided the requirements of (a) through (e) below are met.

- (a) The welding procedure and the welders have been qualified in accordance with CC-4532.1.
- (b) The material is identified and suitable for welding.
- (c) The material is compatible with the material to which it is attached.
- (d) The welding material is identified and compatible with the materials joined.
- (e) The welds are postweld heat treated when required by CC-4552.

CC-4543.5 Stud Welding.

When stud welding is employed to attach shear connectors or other connectors or other attachment to the liner, the following rules apply.

- (a) Studs shall be welded to steel members with automatically timed stud welding equipment connected to a suitable power source.

(b) If two or more stud welding guns are to be operated from the same power source, they shall be interlocked so that only one gun can operate at a time and so that the power source has fully recovered from making one weld before another weld is started.

(c) While in operation, the welding gun shall be held in position without movement until the weld metal has solidified.

(d) At the time of welding, the studs shall be free from rust, rust pits, scale, oil, or other deleterious matter that would adversely affect the welding operation.

(e) The areas on the member to which the studs are to be welded shall be free of scale, rust, or other injurious material to the extent necessary to obtain satisfactory welds. These areas may be cleaned by wire brushing, peening, prick punching, or grinding.

(f) Arc shields shall be broken free after welding from shear connector and anchor studs and, where practicable, from all other studs.

(g) The studs, after welding, shall be free from any defect or substance that would interfere with their intended function.

(h) If the reduction in the length of studs as they are welded becomes less than normal (for example, the length of stud after welding is more than $\frac{1}{16}$ in. (1.6 mm) longer than specified), welding shall be stopped immediately and not resumed until the cause has been corrected.

(i) Stud size shall be $\frac{3}{4}$ in. (19 mm) diameter maximum when stud welding is to be performed in any position other than downflat.

CC-4543.6 Special Requirements for Welding.

When a portion of the liner transmits loads in the through thickness direction, one of the following requirements shall be met if the plate subjected to through thickness loading is 1 in. (25 mm) and greater in thickness.

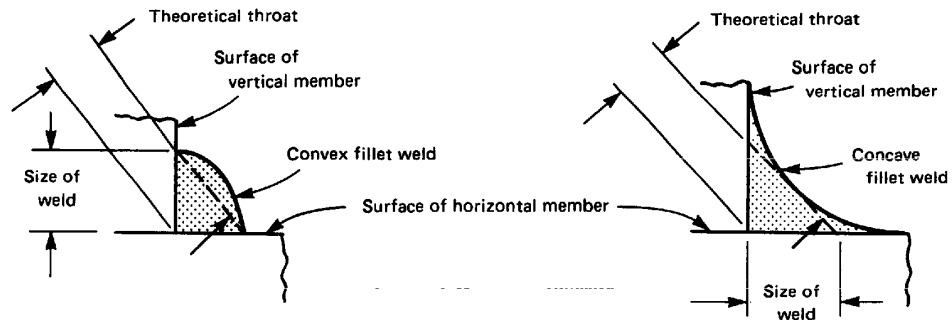
(a) After completion of welding, the base material directly underneath the attachment shall be ultrasonically examined in accordance with the requirements of CC-5500.

(b) A weld metal inlay or overlay shall be made in accordance with Fig. CC-4543.6-1 and ultrasonically examined in accordance with CC-5500, prior to making the weld joining the attachment member to the inlay or overlay.

(c) Special deposition techniques, as illustrated in Fig. CC-4543.6-2, may be used as an alternative to inlay or overlay. Such techniques shall be demonstrated

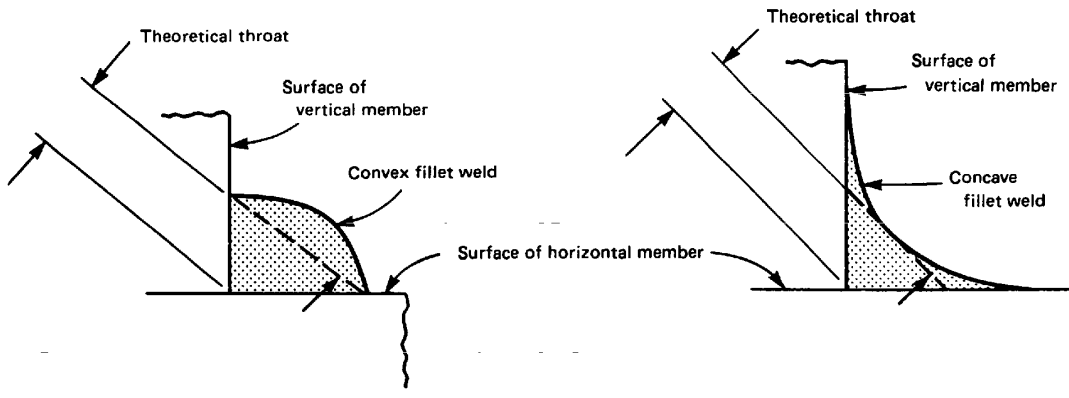
Page 118

to meet the requirements of (a) above on material thickness equal to or greater than the production thickness but need not be more than 4 in. (102 mm), and on material of the same type and grade as the production material. Pages 119-119



GENERAL NOTE:
 The "size" of an equal leg fillet weld is the leg length of the largest inscribed right isosceles triangle.
 $\text{Theoretical throat} = 0.7 \times \text{size}$.

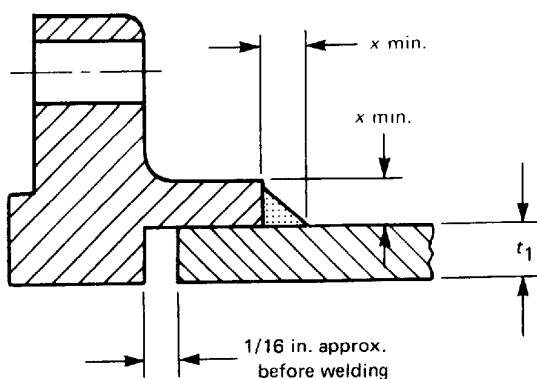
Equal Leg Fillet Weld



GENERAL NOTE:
 The "size" of an unequal leg fillet weld is the shorter leg length of the largest right triangle that can be inscribed within the fillet weld cross section.

Unequal Leg Fillet Weld

FIG. CC-4542-1 FILLET AND SOCKET WELD DIMENSIONS
 (Not Permitted for Connections Over 2 in. Nominal Pipe Size)

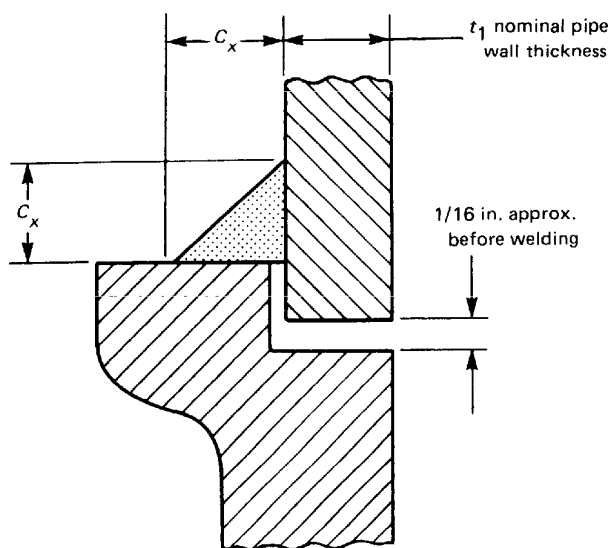


Socket Welding Flange

t_1 = nominal pipe wall thickness

$x \text{ min.} = 1.4t$ or thickness of the hub, whichever is smaller, but not less than 1/8 in.

Size of Fillet Welds



$C_x \text{ min.} = 1.09t$, but not less than 1/8 in.

Welding Details for Socket Welding Flanges

(Not permitted for socket weld connections over 4 in. nominal pipe size.)

FIG. CC-4542-1 FILLET AND SOCKET WELD DIMENSIONS (CONT'D)
(Not Permitted for Connections Over 2 in. Nominal Pipe Size)

FIG. CC-4542-1 FILLET AND SOCKET WELD DIMENSIONS (CONT'D)

(d) The material shall meet the acceptance standards of SA-770, Through-Thickness Tension Testing of Steel Plates for Special Applications.

CC-4544 Examination of Welds

All welds shall be examined in accordance with the requirements of CC-5500.

CC-4545 Repair of Weld Metal Defects

CC-4545.1 General Requirements.

Unacceptable defects in weld metal detected by methods required by CC-5500 shall be eliminated and, when necessary, repaired with the requirements of the following paragraphs.

CC-4545.2 Elimination of Surface Defects.

Weld metal surface defects may be removed by grinding or machining and not repaired by welding, provided the following requirements are met.

- (a) The thickness of the section is not reduced more than $\frac{1}{16}$ in. (1.6 mm).
- (b) The depression, after defect elimination, is blended uniformly into the surrounding surface.
- (c) The area is examined after blending by a magnetic particle or liquid penetrant method meeting the requirements of CC-5500 to ensure that the defect has been removed or the indication reduced to an acceptable limit.

CC-4545.3 Requirements for Making Repairs to Welds.

Excavated cavities in weld metal, when repaired by welding, shall meet the requirements of the following subparagraphs.

CC-4545.3.1 Defect Removal.

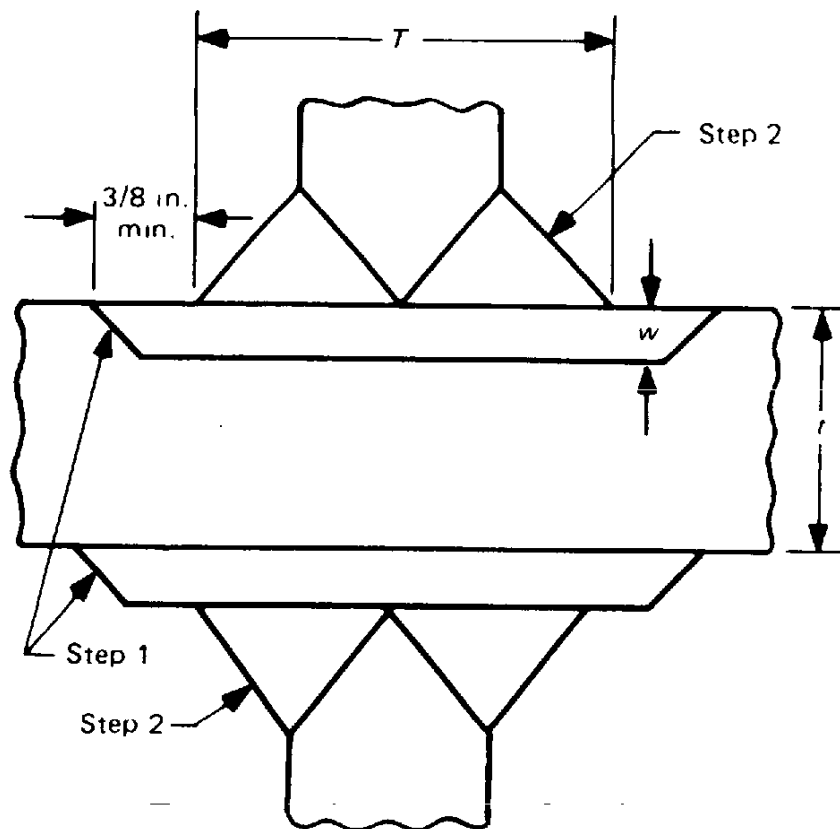
Unacceptable defects detected visually or by the examinations required by CC-5500 shall be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined and comply with the requirements of CC-5533 or CC-5534.

CC-4545.3.2 Requirements for Welding Materials, Procedures, and Welders.

The weld repair shall be made using welding materials, welders, and welding procedures in accordance with CC-4530.

CC-4545.3.3 Blending of Repaired Welds.

After repair the surface shall be blended uniformly into the surrounding surface.



Step 1 Inlay or overlay weldment

Step 2 Completion of weldment

GENERAL NOTES:

- (a) Members may be welded on one side only, or from both sides.
- (b) Inlay or overlay thickness shall be 1/4 in. min. for $t = 1$ in. and shall be increased 1/16 in. for each additional 3/8 in. of t , but need not exceed 1/2 in.
- (c) When T exceeds t , w shall be increased by an additional 1/16 in. for each 3/8 in. of T over t , to a maximum of 1/2 in.
- (d) The minimum specified tensile strength of the electrodes used for inlay or overlay shall not exceed the minimum specified tensile strength of the base material by more than 12 ksi

FIG. CC-4543.6-1 WELD JOINT PRODUCING THROUGH-THICKNESS LOADING

FIG. CC-4543.6-1 WELD JOINT PRODUCING THROUGH-THICKNESS LOADING

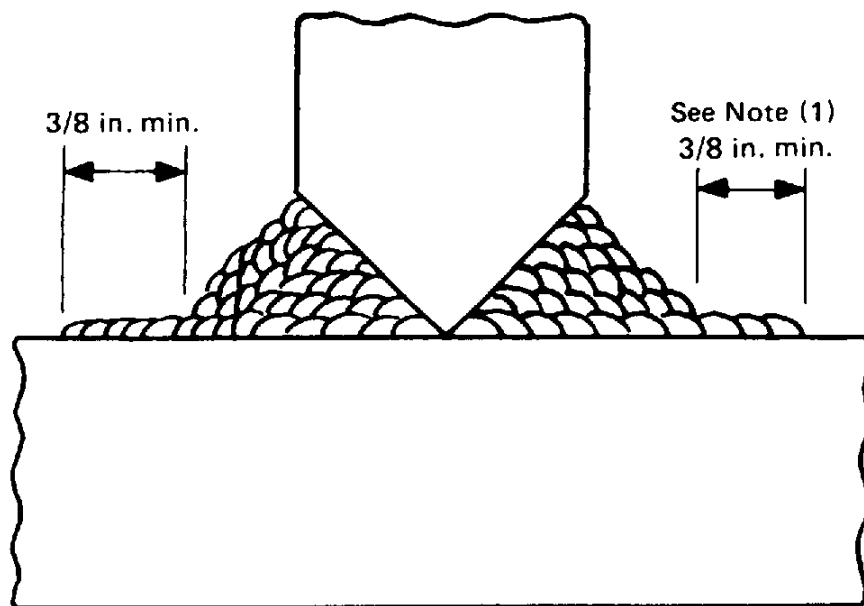
CC-4545.3.4 Examination of Repair Welds.

The examination of weld repairs shall be repeated as required for the original weld except that repair of defects originally detected by magnetic particle or liquid penetrant methods, when the repair cavities do not exceed the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the thickness, need only be reexamined by a magnetic particle or liquid penetrant method.

CC-4545.3.5 Heat Treatment of Repaired Areas.

The area shall be heat treated in accordance with CC-4550 when the original weld required heat treatment.

Page 121



GENERAL NOTE:

Members may be welded on one side only, or from both sides.

NOTE:

- (1) The initial layer(s) shall extend a minimum of $\frac{3}{8}$ in. beyond the toe of the fillet.

FIG. CC-4543.6-2 SPECIAL DEPOSITION TECHNIQUE
FOR WELD JOINT PRODUCING THROUGH-
THICKNESS LOADING (TYPICAL)

FIG. CC-4543.6-2 SPECIAL DEPOSITION TECHNIQUE FOR WELD JOINT PRODUCING THROUGH-THICKNESS LOADING (TYPICAL)

CC-4545.4 Repair of Defective Areas Resulting From Stud Removal

- (a) The areas of liners where defective studs have been removed shall be made smooth and flush by grinding.
- (b) Where in such areas base metal has been pulled out in the course of stud removal, a shielded metal-arc welding process with low hydrogen electrodes in accordance with the requirements of CC-4545.3 shall be used to fill the pockets and the weld surface ground flush.
- (c) Where a replacement stud is to be placed in the defective area, the above repair shall be made prior to welding the replacement stud.

CC-4550 HEAT TREATMENT

CC-4551 Welding Preheat Requirements

CC-4551.1 When Preheat Is Necessary.

The need for preheat and the required temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, temperature elevation, physical properties, and material thicknesses. Some practices used for preheating are given in Appendix D as a general guide for the materials listed by P-Number of Section IX. It is cautioned that the preheating suggested in Appendix D does not necessarily ensure satisfactory completion of the welded joint and that the requirements for individual material within the P-Number listing may have preheating more or less restrictive than this general guide. The Welding Procedure Specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.

CC-4551.2 Preheating Methods.

Preheat for welding or thermal cutting, when employed, may be applied by any method which does not harm the base material or any weld metal already applied, or which does not introduce deleterious material into the welding area which is harmful to the weld.

CC-4552 Postweld Heat Treatment Requirements

CC-4552.1 Means of Heating and Cooling.

Postweld heat treatment (PWHT) may be accomplished by any suitable means of heating and cooling provided the required heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control are maintained.

CC-4552.2 PWHT Time and Temperature Requirements

CC-4552.2.1 Requirements for PWHT.¹

Except as otherwise permitted in CC-4552.2.7, all welds, including repair welds, shall be postweld heat treated. During postweld heat treatment, the metal temperature shall be maintained within the temperature ranges and minimum holding times specified in Table CC-4552-1, except as otherwise permitted by CC-4552.2.4(c). P-Number groups in Table CC-4552-1 are in accordance with QW-420 of Section IX. Except as provided in CC-4552.4.3, PWHT shall be performed in temperature-surveyed and -calibrated furnaces, or PWHT shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. Unless exempted in CC-4552.2.7, all nozzles and penetrations shall be welded into a portion of the liner plate or plates and postweld heat treated as complete subassemblies prior to welding into the liner.

¹ Any postweld heat treatment time which is anticipated to be applied to the material during fabrication or construction after completion of manufacture shall be specified in the Construction

**TABLE CC-4552-1
MANDATORY REQUIREMENTS FOR POSTWELD HEAT TREATMENT (PWHT) OF WELDS¹**

P-Number (Section IX, QW-420)	Holding Temperature Range, °F [Note (2)]	Minimum Holding Time at Temperature For Weld Thickness (Nominal)		
		$\frac{1}{2}$ in. or less	Over $\frac{1}{2}$ in. to 2 in.	Over 2 in.
1	1100–1250	30 min	1 hr/in.	2 hr plus 15 min for each additional inch over 2 in.
8	...	PWHT neither required nor prohibited		

NOTES:

(1) Exceptions to the mandatory requirements of this Table are defined in Table CC-4552-2.

(2) All temperatures are metal temperatures.

TABLE CC-4552-1 MANDATORY REQUIREMENTS FOR POSTWELD HEAT TREATMENT (PWHT) OF WELDS¹

CC-4552.2.2 Time-Temperature Recordings.

Time-temperature recordings of all PWHT shall be made available for review by the Authorized Inspector. Identification on the time-temperature recording shall be to the weld or item as applicable. A summary of the time-temperature recording may be provided for permanent records in accordance with NCA-4134.17(e)(9).

CC-4552.2.3 Definition of Thickness Governing PWHT Time at Temperature Requirements.

Nominal thickness in Table CC-4552-1 and Table CC-4552-2 is the thickness of the weld, liner material, or the thinner of the sections being joined, whichever is less. It is not intended that nominal thickness include material provided for forming allowance, thinning, or mill overrun when excess material does not exceed $\frac{1}{8}$ in. (3.2 mm). For fillet welds, the nominal thickness is the throat thickness; and for partial penetration and material repair welds, the nominal thickness is the depth of the weld groove or preparation.

CC-4552.2.4 Holding Temperatures and Times

(a) The holding time at temperature as specified in Table CC-4552-1 need not be continuous. It may be an accumulation of time of multiple postweld heat treat cycles.

(b) Holding time at temperatures in excess of the minimum requirements of Table CC-4552-1 may be used, provided specimens are tested in accordance with CC-2526, CC-2600, and CC-4530.

(c) Alternatively, when it is impractical to postweld heat treat at the temperature range specified in Table CC-4552-1, it is permissible to perform the postweld heat treatment of P-No. 1 material at lower temperature ranges for longer periods of time in accordance with Table CC-4552-3 and (1) below.

(1) Base materials certified in accordance with CC-2526 may be postweld heat treated at these lower minimum temperatures and increased minimum holding times without recertification. Postweld heat treatment at these lower minimum temperatures and increased minimum holding times may also be the tempering operation, provided a higher tempering temperature is not required by the material specification.

CC-4552.2.5 PWHT Requirements When Differing P-Number Materials Are Joined.

PWHT is not required when joining P-No. 1 material $1\frac{1}{2}$ in. (38 mm) or less in thickness to P-No. 8 materials with electrodes that produce austenitic or non-air-hardening nickel-chrome-iron deposits.

CC-4552.2.6 PWHT Requirements for Material Welded to Liners.

When materials are welded to liner materials, the PWHT temperature range of the liner materials shall control.

CC-4552.2.7 Exemptions to PWHT Mandatory Requirements.

PWHT is not required for the following:

(a) nonferrous material;

(b) welds exempted in Table CC-4552-2;

(c) welds subjected to temperatures above the PWHT temperature range specified in Table CC-4552-1, provided the Welding Procedure Specification is qualified in accordance with Section IX.

CC-4552.3 Heating and Cooling Rate Requirements.

Above 800°F (427°C), the rate of heating and cooling over any hourly interval shall not exceed 400°F (222°C) divided by the maximum thickness in inches of the material being heat treated but shall not exceed 400°F (222°C) and need not be less than 100°F (56°C) over any hourly interval. During the heating and cooling period, there shall not be a greater variation in temperature

Page 123

than 250°F (139°C) within any 15 ft (4.6 m) interval of the weld length.

TABLE CC-4552-2
EXEMPTIONS TO MANDATORY PWHT¹

P-No. (Section IX, QW-420)	Type of Weld	Nominal Thickness (CC-4552.2.3)	Properties of Pressure Retaining Material(s) Being Joined	
			Max. Reported Carbon, %	Min. Preheat Required, °F
1	All welds, including repair welds, in material $1\frac{1}{2}$ in. and less, exclusive of welds joining nozzles or penetrations with an I.D. greater than 2 in.	$1\frac{1}{4}$ in. or less Over $1\frac{1}{4}$ in. to $1\frac{1}{2}$ in. $\frac{3}{4}$ in. or less Over $\frac{3}{4}$ in. to $1\frac{1}{2}$ in.	0.30 or less 0.30 or less Over 0.30 Over 0.30	... 200 ... 200
	All fillet, partial penetration, and repair welds in material over $1\frac{1}{2}$ in., exclusive of welds joining nozzles or penetrations with an I.D. greater than 2 in.	$\frac{3}{4}$ in. or less	...	200
	All welds, including repair welds, in material greater than $1\frac{1}{2}$ in. but equal to or less than $1\frac{3}{4}$ in. [Note (2)]	$1\frac{3}{4}$ in. or less	0.24	200
	All welds joining nozzles or penetrations with a nominal I.D. of 2 in. and less	$\frac{3}{4}$ in. or less	...	200
	Repairs to welds in subassemblies postweld heat treated as required by CC-4552.2.1, with the total accumulated repair length of any weld not exceeding 25% of the original weld length	$\frac{3}{4}$ in. or less	...	200

NOTES:

(1) The exemptions shown in this Table do not apply to electron beam welds in ferritic materials over $\frac{1}{8}$ in. in thickness.

(2) This exemption is limited to SA-299, SA-516, and SA-537 under the following conditions:

(a) the impact test temperature is 40°F below the lowest service temperature;

(b) the C_v energy value is increased by 5 ft-lb over that shown in Table CC-2524.2-2;

(c) exemption from impact testing as provided in CC-2521.1-1 is

**TABLE CC-4552-3
ALTERNATIVE PWHT TEMPERATURES**

Alternative Holding Temperature Range, °F	Alternative Minimum [Note (1)] Holding Time, hr/in. Thickness
1050–1200	2
1000–1150	3
950–1000	5
900–1050	10

NOTE:

(1) All other requirements of CC-4552.2 shall apply.

TABLE CC-4552-3 ALTERNATIVE PWHT TEMPERATURES

CC-4552.4 Methods of PWHT.

The PWHT shall be performed in accordance with the requirements of one of the following subparagraphs.

CC-4552.4.1 Furnace Heating - One Heat.

Heating the item in a closed furnace in one heat is the preferred procedure and should be used whenever practical. The furnace atmosphere shall be controlled so as to avoid excessive oxidation; direct impingement of flame on the component or assembly is prohibited.

Page 124

CC-4552.4.2 Furnace Heating - More Than One Heat.

The item may be heated in more than one heat in a furnace, provided the furnace atmosphere control requirements of CC-4552.4.1 apply and the overlap of the heated sections of the item is at least 5 ft (1.5 m). When this procedure is used, the portion of the item outside the furnace shall be shielded so that the temperature gradient is not harmful. The cross section where the item projects from the furnace shall not intersect a nozzle or other structural discontinuity.

CC-4552.4.3 Local Heating.

Welds may be locally postweld heat treated when it is not practical to heat treat the entire item. Local PWHT shall consist of heating a circumferential band at temperatures within the ranges specified in Table CC-4552-1 or Table CC-4552-3. The width of the controlled band at each side of the weld, on the face of greatest weld width, shall be not less than the thickness of the weld or 2 in., whichever is less. The temperature of the item shall be gradually diminished from the edge of the controlled band outward so as to avoid harmful thermal gradients. This procedure

diminished from the edge of the controlled band outward so as to avoid harmful thermal gradients. This procedure may also be used for PWHT after repairs.

CC-4552.4.4 Heating Components Internally.

The item may be heated internally by appropriate means and with adequate indicating and recording temperature devices to aid in the control and maintenance of a uniform distribution of temperature in the vessel. Previous to this operation, the item shall be fully enclosed with insulating material.

CC-4553 Intermediate PWHT

The temperature, time at temperature, and heating and cooling rate requirements of CC-4552 are not mandatory for intermediate heat treatments.

CC-4554 Heat Treatment After Repairs by Welding

CC-4554.1 Rules Governing Heat Treatment After Repair by Welding.

Liners or portions of liners, including materials that have been repaired by welding, shall be postweld heat treated in accordance with the requirements of CC-4552.

CC-4555 Heat Treatment During Fabrication

When material is subjected to heat treatment during fabrication, the test specimens required by the applicable SA material specification shall be obtained from the sample coupons which have been heat treated in the same manner as the material, including such heat treatments as were applied by the producer before shipment. The required tests may be performed by the material producer or the Fabricator or Constructor. When plate specification heat treatments are not performed by the mill, they shall be performed by or under the control of the Fabricator or Constructor, who shall then place the letter "T" following the letter "G" in the mill plate marking (SA-20) to indicate that the material specification heat treatments have been performed. The Fabricator or Constructor shall also show by a supplement to the appropriate Certified Material Test Report that the specified heat treatment has been performed.

CC-4560 PROTECTION OF ATTACHMENTS

All attachments and penetrations shall be protected against entry of deleterious materials or dislodgement during construction operations.

CC-4600 FABRICATION OF EMBEDMENT ANCHORS

CC-4610 GENERAL REQUIREMENTS

CC-4611 Introduction

- (a) The rules in the following paragraphs apply specifically to the fabrication and construction of embedment anchors.
- (b) Each Certificate Holder shall be responsible for the quality of the welding done by his organization, and shall conduct tests of the welding procedure to determine its suitability and also of the welders and welding operators to determine their ability to apply the procedure properly.
- (c) No production work shall be undertaken until both the welding procedure and the welders or welding operators have been qualified in accordance with Section IX.

CC-4612 Elimination and Repair of Defects

CC-4612.1 Repair of Material.

Material originally accepted on delivery in which defects exceeding the limits of CC-2730 are known or discovered during the process of fabrication or installation is unacceptable. The material may be used provided the condition is

- (a) the limitation on the depth of the weld repair does not apply; and
- (b) the time of examination of the weld repairs to weld edge preparations shall be in accordance with CC-5500.

CC-4620 FORMING, FITTING, AND ALIGNING

CC-4621 Cutting, Forming, and Bending

CC-4621.1 Cutting.

Cutting of material shall be in accordance with CC-4521.1.

CC-4621.2 Forming and Bending Processes.

Forming and bending processes shall be in accordance with CC-4521.2.

CC-4621.3 Qualification of Forming Processes and Acceptance Criteria for Formed Material.

Qualification of forming and bending processes shall be in accordance with CC-4521.3.

CC-4621.4 Minimum Thickness of Fabricated Material.

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of CC-3000, the material may be repaired in accordance with CC-4612.

CC-4622 Forming Tolerances

CC-4622.1 Tolerances for Embedment Anchors.

Tolerances for embedment anchors shall be specified in the Design Specifications.

CC-4623 Fitting and Aligning

CC-4623.1 Fitting and Aligning Methods.

Parts that are to be joined may be fitted, aligned, and retained in position during the joining operation by the use of bars, jacks, clamps, drift pins, tack welds, or temporary attachments. Mechanical devices shall be carefully used to avoid damage to surfaces of the parts and to avoid enlargement of bolt holes.

CC-4623.1.1 Tack Welds.

Tack welds used to secure alignment shall either be removed completely, when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified welders using qualified welding procedures. When tack welds are to become part of the finished weld, they shall be visually examined and defective tack welds removed.

CC-4623.1.2 Temporary Attachments and Their Removal.

Attachments which are welded onto the embedment anchors or parts during the process of manufacture or installation but which are not incorporated into the final support are permitted provided the requirements of (a) through (e) below are met.

- (a) The material is identified and is suitable for welding but need not be certified material.
- (b) The material is compatible for welding to the embedment anchor material to which it is attached.

- (c) The welding material is compatible with the base material and is certified in accordance with CC-2130.
- (d) The welder and welding procedure are qualified in accordance with CC-4532.
- (e) The temporary attachment is completely removed in accordance with the procedures of CC-4621.1.

CC-4623.2 Maximum Offset of Aligned Sections.

Alignment of butt joints shall be such that the maximum offset of the finished weld will not be greater than the applicable amount listed in Table CC-4523-1, where t is the nominal thickness of the thinner section of the joint.

CC-4623.2.1 Fairing of Offsets.

Any offset within the allowable tolerance of Table CC-4523-1 shall be blended uniformly over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld.

CC-4630 WELDING QUALIFICATIONS

CC-4631 General Requirements

CC-4631.1 Types of Processes Permitted.

Only those welding processes which are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Subsection shall be used for welding embedment anchor material or attachments thereto. Any process used shall be such that the records required by CC-4632 can be prepared, except that records for stud welds shall be traceable to the welders and welding operators and not necessarily to each specific weld.

CC-4631.1.1 Stud Welding.

Stud welding shall be in accordance with CC-4543.5.

CC-4632 Welding Qualification and Records

CC-4632.1 Required Qualifications

(a) Each Certificate Holder is responsible for the welding done by his organization and shall establish the procedure and conduct the test required by this

Page 126

Article and Section IX in order to qualify both the welding procedures and the performances of welders and welding operators who apply these procedures.

(b) Procedures, welders, and welding operators used to join permanent or temporary attachments to embedment anchors and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Article.

(c) When making procedure test plates for butt welds, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

CC-4632.2 Maintenance and Certification of Records.

Maintenance and certification of records shall be in accordance with CC-4532.2.

CC-4632.2.1 Identification of Joints

(a) For partial penetration welds with a depth less than 1 in., fillet welds with a throat dimension less than 1 in., and stud welds, the Certificate Holder need not identify the welder or welding operator who welded each joint provided:

(1) the Certificate Holder maintains a system that will identify the welders or welding operators who made such welds so that the Inspector can verify that the welders or welding operators were all properly qualified;

(2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification;

(b) the identification of welder or welding operator is not required for tack welds;

(c) the Certificate Holder shall certify that only welders and welding operators qualified in accordance with CC-4632.1 and Section IX were used in making all welds.

CC-4632.3 Welding Prior to Qualification.

No welding shall be undertaken until after the welding procedures which are to be used have been qualified.

CC-4632.4 Transferring Qualifications.

The welding procedures qualification and the performance qualification tests for welders and welding operators conducted by one Certificate Holder shall not qualify welding procedures and shall not qualify welders or welding operators to weld for any other Certificate Holder, except as provided in Section IX, QW-201 and QW-300.2.

CC-4633 General Requirements for Welding Procedure Qualification Test

The requirements for welding procedure qualification tests shall be in accordance with CC-4533.

CC-4634 Continuing Performance Test for Stud Welding

Continuing performance test for stud welding shall be in accordance with CC-4534.

CC-4640 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS

CC-4641 Precautions to Be Taken Before Welding

Precautions to be taken before welding shall be in accordance with CC-4541.

CC-4642 Rules for Making Welded Joints

CC-4642.1 Welded Joints.

The materials for backing strips, when used, shall be compatible with the base metal. Backing strips shall be continuous and any joints shall be made with full penetration welds.

CC-4642.2 Peening.

The weld metal may be peened when it is deemed necessary or helpful to control distortion. Peening is prohibited on root pass and final pass.

CC-4642.3 Double-Welded Joints.

Before applying weld metal on the second side to be welded, the root of full penetration double-welded joints shall be prepared by suitable methods, such as chipping, grinding, or thermal gouging to sound metal except for those processes of welding by which proper fusion and penetration are otherwise obtained and demonstrated to be satisfactory by welding procedure qualification.

CC-4642.4 Surfaces of Welds.

As-welded surfaces are permitted. However, the surfaces of welds shall be sufficiently free from coarse ripples, grooves, overlaps, abrupt ridges, and valleys to meet the requirements of (a) through (e) below.

(a) The surface condition of the finished weld shall be suitable for the proper interpretation of radiographic and other required nondestructive examinations of the welds. In those cases where there is a question regarding the surface condition on the interpretation of a radiographic film, the film shall be compared to the actual

Page 127

weld surface for interpretation and determination of acceptability.

(b) Reinforcements are permitted in accordance with CC-4642.5.

(c) Undercuts shall not exceed $\frac{1}{32}$ in. (0.8 mm).

(d) Concavity on the root side of a single welded circumferential butt weld is permitted when the resulting thickness of the weld is at least equal to the thickness of the thinner member of the two sections being joined.

(e) If the surface of the weld required grinding to meet the above criteria, care shall be taken to avoid reducing the weld or base material below the required thickness.

CC-4642.5 Reinforcement of Butt Welds.

The surface of the reinforcement of all butt welded joints may be flush with the base material or may have uniform crowns. The height of reinforcement on each face of the weld shall not exceed the following thickness:

Nominal Thickness, in.	Maximum Reinforcement, in.
Up to 1, incl.	$\frac{3}{32}$
Over 1 to 2, incl.	$\frac{1}{8}$
Over 2 to 3, incl.	$\frac{5}{32}$
Over 3 to 4, incl.	$\frac{7}{32}$
Over 4 to 5, incl.	$\frac{1}{4}$
Over 5	$\frac{5}{16}$

CC-4642.6 Shape and Size of Fillet Welds.

Fillet welds may vary from convex to concave. The size of the weld shall be in accordance with the requirements of Fig. CC-4542-1. A fillet weld in any single continuous weld may be less than the specified fillet weld dimension by not more than $\frac{1}{16}$ in. (1.6 mm), provided that the total undersize portion of the weld does not exceed 10% of the length of the weld. Individual undersize weld portions shall not exceed 2 in. (51 mm) in length. On web-to-flange welds on girders, no underrun is permitted at the ends for a length equal to twice the width of the flange. In making fillet welds, the weld metal shall be deposited in such a way that adequate penetration into the base metal at the root of the weld is secured.

CC-4642.7 Plug Welds.

When plug welds are used on embedment anchors, a fillet weld shall first be deposited around the circumference at the bottom of the hole.

CC-4642.8 Stud Welding.

Stud welding shall be in accordance with the requirements of CC-4543.5.

CC-4644 Examination of Welds

All welds shall be examined in accordance with the requirements of CC-5500.

CC-4645 Repair of the Weld Metal Defects

Repair of weld metal defects shall be in accordance with CC-4545.

CC-4650 HEAT TREATMENT

Heat treatment of concrete embedment material shall be in accordance with CC-4550.

CC-4660 BOLTED CONSTRUCTION

Requirements for bolted construction shall be defined in the Construction Specification.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 CC-5000

ARTICLE CC-5000 CONSTRUCTION TESTING AND EXAMINATION

Page 129

CC-5100 GENERAL REQUIREMENTS FOR EXAMINATION

CC-5110 PROCEDURES, QUALIFICATION, AND EVALUATIONS

CC-5111 General Requirements

Nondestructive examinations, except vacuum box examination, shall be in accordance with the examination procedures of Section V. Vacuum box examination shall be in accordance with Appendix IX. For radiography, geometric unsharpness shall not exceed the limits of T-285 of Section V. The examinations shall be performed by personnel who have been qualified as required in this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards of this Article. The examination of parts and appurtenances meeting the requirements for Class MC and which are not backed up by concrete for load carrying purposes shall meet the requirements of NE-5000 and Subsection NCA. Examination of embedded attachments to parts examined to the requirements of Division 1 shall meet the requirements of this Article.

CC-5112 Nondestructive Examination Procedures

All nondestructive examinations required by this Article shall be performed in accordance with detailed written procedures, which have been proven by actual demonstration, to the satisfaction of the Inspector. The procedures shall comply with the appropriate Article of Section V and this Subsection for the particular examination method. Special configurations and materials may require modified methods and techniques. In these cases, special procedures which are at least equivalent to the methods and techniques described in Section V shall be developed. Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Inspector upon request. At least one copy of each procedure shall be readily available to all appropriate nondestructive examination personnel for reference and use.

CC-5113 Post-Examination Cleaning

Following any nondestructive examination in which examination materials are applied to the piece, the piece shall be thoroughly cleaned in accordance with procedure specifications.

CC-5120 QUALIFICATION AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

CC-5121 General Requirements

Organizations performing Code required nondestructive examinations shall use personnel competent and knowledgeable

to the degree specified by CC-5122. When these services are subcontracted by the Certificate Holder or Quality System Certificate Holder, he shall verify the qualification of personnel to the requirements of CC-5122. All nondestructive examinations required by this Subsection shall be performed by and the results evaluated by qualified nondestructive examination personnel.

CC-5122 Personnel Qualification, Certification, and Verification

CC-5122.1 Qualification Procedure

(a) Personnel performing nondestructive examinations shall be qualified in accordance with the recommended

Page 132

guidelines of SNT-TC-1A.¹² The Employer's³ written practice required by paragraph 5 of SNT-TC-1A shall identify his requirements relative to the recommended guidelines. The recommended guidelines of SNT-TC-1A shall be considered minimum requirements, except as modified in (1) through (5) below.

(1) Qualification of Level III nondestructive examination personnel shall be by examination.

(a) The basic and method examinations, paragraphs 8.3.3(1) and 8.3.3(2) of SNT-TC-1A, may be prepared and administered by the Employer, ASNT, or an outside agency.

(b) The specific examination, paragraph 8.3.3(3) of SNT-TC-1A, shall be prepared and administered by the Employer or an outside agency. The Employer or outside agency administering the specific examination shall identify the minimum grade requirement in the written program when the basic and method examinations have been administered by ASNT, which issues grades on a pass/fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(2) The written practice identified in paragraph 5 of SNT-TC-1A and the procedures used for examination of personnel shall be referenced in the Employer's Quality Program.

(3) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform nondestructive examination of limited scope, may be less than that recommended in Table 6.3.1 of SNT-TC-1A. The training and experience times shall be described in the written practice, and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate.

(4) For visual examination, the Jaeger Number 1 letters shall be used in lieu of the Jaeger Number 2 letters specified in paragraph 8.1.1(1) of SNT-TC-1A. The use of equivalent type and size letters is permitted.

1 SNT-TC-1A is a Recommended Practice for Nondestructive Testing Personnel Qualification and Certification published by the American Society for Nondestructive Testing, 4153 Arlington Plaza, Columbus, Ohio 43221. SNT-TC-1A-1980 is the applicable edition.

2 Personnel qualified by examination and recertified to the 1975 edition are considered to be qualified to the 1980 edition when the recertification is based on continuing satisfactory performance. All reexaminations and new examinations shall be in accordance with the 1980 edition.

3 Employer as used in this Article shall include: N Certificate Holders; Quality System Certificate Holders; Material Manufacturers and Material Suppliers who are qualified in accordance with NCA-3862(a)(1); and organizations who provide subcontracted nondestructive examination services to organizations described above.

(5) A Level I individual shall be qualified to perform specific setups, calibrations, and tests, and to record and evaluate data by comparison with specific acceptance criteria defined in written instructions. The Level I individual shall implement these written NDE instructions under the guidance of a Level II or III individual. A Level I individual may independently accept the results of nondestructive examinations when the specific acceptance criteria are defined in the written instructions.

(b) For nondestructive examination methods not covered by SNT-TC-1A documents, personnel shall be qualified to comparable levels of competency by subjection to comparable examinations on the particular method involved.

(c) The emphasis shall be on the individual's ability to perform the nondestructive examination in accordance with the applicable procedure for the intended application.

(d) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use

personnel qualified to perform one or more operations. As an example, one person may be used who is qualified to conduct radiographic examination and another may be used who is qualified to interpret and evaluate the radiographic film.

CC-5122.2 Certification of Personnel

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of Levels I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations CC-5122.2(a)(2), the Employer may use a letter from ASNT as evidence on which to base the certification.

(c) When an outside agency is the examining agent for Level III qualification of the Employer's personnel, the examination results shall be included with the Employer's record.

CC-5122.3 Verification of Nondestructive Examination Personnel Certification.

The Certificate Holder has the responsibility to verify the qualification and certification of nondestructive examination personnel employed by Material Manufacturers and Material Suppliers and qualified by them in accordance with NCA-3820 and subcontractors who provide nondestructive examination services to them.

CC-5122.4 Records.

Personnel qualification records identified in paragraph 9.6.1 of SNT-TC-1A shall be retained by the Employer.

Page 133

CC-5130 QUALIFICATION OF CONCRETE INSPECTION AND TESTING PERSONNEL

CC-5131 General Requirements

It shall be the responsibility of each organization (NCA-3000) to ensure that all personnel performing concrete inspection and testing functions under this Division are competent and knowledgeable of the applicable requirements to the degree specified in CC-5132. All concrete inspection and testing required by this Division shall be performed and the results evaluated by qualified concrete inspection and testing personnel. The assignment of responsibilities to individual personnel will be at the discretion of the responsible organization.

CC-5132 Personnel Qualification

Personnel performing concrete inspection and testing functions shall be qualified in accordance with Appendix VII of this Division.

CC-5133 Verification by Authorized Inspectors

The Authorized Inspector has the duty to verify the organization's certification of concrete inspection and testing personnel in accordance with Appendix VII, and has the prerogative to audit the program and require requalification of any concrete inspection and testing personnel when the Authorized Inspector has reason to question the performance of that individual.

CC-5140 RECORDS

Personnel qualification records shall be retained in accordance with NCA-4134.17.

CC-5200 CONCRETE EXAMINATION

CC-5210 GENERAL

Concrete and concrete constituents shall be examined and tested in accordance with the rules established herein. The results of these tests shall not represent constituents previously used, but will be used only to qualify or disqualify the lot of

concrete constituents represented. The examinations and tests required by this Subarticle shall be performed by the Constructor, Fabricator, or Manufacturer of Nonmetallic Materials and monitored by the Authorized Inspector in accordance with NCA-5000. If the examinations and tests are performed by the Manufacturer of Nonmetallic Materials, provisions shall be made for the Authorized Inspector of the Constructor or Fabricator, as applicable, to make the necessary inspections to ensure compliance with this Subarticle. The results shall be verified by the Fabricator or Constructor.

CC-5211 Laboratory Qualification

The tests required by CC-5200 shall be performed by an accredited laboratory that complies with ASTM C 1077, Standard Practice for Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation, except that testing personnel shall be qualified in accordance with CC-5132.⁴

CC-5220 CONCRETE CONSTITUENTS

CC-5221 Cement

CC-5221.1 Requirements.

Quality control testing shall be performed by the Constructor to ascertain conformance with the applicable requirements of ASTM C 150, or ASTM C 595, as shown in Table CC-5200-1.

CC-5221.2 Testing Frequency.

The frequency of testing shall be as shown in Table CC-5200-1.

CC-5222 Admixtures

CC-5222.1 Air-Entraining Admixtures

CC-5222.1.1 Requirements.

In addition to the testing required by ASTM C 260 of the admixture Manufacturer, the following quality control tests shall be performed using procedures recommended by the Manufacturer: infrared analysis, pH, and solids content. Additionally, the optional uniformity requirements of ASTM C 260 shall apply - pH, specific gravity, and air content.

CC-5222.1.2 Testing Frequency.

Quality control tests shall be conducted on the air-entraining admixture prior to use in accordance with Table CC-5200-1.

CC-5222.2 Mineral Admixtures (Fly Ash and Pozzolan)

⁴ Such laboratory inspections can be provided by the Cement and Concrete Reference Laboratory (CCRL) of the National Institute of Standards and Technology, with accreditation programs provided by the National Voluntary Laboratory Accreditation Program (NVLAP), American Association for Laboratory Accreditation (AALA), and American Materials Engineering Council (CEMC).

CC-5222.2.1 Requirements.

Quality control testing shall be performed to ascertain conformance with

Page 134

Page 137

the applicable requirements of ASTM C 618, as shown in Table CC-5200-1. Pages 135-136

**TABLE CC-5200-1
MINIMUM TESTING FREQUENCIES FOR CONCRETE CONSTITUENTS AND CONCRETE**

Material	Requirements	Test Method	Frequency [Note (1)]	
			Initial [Note (2)]	After Field Experience [Note (3)]
Cement	Standard chemical properties	ASTM C 114	Each 1200 tons	Each 1200 tons
	Fineness	ASTM C 204 or ASTM C 115	Each 1200 tons	Each 1200 tons
	Autoclave expansion	ASTM C 151	Each 1200 tons	Each 1200 tons
	Compressive strength	ASTM C 109	Each 1200 tons	Each 1200 tons
	Time of setting	ASTM C 266 or ASTM C 191	Each 1200 tons	Each 1200 tons
Air-Entraining Admixtures	Uniformity	Infrared spectrophotometry, pH, and solids content in accordance with ASTM C 260	Composite of each shipment or production lot	Composite of each shipment or production lot
Mineral Admixtures (Fly Ash and Pozzolans)	Loss on ignition	ASTM C 311	Each 400 tons	Each 400 tons
	Fineness (No. 325 sieve analysis)	ASTM C 311	Each 400 tons	Each 400 tons
	Specific gravity	ASTM C 311	Each 400 tons	Each 400 tons
	Reactivity with cement alkalies [Note (4)]	ASTM C 441	Each 2000 tons	Each 2000 tons
	Available alkalies [Note (4)]	ASTM C 311	Each 2000 tons	Each 2000 tons
Chemical Admixtures	Uniformity	Infrared analysis, specific gravity (liquids singly), and residue by oven drying in accordance with ASTM C 494	Composite of each shipment or production lot	Composite of each shipment or production lot
Grout Fluidifier	Physical properties	ASTM C 937	Composite of each shipment or production lot	Composite of each shipment or production lot

TABLE CC-5200-1 MINIMUM TESTING FREQUENCIES FOR CONCRETE CONSTITUENTS AND CONCRETE

Aggregate	Gradation	ASTM C 136	Each 1000 cu yd concrete	Each 2000 cu yd concrete
	Moisture content	ASTM C 566	Twice daily during production	
	Material finer than #200 sieve	ASTM C 117	Each 1000 cu yd concrete	Each 2000 cu yd concrete
	Organic impurities [Note (5)]	ASTM C 40	Each 1000 cu yd concrete	Each 2000 cu yd concrete
	Flat and elongated particles	CRD-C 119	Monthly	Every 6 months
	Friable particles [Note (5)]	ASTM C 142	Monthly	Every 6 months
	Lightweight particles [Note (5)]	ASTM C 123	Monthly	Every 6 months
	Specific gravity and absorption	ASTM C 127 or ASTM C 128	Monthly	Every 6 months
	Los Angeles abrasion	ASTM C 131 or ASTM C 535	Every 6 months	Every 6 months
	Water soluble chloride [Note (6)]	ASTM D 1411	Every 6 months	Every 6 months
Water and Ice	Petrographic examination [Note (7)]	ASTM C 295	Every 6 months	Every 6 months
	Effect on compressive strength			
	Total solids	ASTM C 109	Every 6 months	Every 6 months
	Chlorides [Note (6)]	ASTM D 1888 ASTM D 512	Monthly	Monthly
Concrete	Mixer uniformity	ASTM C 94	Initially and every 6 months	Initially and every 6 months
	Compressive strength	ASTM C 39 or ASTM C 943	One set of 2 cylinders from each 100 cu yd with a minimum of one set per day [Note (8)]	One set of 2 cylinders from each 200 cu yd with a minimum of one set on any day that more than 50 cu yd of concrete are placed [Note (8)]
				First batch placed each day and every 100 cu yd placed [Note (8)]
	Slump	ASTM C 143	First batch placed each day and every 50 cu yd placed [Note (8)]	First batch placed each day and every 100 cu yd placed [Note (8)]
	Air content	ASTM C 173 or ASTM C 231	First batch placed each day and every 50 cu yd placed [Note (8)]	First batch placed each day and every 100 cu yd placed [Note (8)]
	Temperature		First batch placed each day and every 50 cu yd placed [Note (8)]	First batch placed each day and every 100 cu yd placed [Note (8)]
	Unit weight	ASTM C 138	Daily [Note (8)]	Test in conjunction with one set of compressive strength test cylinders [Note (8)]
	Compressive strength	ASTM C 109 or CRD-C 621	Daily	Daily
General Purpose Grout				

TABLE CC-5200-1 (CONT'D)

NOTES:

- (1) Testing frequencies on a time basis apply only during production and placement of concrete or grout and when the constituent is being used.
- (2) Initially during the development of the first 30 tests of production concrete and whenever the criteria for the alternate frequency [Note (3)] cannot be met.
- (3) Whenever the average strength f_{cr} of the latest 30 consecutive compressive strength test results exceeds the specified strength f'_c by an amount expressed as $f_{cr} = f'_c + 1.419 (f'_c/8.69)$.
- (4) If required by the Construction Specification.
- (5) Not required for crushed stone quarried from rock strata unless petrographic analysis indicates acceptable but significant quantities of these contaminants.
- (6) The chloride content of the concrete shall be calculated in accordance with CC-5231.
- (7) The report shall be evaluated by the Designer.
- (8) Test frequencies apply to each concrete mix design placed each day.

TABLE CC-5200-1 (CONT'D)

CC-5222.2.2 Testing Frequency.

The frequency of testing shall be as shown in Table CC-5200-1.

CC-5222.2.3 Uniformity Requirements.

The quality control testing results of CC-5222.2.1 shall be evaluated to ascertain conformance with the ASTM C 618 uniformity requirements for:

(a) specific gravity; and

(b) fineness.

CC-5222.3 Chemical Admixtures

CC-5222.3.1 Requirements.

In addition to the testing required of the admixture Manufacturer by ASTM C 494, the following quality control tests shall be performed using procedures recommended by the Manufacturer and as stipulated in ASTM C 494 to assure uniformity: infrared analysis, specific gravity (liquids singly), and residue by oven drying.

CC-5222.3.2 Testing Frequency.

Quality control tests shall be conducted on the admixture prior to use in accordance with Table CC-5200-1.

CC-5222.4 Grout Fluidifier

CC-5222.4.1 Requirements.

Quality control testing shall be performed to ascertain conformance to ASTM C 937.

CC-5222.4.2 Testing Frequency.

Quality control tests shall be conducted on the fluidifier in accordance with Table CC-5200-1.

CC-5223 Aggregates

CC-5223.1 Requirements.

Quality control tests shall be as shown in Table CC-5200-1. Aggregate samples for gradation, moisture content, and material finer than #200 sieve tests shall be obtained from conveyors, bins, or chutes at the batch plant. Aggregate samples for other quality control tests may be obtained from these same locations, at the point of delivery, or from stockpiles.

If the aggregate sampled for gradation and materials finer than #200 sieve tests are not within the specification limits, two additional samples shall be obtained from the same location and tested. If both of the retest samples are within specification limits, the aggregate is acceptable. If either or both of the retest samples is outside of the specification limits, the three test results shall be averaged. This test result shall be averaged with the previous five aggregate test results. If the average of the six tests is within specification limits, the remaining aggregate is acceptable. If the average of the six tests is outside specification limits, the remaining aggregate shall be adjusted to bring the aggregate within limits or the aggregate shall be rejected.

If the aggregate sampled for the other quality control tests is outside the specification limits, two additional aggregate samples shall be obtained from the same location and tested. If both samples are within the specification limits, the aggregate is acceptable.

CC-5223.2 Testing Frequency.

The frequency of testing shall be as shown in Table CC-5200-1.

CC-5224 Mixing Water

CC-5224.1 Requirements.

Quality control testing shall be performed to ensure conformity with the requirements of CC-2223.

CC-5224.2 Testing Frequency.

The frequency of testing shall be as shown in Table CC-5200-1.

CC-5230 CONCRETE

CC-5231 Mixer Uniformity

Mixer uniformity tests shall be performed on stationary and truck mixers to determine that the mixers are capable of combining the concrete constituents into a thoroughly mixed and uniform mass.

CC-5231.1 Requirements.

Mixer uniformity shall be established in accordance with ASTM C 94.

CC-5231.2 Testing Frequency.

The frequency of testing shall be as shown in Table CC-5200-1.

CC-5232 Concrete Properties

(a) Concrete slump, temperature, air content, unit weight, and physical properties examination shall be performed on a common sample to establish conformance with the provisions of the Construction Specification. The sampling of freshly mixed concrete for the above tests shall be in accordance with ASTM C 172, Sampling Fresh Concrete. This sampling shall take place after all material and water additions have been made.

(b) The chloride content of the concrete shall be calculated and evaluated each time chloride test results are received on any one of the constituents. The calculation shall be based on the most recent chloride test results of the other constituents.

Page 138

CC-5232.1 Slump

CC-5232.1.1 Requirements.

Quality control testing in accordance with ASTM C 143, Slump of Portland Cement Concrete, shall be performed to ensure conformity to the requirements of the Construction Specification.

CC-5232.1.2 Testing Frequency.

The frequency of testing shall be as shown in Table CC-5200-1.

CC-5232.2 Temperature, Air Content, and Unit Weight

CC-5232.2.1 Requirements.

Temperature, air content, and unit weight shall be measured to ensure conformance with the Construction Specification. Air content tests shall be made in accordance with ASTM C 173, Test for Air Content of Freshly Mixed Concrete by the Volumetric Method, or ASTM C 231, Test for Air Content of Freshly Mixed Concrete by the Pressure Method. Unit weight tests shall be made in accordance with ASTM C 138, Method of Test for Weight per

Cu. Ft., Yield, Cement Factor, and Air Content (Gravimetric) of Concrete.

CC-5232.2.2 Testing Frequency.

The frequency of testing shall be as shown in Table CC-5200-1.

CC-5232.2.3 Evaluation and Acceptance.

The concrete is acceptable if no more than one individual air content test result in a placement is outside the specified range of air content by more than 20%, provided the average of all air content test results in each placement is within the limits specified in Table CC-2232.3.1.

CC-5232.3 Physical Properties

CC-5232.3.1 Requirements.

Testing of concrete physical properties shall be performed for the purpose of establishing conformance with the provisions of the Construction Specification.

CC-5232.3.2 Evaluation and Acceptance

(a) Samples for compressive strength tests of each class of concrete shall be taken at the frequency of testing shown in Table CC-5200-1. Concrete for compressive strength tests shall be sampled in accordance with ASTM C 172. Cylinders for acceptance tests shall be molded and laboratory cured in accordance with ASTM C 31, Standard Method of Making and Curing Test Specimens in the Field, and tested in accordance with ASTM C 39. Each strength test result shall be the average of two or more cylinders made from the same sample tested at 28 days or other age "a" days when specified in the Design Documents.

(b) When the frequency of testing will provide less than five tests for a given concrete mix for the containment, tests shall be made from at least five randomly selected batches, or from each batch if fewer than five are used.

(c) The strength level of the concrete will be considered satisfactory if the averages of all sets of three consecutive strength tests at "a" days equal or exceed the specified strength and no individual strength test result falls below the specified strength by more than 500 psi.

(d) Supplementary compressive strength tests may be required to check the adequacy of curing and to determine form removal time. When such strength tests are required, the specimens shall be molded and cured under field conditions in accordance with ASTM C 31 and tested in accordance with ASTM C 39. Such specimens shall be molded at the same time and from the same batch as the laboratory cured acceptance test specimens. Procedures for protecting and curing the concrete in the structure shall be improved when the strength of field cured cylinders at "a" days is less than 85% of that of the companion laboratory cured cylinders. When the laboratory cured cylinder strengths are appreciably higher than the specified strengths, the field cured cylinder strengths need not exceed the specified strength by more than 500 psi (3.4 MPa) even though the 85% criterion is not met.

(e) If verification of tensile strength is required, eight sets of four test specimens shall be prepared for each type of concrete throughout the period of construction. They shall be molded and laboratory cured in accordance with ASTM C 31 and tested at "a" days in accordance with ASTM C 78, Flexure Strength of Concrete (Using Simple Beam with Third Point Loading), or ASTM C 496, Test for Splitting Tensile Strength of Cylindrical Concrete Specimens. For each set, three specimens shall be tested for flexure or splitting tensile strength and one for compression.

(f) If the test results do not satisfy the acceptance criteria, the Constructor or Fabricator shall prove to the satisfaction of the Designer that the load carrying capacity of the structure is not jeopardized. If the possibility of low strength concrete is confirmed and computations indicate that the load carrying capacity may have been significantly reduced, test of cores drilled from the area in question may be required in accordance with ASTM C 42, Standard Method of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete. Three cores shall be taken for each case of a cylinder test more than 500 psi (3.4 MPa) below the specified strength.

(g) Concrete in the area represented by the core will be considered structurally adequate if the average of the three strength values is equal to at least 85% of specified strength and if no single core is less than 75% of specified strength. To check testing accuracy, locations represented by the erratic core strengths may be retested. If the strength acceptance criteria are not met by the retests and if structural adequacy remains in doubt, the nonconforming concrete must be replaced. The structural adequacy shall be determined by the Designer.

CC-5233 Preplaced Aggregate Concrete

CC-5233.1 Aggregate

(a) Tests for cleanliness, in accordance with ASTM C 117, and gradation, in accordance with ASTM C 136, shall be performed for each 200 tons (181,000 kg) of aggregate placed in the forms.

(b) Visual examination of aggregate for cleanliness shall be maintained while washing, transporting, and placing aggregate.

CC-5233.2 Cement, Mineral Filler, and Fluidifier

(a) Material shall be tested in accordance with CC-5220.

(b) Grout fluidifier shall be tested in accordance with ASTM C 937. In addition, the grout fluidifier shall be certified by the Constructor, Fabricator, Nonmetallic Material Manufacturer, or Nonmetallic Constituent Supplier to possess the same physical and chemical properties as the grout fluidifier developed and used in trial mix tests.

CC-5233.3 Intrusion Grout

(a) The viscosity of each batch of intrusion grout shall be determined in accordance with ASTM C 939 (flow cone method). The Construction Specification shall establish the flow factor units to be used as the basis for acceptance, rejection, and adjustment of each grout batch mix.

(1) Prior to transferring grout from the mixer to the agitator (if no intermediate agitation is planned prior to pumping), at least one flow cone test for each mix shall fall within the specified limits. Grout not meeting the specified flow factors shall not be transferred to the agitator.

(2) During agitation, if the grout is stiffening, a flow cone test shall be performed just prior to pumping. If the flow cone test result falls outside the specified flow factor limits, the grout batch shall be discarded. Each flow cone test result shall be recorded and its time verified.

(b) The temperature of each grout batch shall be measured at the mixer, at the agitator, and after the grout has left the pump at the point of injection, and recorded. If the temperature of the grout at the place of entering the form is outside of the specified limits for more than one in five consecutive batches, corrective measures shall be taken.

(c) Expansion and bleeding tests shall be performed on a grout sample taken from an actual batch just prior to pumping in accordance with ASTM C 940, Test for Expansion of Grout Mixtures, as modified by the Construction Specification. Expansion and bleeding tests shall be made for each grout batch from which test cylinders are taken.

(d) The time of set shall be determined on a grout sample taken from an actual batch just prior to pumping in accordance with ASTM C 953, Test for Time of Setting of Grout Mixtures, or as modified by the Construction Specification.

CC-5233.4 Concrete.

For each preplaced aggregate concrete placement, test cylinders shall be fabricated from each specified batch or each 100 cu yd of grout, or fraction thereof, pumped during the grouting operation. The number of test cylinders and their test age shall be as specified in the Construction Specification. The 6 in. × 12 in. (152 mm × 305 mm) heavy-duty test cylinder molds and casting procedures shall conform to the requirements of ASTM C 943. Cylinders shall be moist-cured in accordance with ASTM C 31 until tested in accordance with ASTM C 39.

CC-5234 General Purpose Grout

CC-5234.1 Constituents

CC-5234.1.1 Requirements.

Quality control tests shall be conducted on grout constituents in accordance with the requirements of CC-5220.

CC-5234.1.2 Test Frequency.

The frequency of testing shall be as shown in Table CC-5200-1.

CC-5234.2 Physical Properties

CC-5234.2.1 Requirements.

Grout shall be tested in accordance with ASTM C 109 or CRD C 621 for the purpose of establishing conformance of compressive strength to the requirements of the construction specifications.

CC-5234.2.2 Test Frequency.

The frequency of testing shall be as shown in Table CC-5200-1.

Page 140

CC-5240 CEMENT GROUT FOR GROUTED TENDON SYSTEMS

CC-5241 General

Grout fluidity or viscosity, bleeding, and compressive strength shall be specified in the Construction Specification and determined on a common sample in accordance with CC-2240.

CC-5242 In-Process Testing Frequencies

CC-5242.1 Temperatures.

Temperature of the air and combined grout constituents shall be measured and recorded hourly during the grouting operation to determine compliance with the Construction Specification.

CC-5242.2 Fluidity/Viscosity.

The fluidity or viscosity of the grout, as appropriate, shall be measured prior to placement of the first batch each day. An additional test shall be made for each 20 subsequent batches but not less than one test for every fourth tendon grouted each day.

CC-5242.3 Compressive Strength.

Grout strength tests consisting of a set of 3 cube specimens shall be made at the rate of one set for each 100 batches of grout, but not less than one set per day. The tests shall be performed in accordance with CRD C 621.

CC-5242.4 Chemical Requirements.

During grouting the amounts of chloride-nitrate in the grout constituents shall be determined weekly for each lot or batch of constituents.

CC-5300 EXAMINATION OF REINFORCING SYSTEMS

CC-5310 GENERAL

This Subarticle describes the requirements for the examination of reinforcing bars and their splices and joints.

CC-5320 EXAMINATION OF MECHANICAL SPLICES

Acceptance criteria for all splicing systems shall be as described in the Construction Specification.

CC-5321 Sleeve With Ferrous Filler Metal Splices

(a) One sleeved connection from each day's work per splicing crew shall be examined daily for proper fit-up.

(b) All completed sleeved connections shall be visually examined after cooling for acceptable bar end locations. Filler metal shall be visible at each accessible end of the splice sleeve and at the tap hole. Each accessible end of the splice sleeve shall also be subjected to the maximum allowable void criteria as described in the Construction Specification. Splices not meeting these criteria shall be removed and replaced.

CC-5322 Taper Threaded Splices

(a) Bar ends and splice sleeves shall be visually examined prior to assembly for cleanliness.

(b) Threads shall be checked with a Manufacturer's thread gage.

(c) Bars shall be marked with a suitable marker to indicate depth of insertion into splice. After assembly, the actual depth of insertion shall be checked for compliance with CC-4333.3 by means of this mark.

(d) Proper assembly and torque shall be checked for compliance with the installation procedure described in the Construction Specification.

(e) One splice of each 100 production splices shall be disassembled, inspected for compliance with CC-4333.3, and all threads rechecked with the Manufacturer's thread gage.

CC-5323 Swaged Splices

(a) Bar ends and splice sleeves shall be visually examined prior to assembly for cleanliness and proper end preparation.

(b) Bars shall be marked with a suitable marker to indicate depth of insertion into splice. After completion, the actual depth of insertion shall be checked for compliance with CC-4333.3 by means of this mark.

(c) Proper assembly and swaging pressure shall be checked for compliance with the installation procedure described in the Construction Specification.

CC-5324 Threaded Splices in Thread Deformed Reinforcing Bar

(a) Bar ends and splice sleeves shall be visually examined for damage, cleanliness, and proper end preparation prior to assembly.

Page 141

(b) Threads shall be checked with a Manufacturer's thread gage.

(c) Bars shall be marked with a suitable marker to indicate depth of insertion into splice. After assembly, the actual depth of insertion shall be checked for compliance with CC-4333.3 by means of this mark.

(d) Proper assembly and torque at both ends of coupling shall be checked for compliance with the installation procedure described in the Construction Specification.

CC-5340 EXAMINATION OF BENDS

The bent or straightened surfaces of all reinforcing bars that are partially embedded in concrete and that are bent and/or straightened in the field shall be visually examined for indications of cracks.

(a) Bars exhibiting transverse cracks or fissures shall be rejected and the bent or straightened section shall be removed and replaced using a splice in accordance with CC-4330.

(b) The presence of longitudinal seams shall not be cause for removal.

CC-5400 EXAMINATION OF PRESTRESSING SYSTEMS

CC-5410 GENERAL

This Subarticle describes the examination requirements for prestressing systems. Aspects of the systems which affect quality such as tendon fabrication, placement and tensioning of tendons, installation of ducts and bearing plates, and the application of the corrosion prevention materials shall be examined.

CC-5420 REQUIRED EXAMINATION

CC-5421 General

The design, fabrication, and installation of pre-stressing systems shall be in conformance with the Construction Specification. The Construction Specification shall include provisions to control and examine tendon length, twist, temporary protective coatings if required, anchorage hardware, conformance to Manufacturer's standards, coiling and packaging requirements, handling, shipping, and storage procedures.

CC-5422 Bearing Plates

CC-5422.1 Preplacement.

Bearing plates shall be examined for dimensional accuracy, out-of-square, and surface smoothness in accordance with the criteria stated in the Construction Specification.

CC-5422.2 Post-Placement.

Following installation, the position of all bearing plates shall be examined prior to concrete placement for proper location and orientation. Placement tolerances shall be in accordance with the Construction Specification. If the orientation of the plate tends to inhibit concrete placement, a program shall be specified in the Construction Specification for the examination of the soundness of the concrete in the bearing zone.

CC-5423 Tendon Ducts

CC-5423.1 Preplacement.

Tendon ducts shall be examined to ensure compliance with requirements of the Construction Specification as to type, diameter, and wall thickness. The frequency of examination shall be specified in the Construction Specification.

CC-5423.2 Post-Placement.

Tendon ducts shall be examined for position and alignment in accordance with CC-4452. After installation, but prior to concrete placement, the ducts shall be visually examined for damage, including holes and cracks, and for dents and ovaling which may affect required minimum clear aperture. The criteria for the visual examination shall be given in the Construction Specification. Prior to and following concrete placement, all ducts shall be examined to ensure that minimum clear aperture is provided.

CC-5424 Prestressing Steel

(a) All tendons shall be examined to verify that proper element quantities are present. The elements shall be examined at the frequency defined in the Construction Specification to verify proper diameter.

(b) The exposed surfaces of the prestressing elements shall be visually examined upon shipping, receipt, and prior to installation to ensure that damage such as nicks, bends, or corrosion has not occurred to a detrimental degree. Criteria for acceptance shall be given in the Construction Specification. Tendons shall be examined for banding and twisting of the bundle to ensure compliance with the field drawings.

CC-5425 Anchorage Components

(a) Anchorage components shall be examined for dimensions, thread, and surface conditions. The frequency of such examinations, as well as tolerance and any other acceptance criteria, shall be in accordance with the Construction Specification.

(b) Following tensioning, all anchorage assemblies shall be visually examined. The total number of rejectable wires, strands, or bars shall not exceed the limit set forth in CC-4465.

CC-5426 Tensioning

The tensioning of tendons shall be examined for conformance with written procedures. The frequency of this examination shall be specified in the Construction Specification.

CC-5500 EXAMINATION OF WELDS**CC-5510 GENERAL****CC-5511 Scope**

This Subarticle contains the nondestructive examination requirements for the welding of liners and attachments thereto.

CC-5512 Time of Examination of Welds

Acceptance examination of welds shall be performed at the times stipulated in (a) through (d) below, except as otherwise specified in CC-5520.

(a) Radiographic examination of all welds in liners may be performed prior to any required postweld heat treatment for P-No.1 material.

(b) Magnetic particle or ultrasonic examinations shall be performed after any required postweld heat treatment, except P-No.1 materials may be examined prior to PWHT.

(c) All dissimilar metal weld joints shall be examined after final postweld heat treatment.

(d) Vacuum box or gas medium examinations shall be performed after any required final PWHT.

CC-5520 REQUIRED EXAMINATION OF WELDS**CC-5521 Welding Categories**

(a) Category A and B welds shall be radiographed in accordance with CC-5531, except where backup bars are used in accordance with CC-4542.1. Category A and B welds with backup bars shall be examined by the magnetic particle or ultrasonic examination method for the full length of the weld.

(b) Category D butt welds shall be examined in accordance with (a) above. Where the Category D weld around the insert plate is within a distance from the center of the opening equal to the diameter of the opening, the weld shall be 100% radiographed in that area. All butt welds in the insert plate shall be 100% radiographed.

(c) Other Category D welds and Category E, F, G, J, and full penetration category H welds shall be examined by the magnetic particle or ultrasonic examination method for the full length of the weld.

(d) All Category H partial penetration of fillet welds that have a groove depth or throat dimensions greater than 1 in. (25 mm) and T-welded joints welded with throat dimensions of $\frac{1}{2}$ in. (13 mm) or greater shall be examined by the liquid penetrant or magnetic particle method, except that the exposed ends of welds need only be visually examined.

(e) All welds, except attachment welds which do not penetrate the liner, shall be leak tested in accordance with CC-5536 for the full length of the weld.

for the full length of the weld.

(f) For all austenitic welds, liquid penetrant shall be substituted for magnetic particle examination.

(g) Permanent structural, non-structural, and temporary attachment welds shall be examined by the magnetic particle or liquid penetrant method for the full length of the weld.

CC-5522 Weld Joints in Backups

Weld joints in backup bars, and structural shapes used as backups, shall be examined by the magnetic particle, liquid penetrant, or ultrasonic examination method.

CC-5523 Splice Sleeve Welds

The surfaces of all welds between splice sleeves and the liner shall be visually examined.

CC-5524 Stud Welds

Stud welds shall be visually examined.

CC-5525 Leak-Chase Systems

All the welds in the leak-chase systems shall be leak tested.

Page 143

CC-5526 Electroslag Welds

In addition to the requirements for the type of weld being examined, all complete penetration welds made by the electroslag welding process in ferritic materials shall be ultrasonically examined.

CC-5530 EXAMINATION PROCEDURES

CC-5531 Radiographic Examination

CC-5531.1 Examination Procedure.

Radiographic examination as required by CC-5520 shall be performed in accordance with Article 2 of Section V, except that the geometric unsharpness shall not exceed the limits of T-251.

CC-5531.2 Extent of Examination.

The first 10 ft (3.0 m) of weld and one spot (not less than 10 in. (254 mm) in length) in each additional 50 ft (15.2 m) increment of weld (weld test unit), or fraction thereof, shall be radiographed for each welder and welding position (flat, vertical, horizontal, and overhead). In any case, a minimum of 2%, by length, of all butt welds shall be radiographed, except that when backup bars are used for a liner height exceeding 10 ft (3.0 m), the extent of radiography shall be increased to 4%. The 100% radiography required by CC-5521(b) shall not be included in determining the 2% or 4%.

CC-5531.3 Selection of Spots for Radiographic Examination.

The spots of welds to be radiographically examined shall be randomly selected but no two spots in adjacent weld test units shall be closer than 10 ft. The location of all spots shall be recorded.

CC-5531.4 Time of Examination.

Radiographic examination shall be performed prior to the placement of concrete or other obstructions.

CC-5531.5 Repair and Reexamination

(a) The examination of the first 10 ft (3.0 m) of weld required by CC-5531.2 is acceptable when the aggregate length of

unacceptable discontinuities is less than 10 in. If this requirement is not met, the welder's next 10 ft of weld shall be radiographed and evaluated to the acceptance criteria above. All defective welding disclosed shall be repaired and reradiographed.

(b) When a radiographed spot meets the acceptance standards of CC-5542, the entire weld unit represented by the spot is considered acceptable. When a radiographed spot fails to meet the specified acceptance standards, two additional spots shall be radiographically examined in the same weld test unit at locations at least 1 ft (305 mm) removed on each side from the original spot. The locations of these additional spots shall be determined using the same procedure followed in the selection of the original spot for examination, and the examination results shall determine the corrective actions of (1) and (2) below.

(1) If the two additional spots examined meet the acceptance standards, the entire weld unit represented by the three spot radiographs is considered acceptable. However, the defective welding disclosed by the first of the three radiographs shall be repaired and reradiographed.

(2) If either of the two additional spots examined fails to meet the specified acceptance standards, the entire weld test unit is unacceptable. The entire unacceptable weld shall be removed and the joint shall be rewelded or, optionally, the entire weld unit may be completely radiographed and defective welding only need be repaired.

(c) Repair welding shall be performed using a qualified procedure. The weld repaired areas in each weld test unit shall be radiographed to meet the acceptance criteria specified in CC-5542.

CC-5533 Liquid Penetrant Examination

Liquid penetrant examination shall be performed in accordance with Article 6 of Section V.

CC-5534 Magnetic Particle Examination

Magnetic particle examination shall be performed in accordance with Article 7 of Section Vi.

CC-5535 Ultrasonic Examination

Ultrasonic examination shall be performed in accordance with Article 5 of Section V.

CC-5536 Leak Testing

CC-5536.1 Liner Welds.

Leak testing of liner welds shall be performed by either the vacuum box method in accordance with Appendix IX of this Division, the solution film test in accordance with Appendix I in Article 10 of Section V, the halogen diode method in accordance with Appendix III in Article 10 of Section V, or the helium mass spectrometer method in accordance with Appendix IV in Article 10 of Section V.

CC-5536.2 Leak-Chase Systems.

Leak testing of leak-chase systems shall be performed as follows.

The channels shall be pressurized to at least 115% of the design pressure, but not less than 25 psi (172 kPa).

Page 144

The pressure shall be gradually increased to not more than one-half of the test pressure, after which the pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached. The final test pressure shall not be applied until the leak chase channels and pressuring medium are approximately the same temperature.

The test gage shall conform to the requirements of CC-6222. The test pressure shall be held for a minimum of 2 hr. The pressure decay shall not exceed $\frac{1}{2}$ of 1% of the test pressure.

CC-5537 Visual Examination

Visual examination shall be performed in accordance with Article 9 of Section V.

CC-5540 ACCEPTANCE STANDARDS

CC-5541 General Requirements

Unacceptable weld defects shall be removed or reduced to an acceptable size, and, when required, the weld shall be repaired and reexamined in accordance with CC-4540. Acceptance standards for welds shall be as stated in CC-5540, while acceptance standards for material adjacent to the weld shall be as stated in CC-2530.

CC-5542 Radiographic Acceptance Standards

Welds that are shown by radiography to have any of the following types of discontinuities are unacceptable:

(a) any type of crack or zone of incomplete fusion or penetration;

(b) any other elongated indication which has a length greater than:

(1) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive

(2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (57 mm), inclusive

(3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm) where t is the thickness of the thinner portion of the weld;

(c) any group of indications in line that have an aggregate length greater than t in a length of $12t$, except where the distance between the successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication;

(d) porosity in excess of that shown as acceptable in Appendix VI.

CC-5544 Liquid Penetrant Acceptance Standards

CC-5544.1 Evaluation of Indications

(a) Mechanical discontinuities at the surface will be indicated by bleeding out of the penetrant; however, localized surface imperfections such as may occur from machining marks or surface conditions may produce similar indications which are nonrelevant to the detection of unacceptable discontinuities.

(b) Any indication which is believed to be nonrelevant shall be regarded as a defect and shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask indications of defects are unacceptable.

(c) Relevant indications are indications which result from mechanical discontinuities. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length less than three times the width.

CC-5544.2 Acceptance Standards

(a) Only indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant.

(b) Unless otherwise specified in this Subsection, the following relevant indications are unacceptable:

(1) any cracks or linear indications;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);

(3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm), with the area taken in the most unfavorable location relative to the indications being evaluated.

CC-5545

CC-5545 Magnetic Particle Acceptance Standards

CC-5545.1 Evaluation of Indications

(a) Mechanical discontinuities at the surface will be indicated by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant to the detection of unacceptable discontinuities.

(b) Any indication which is believed to be nonrelevant should be regarded as a defect and shall be reexamined by the same or other nondestructive examination

Page 145

methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. After an indication has been verified to be nonrelevant, it is not necessary to reinvestigate repetitive, nonrelevant indications of the same type. Nonrelevant indications which would mask indications of defects are unacceptable.

(c) Relevant indications are indications which result from unacceptable mechanical discontinuities. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length less than three times the width.

CC-5545.2 Acceptance Standards

(a) Only indications with major dimensions greater than $\frac{1}{16}$ in. shall be considered relevant.

(b) Unless otherwise specified in this Subsection, the following relevant indications are unacceptable:

(1) any cracks or linear indications;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);

(3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 sq in. (3871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) with the area taken in the most unfavorable location relative to the indications being evaluated.

CC-5546 Ultrasonic Acceptance Standards

All indications which produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such reflectors and evaluate them in terms of the acceptance rejection standards as given in (a) and (b) below.

(a) Indications are unacceptable if the amplitude exceeds the reference level and discontinuities have lengths which exceed:

(1) $\frac{1}{4}$ in. (6 mm) for t up to $\frac{3}{4}$ in. (19 mm), inclusive

(2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19 mm) to $2\frac{1}{4}$ in. (57 mm), inclusive

(3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm). where t is the thickness of the weld being examined. If a weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses.

(b) Where indications are interpreted to be cracks, lack of fusion, or incomplete penetration, they are unacceptable regardless of discontinuity or signal amplitude.

CC-5547 Leak Testing Acceptance Standards

CC-5547.1 Evaluation of Indications

CC-5547.1.1 Vacuum Box and Leak-Chase System Testing.

Through-thickness discontinuities will be indicated by the formation of a continuous stream of bubbles in the soap solution. The formation of small single bubbles shall not be considered relevant.

CC-5547.1.2 Halogen Diode or Helium Mass Spectrometer Test.

Through-thickness discontinuities will be indicated when the leakage rate exceeds that obtained from the applicable capillary leak calibration.

CC-5547.2 Acceptance Standards.

All through-thickness indications are unacceptable and shall be repaired and retested.

CC-5548 Visual Acceptance Standards

(a) All areas around each stud weld which indicate lack of fusion or absence of weld are unacceptable and shall be repaired.

(b) For welds between splice sleeves and the liner or structural element, and welds in embedment anchors (CC-5600), the following imperfections are unacceptable:

(1) any crack;

(2) surface porosity, the sum of whose diameters exceeds $\frac{3}{8}$ in. (10 mm) in any linear inch of weld or $\frac{3}{4}$ in. (19 mm) in any 12 in. (305 mm) length of weld. As-welded surfaces are permitted; however, the surface of welds shall be free from coarse ripples and grooves and abrupt ridges and valleys. Unacceptable imperfections shall be removed or reduced in order to meet the above limits and reexamined.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 CC-6000

ARTICLE CC-6000 STRUCTURAL INTEGRITY TEST OF CONCRETE CONTAINMENTS

Page 147

CC-6100 GENERAL REQUIREMENTS

CC-6110 INTRODUCTION

This Article contains the requirements for structural integrity testing of concrete containments (CC). The CC shall be tested for structural acceptability as a prerequisite for Code acceptance and stamping. The test is performed at a test pressure of at least 1.15 times the containment design pressure to demonstrate the quality of construction and to verify the acceptable performance of new design features. The structural integrity test (SIT) shall include the differential pressure test of the boundary between the drywell and wetwell compartments of pressure suppression type containments if the boundary loading induces stresses in the containment structure. The differential pressure shall be at least 1.0 times the maximum design differential pressure. However, measurements made solely to demonstrate integrity of the compartment boundary, as distinct from the containment, are not subject to the requirements of this Article. The requirements for the structural test are contained in CC-6300. The test and instrumentation plan shall be defined by the Designer and implemented by the Constructor. The Designer or his designated representative shall witness the integrity test. Test results and conclusions shall be documented in the construction report. The duties of the Authorized Inspector with respect to this test are stipulated in NCA-5280 and NCA-5290.

CC-6120 TEST AND INSTRUMENT PLAN

CC-6121 Scope

The test and instrumentation requirements shall be defined in the Design Specification and included in the Construction Specification. The Construction Specification shall describe the type and location of instrumentation and shall also include

Specification. The Construction Specification shall describe the type and location of instrumentation and shall also include a description of the method of applying the test pressure. This test plan shall be available prior to construction so that sufficient time will be available for the placement of any instrumentation to be embedded in concrete or otherwise installed during construction.

CC-6122 Alteration of Test Plan

The Designer may alter the test plan required by CC-6121 at any time prior to completion of the test.

CC-6123 Weather

The limits of design environmental conditions under which the test may be conducted shall be specified by the Designer. The test shall be postponed or interrupted if environmental conditions are not within the limits specified by the Designer or are such as to pose a safety hazard to test personnel.

CC-6130 TESTING OF DIVISION 1 PARTS, APPURTENANCES, AND COMPONENTS

If parts, appurtenances, and components designed under the rules of Division 1 are to be tested during the containment structural integrity test, they shall be examined in accordance with the rules of Division 1. Any examination required by Division 1 to be performed at elevated pressure shall be done at the structural integrity test pressure ($1.15 \times$ design pressure).

CC-6140 PRETEST CONDITIONS

The CC shall be structurally complete and equipped with the permanent access hatch covers and airlock doors. Piping and electrical penetrations shall either be

Page 150

complete or the penetration sleeves fitted with temporary closures which transfer the pressure load to the sleeve in a similar manner as the permanent penetration device.

CC-6150 CLASSIFICATION OF STRUCTURE

CC-6151 Prototype Containments

A CC incorporating new or unusual design features not yet confirmed by tests, as determined by the Designer, shall be designated a prototype containment.

CC-6152 Nonprototype Containments

A CC shall be designated a nonprototype containment when the Designer has determined that the design has been verified by previous tests on prototype containments.

CC-6160 STRUCTURAL RESPONSE PREDICTIONS

Predictions of displacements, and, in prototype containments, strains, shall be made prior to the start of the test.

CC-6200 TEST PROCEDURE

CC-6210 PRETEST EXAMINATION

Prior to pressure testing, a thorough visual examination of the accessible portions of the containment shall be made by the Designer or his designee. The object of such examination is to record conditions such as spalling or unusual cracking of the concrete, bulging, deformation, or other damage to the liner, and other data which may be needed to interpret the behavior of the containment.

CC-6220 INSTRUMENTATION

CC-6221 Purpose

Instrumentation shall be incorporated into the CC for measurement of displacements. Prototype containments shall also include provisions for strain measurements.

CC-6222 Pressure

Pressure gages used in pressure testing shall be connected directly to the internal environment of the containment, and measure the differential pressure between the internal and external environments.

CC-6222.1 Range of Pressure Gages.

Pressure gages used in testing shall have a range of not more than four times the test pressure.

CC-6222.2 Calibration of Pressure Gages.

Gages shall be calibrated against a deadweight tester or a calibrated master gage prior to and after each test.

CC-6222.3 Accuracy.

Gages shall be accurate to within $\pm 2\%$ of test pressure.

CC-6223 Displacements

Displacement measuring instrumentation shall be attached directly to the containment shell. If the attachment is made to the liner, the Designer shall identify locations. Consideration shall be given to possible separation between the liner and the concrete. Devices may be connected either to two points on the containment or to one point on the containment and a point on a reference structure inside or outside of the containment.

CC-6223.1 Accuracy of Measurements.

Specifications for displacement transducers shall provide for an accuracy of $\pm 5\%$ of the anticipated displacement at the point of maximum displacement as predicted or within 0.01 in. (0.25 mm), whichever is greater.

CC-6224 Strain

Strain measuring devices shall be appropriate for the material for which strain is to be measured.

CC-6224.1 Accuracy of Strain Measuring Devices.

Devices used for strain measurements shall be specified to have an accuracy of $\pm 5\%$ of the maximum anticipated strain on the structure or $10 \mu\text{in./in.}$, whichever is greater. The minimum gage length shall be 4 in. (102 mm) for measurement of internal concrete strains or measurement of strains on concrete surfaces.

CC-6225 Crack Measurements

The widths of cracks shall be measured in the specified areas with optical comparators or wire gages. Lengths of cracks shall be measured with linear scales, or estimated if a grid is marked on the crack mapping area. Measuring devices used to measure cracks shall be capable of measuring a minimum width of 0.005 in. (0.13 mm) and have a resolution of 0.003 in. (0.076 mm).

Page 151

CC-6226 Temperature

Concrete temperatures measured in conjunction with strains shall be measured with thermocouples or resistance elements. Standard thermometry devices may be used to measure ambient air temperature inside and outside the CC. Temperature measuring devices shall have an accuracy of $\pm 2^\circ\text{F}$ ($\pm 1.1^\circ\text{C}$) and a range sufficient to cover the range of temperatures expected at the device location during the test. Devices which are embedded in concrete shall be designed for long-term operation in the concrete environment.

CC-6230 PRETEST OF INSTRUMENTATION

Prior to the start of the test, the output of all instruments shall be recorded. Instruments which display undue drift or erratic readings shall be corrected, if possible, or noted. All malfunctioning instrumentation shall be reported to and evaluated by the Designer.

CC-6231 Instrument Malfunction During Test

Instruments which become erratic or inoperative during the test shall be reported to the Designer. If the Designer determines that data at this location is essential, alternate instrumentation shall be installed before proceeding with the test.

CC-6300 STRUCTURAL TEST REQUIREMENTS

CC-6310 INTRODUCTION

This subarticle contains the requirements for containment pressurization, measurements of structural response, and data collection during the SIT. These requirements apply to the containment configurations defined below. If containment configuration is such that these requirements cannot be implemented, the Designer shall specify alternative requirements. The following four containment configurations are addressed in this subarticle.

(a) Cylinder dome containments consist of a free-standing concrete cylinder, supported on a reinforced concrete base mat and closed by a concrete dome. The cylindrical wall and dome may be conventionally reinforced or prestressed. Cylinder dome containments may be of the pressurized water reactor (PWR) type or the boiler water reactor (BWR) type with a drywell structure supported by the base mat and enclosed by the containment.

(b) Cylinder cone containments consist of a concrete cylinder supported by a reinforced concrete base mat and topped by a concrete cone. The top of the cone is closed by a steel dome head. The cone and cylinder are the drywell and wetwell compartments of a BWR containment, respectively, and are separated by a diaphragm slab which may or may not transmit forces to the cylinder-cone juncture. The concrete cylinder and cone may be conventionally reinforced or prestressed.

(c) Hybrid containments consist of mixed construction of reinforced concrete and steel. The transition of steel to concrete may be at the cylinder-to-mat junction, the cylinder-to-dome junction, or at any location in between.

(d) Other containments are those with vertical and horizontal (including curved or dome type) pressure boundaries with configurations not defined above.

CC-6320 PRESSURIZATION

Containments shall be subjected to an integrity test during which the internal pressure is increased from atmospheric pressure to the test pressure and held for at least 1 hr. If the differential pressure test of the boundary between the drywell and wetwell compartments of pressure suppression type containments induces stresses in the containment shell, the differential pressure test sequence shall be included in the pressurization plan. The test requirements herein are based on the use of atmospheric air as the testing medium.

CC-6321 Rate

The CC shall be pressurized and depressurized at rates not to exceed 20% of test pressure per hour.

CC-6330 TEMPERATURE

The internal temperature shall be controlled as required for any Division 1 components, parts, or appurtenances which are pressurized during this test. Representative temperatures shall be measured if required for displacement and strain measurement corrections.

CC-6340 DATA REQUIRED

Strains, displacements, temperatures, and pressures shall be recorded at atmospheric pressure prior to starting pressurization, at reaching the test pressure, 1 hr after reaching test pressure, and upon completion of depressurization. In addition, at least five sets of

readings shall be taken during pressurization and depressurization to monitor the containment response.

CC-6350 SURFACE CRACKING

The patterns of cracks that exceed 0.01 in. (0.25 mm) in width and 6 in. (152 mm) in length shall be mapped at specified locations before the test, at maximum pressure, and after the test. Locations shall be specified by the Designer and shall include areas where high surface tensile strain is predicted. At each location, an area of at least 40 sq ft (3.7 m²) shall be mapped.

CC-6360 DISPLACEMENT MEASUREMENTS

The Designer shall evaluate the recorded test data during the test as necessary to permit a determination that the test may proceed safely.

CC-6361 Cylinder Dome Containments

Displacement measurements of the CC as defined in CC-6310 shall meet the following provisions.

(a) Radial displacements of the cylinder at a minimum of five approximately equally spaced elevations located at 20%, 40%, 60%, 80%, and 100% of the distance between the base and the spring line. However, if the CC has a thickened lower wall section (thickness increase greater than 25% extending more than three nominal wall thicknesses in height above the base slab), one of the five displacement measurement elevations shall be at the discontinuity between the thickened wall and the nominal wall. The remaining elevations specified for radial displacements shall be readjusted to provide approximately equal spacing between the base slab and the discontinuity and between the discontinuity and the spring line. These measurements shall be made at a minimum of four approximately equally spaced azimuths. Measurement of the total displacement may be made between diametrically opposite locations on the containment wall. The radial displacement may be assumed to be equal to one-half of the measured change in diameter.

(b) Radial displacements of the containment wall adjacent to the largest opening, at a minimum of 12 points, four equally spaced on each of three concentric circles. The diameter of the inner circle shall be just large enough to permit measurements to be made on the concrete rather than on the steel sleeve; the middle approximately 1.75 times the diameter of the opening; and the outer approximately 2.5 times the diameter of the opening. For hatch designs with thickened wall sections, the concentric circle at 1.75 times the diameter shall be relocated at the wall thickness discontinuity and the remaining circle shall be relocated approximately two wall thicknesses outside the discontinuity. The increase in diameter of the opening shall be measured in the horizontal and vertical directions. If other openings require structural verification as determined by the Designer, displacement measurements shall be made in the same manner as stipulated for the largest opening.

(c) Vertical displacement of the top of the cylinder relative to the base, at a minimum of four approximately equally spaced azimuths.

(d) Vertical displacements of the dome of the containment at a point near the apex and two other approximately equally spaced intermediate points between the apex and the spring line on at least one azimuth.

CC-6362 Cylinder Cone Containments

Displacement measurements of CC as defined in CC-6310 shall meet the following provisions.

(a) Radial displacement measurements at midheight of the cylinder, midheight of the cone, the top of the cone, and the cone-cylinder junction if the drywell floor is not constructed integral with the containment wall, shall be made at a minimum of four approximately equally spaced azimuths. Measurements should be perpendicular to the containment centerline or corrections made so these measurements refer to the containment centerline.

(b) Radial displacements of the containment wall adjacent to the largest opening, at a minimum of 12 points, four equally spaced on each of three concentric circles. The diameter for the inner circle shall be large enough to permit measurements to be made on the concrete rather than on the steel sleeve; the middle approximately 1.75 times the diameter of the

opening; and the outer approximately 2.5 times the diameter of the opening. The change in diameter of the opening shall be measured on the horizontal and vertical axes. If other openings require structural verification as determined by the Designer, displacement measurements shall be made in the same manner as stipulated for the largest opening.

(c) Vertical displacement of the top of the cone relative to the base mat-wall junction shall be measured at a minimum of four approximately equally spaced azimuths.

Page 153

CC-6363 Hybrid Containmentment

Displacement measurements of the CC as defined in CC-6310 shall meet the following provisions.

(a) Radial displacements of the concrete construction portion of the cylinder at a minimum of three elevations approximately equally spaced between the base slab and the steel-concrete juncture for containments in which the steel-concrete juncture is located in the upper one-third of the cylinder wall. For steel-concrete juncture locations in the mid one-third of the cylinder wall, radial displacements shall be measured in the concrete portion at two elevations approximately equally spaced. For steel-concrete juncture locations in the lower one-third of the cylinder wall, radial displacements shall be measured in the concrete portion at one elevation approximately equidistant between the base slab and the steel-concrete juncture. In addition, radial displacements shall be measured at the steel-concrete juncture for all juncture locations. These measurements shall be made at a minimum of four approximately equally spaced azimuths. For containments in which the steel-concrete juncture is at the cylinder-base mat intersection, no radial or vertical displacement measurements are required.

(b) Radial displacements of the containment wall adjacent to the largest opening if located in the concrete construction portion. The displacement measurements shall meet the provisions of CC-6361.

(c) Vertical displacement of the concrete portion of the cylinder at a minimum of four approximately equally spaced azimuths measured from the base slab to the wall steel-concrete juncture.

The steel shell shall be examined for leakage in compliance with NE-6224 except as noted in CC-6130.

CC-6365 Other Containmentments

Displacement measurement of containments as defined in CC-6310 which have vertical pressure boundaries and horizontal closures shall meet the following general provisions.

(a) Horizontal (radial) displacement of the primary vertical pressure retaining walls at a minimum of three elevations approximately equally spaced between major load carrying restraints (base slab, diaphragm slabs, spring lines, etc.) or major discontinuities (wall thickness transitions, steel-concrete junctures, etc.), and at the elevations of major discontinuities. These measurements shall be made at a minimum of four approximately equally spaced azimuths.

(b) Vertical displacement of the primary pressure retaining walls at a minimum of four locations nominally spaced to verify gross extension as determined by the Designer.

(c) Vertical displacement of horizontal primary pressure boundaries (domes, slabs, etc.) at a minimum of the structural centerline or as near as practical to the centerline (dome apex) and two other approximately equally spaced locations between the structural centerline and the vertical primary pressure retaining walls on a common azimuth.

(d) Radial displacements of the pressure boundary adjacent to the largest opening. The displacement measurements shall follow the provisions of CC-6361 to the extent possible.

CC-6370 STRAIN MEASUREMENTS

Prototype containments shall be instrumented to measure strain. The strain measuring instrumentation shall be located so as to demonstrate the structural behavior of the prototypical features and the influence of these features on adjacent areas of the containment. The Designer shall, in selecting locations for strain measurement, give particular attention to the influence of the prototypical features on the following areas of the containment:

(a) the intersection of the wall and base slab;

- (b) the vicinity of the largest opening in the concrete construction portion;
- (c) other areas of major discontinuity in the curvature, slope, or thickness of the shell;
- (d) horizontally or vertically restrained areas;
- (e) steel-to-concrete transition areas.

These areas shall be instrumented to measure strain if structurally influenced by the prototypical feature.

CC-6371 Baseline Measurements

Strains and associated temperatures shall be measured for a minimum period of 24 hr prior to the test to evaluate the strain variations resulting from temperature changes.

CC-6380 TEMPERATURE MEASUREMENTS

When strain measurements are to be made, temperatures shall be measured at containment shell locations as specified in the Design Specifications to establish representative temperatures for strain measurements. Temperature measurements shall be used to correct measured strain values for thermal effects.

Page 154

CC-6390 POST-TEST EXAMINATION

A post-test examination shall be made within 1 week of depressurizing. The same examination made during the pretest required by CC-6210 shall be performed.

CC-6400 EVALUATION OF TEST RESULTS

CC-6410 ACCEPTANCE CRITERIA

The CC shall be considered to have satisfied the structural integrity test if the following minimum requirements are met.

- (a) Yielding of conventional reinforcement does not develop as determined from analysis of crack width, strain, or displacement data.
- (b) No visible signs of permanent damage to either the concrete structure or the steel liner are detected. Evidence, resulting from the test, of spalling, laminations, or voids behind the liner are pertinent considerations. Special care shall be exercised in the post-test examination (CC-6390) to detect evidence of localized distress which may not be revealed by strain or displacement data. The significance of such distress, if detected, must be determined by the Designer and be acceptable to the Owner.
- (c) Residual displacements at the points of maximum predicted radial and vertical displacement at the completion of depressurization or up to 24 hr later shall not exceed the following.
 - (1) For conventionally reinforced containments or conventionally reinforced directions of partially prestressed containments: 30% of measured or predicted displacement at maximum test pressure, whichever is greater, plus 0.01 in. (0.25 mm) plus measurement tolerance.
 - (2) For prestressed containments or prestressed directions of partially prestressed containments: 20% of measured or predicted displacement at maximum test pressure, whichever is greater, plus 0.01 in. (0.25 mm) plus measurement tolerance.

The above criteria shall be applied to the average of radial displacements measured at the same elevation.

- (d) The measured displacements at test pressure at points of predicted maximum radial and vertical displacements do not exceed predicted values by more than 30% plus measurement tolerance. This criterion shall apply to the average of radial displacement measured at the same elevation. This requirement may be waived if the residual displacements within 24 hr are not greater than 10% for prestressed structures or 20% for conventionally reinforced concrete structures.

CC-6420 SURFACE CRACKS

Cracks data shall be reviewed by the Designer for evaluation of overall test results.

CC-6430 RETEST

If the measurements indicate that the requirements of CC-6410 are not met, further study by the Designer will be required. Consideration should be given to the possible effects of creep and temperature change, as well as possible inaccuracies in the measured quantities or the predicted values. If such studies still indicate that requirements of CC-6410 are not fulfilled, remedial measures shall be undertaken or a retest shall be conducted. If the containment experiences major structural changes or significant damage requiring repairs after the test, the integrity test shall be repeated following the completion of the corrective actions. In the areas where major structural repairs are performed, additional instrumentation shall be provided to determine whether the structural repair is providing suitable structural capability. Special attention shall be given to shrinkage and creep effects caused by variations in age and composition of the repaired area.

CC-6440 STRAINS

Strain measurements shall be reviewed by the Designer for evaluation of the overall test results.

CC-6500 ANALYSIS OF DATA AND PREPARATION OF REPORT

CC-6510 RESOLUTION OF TEST DATA

The results of the test shall be furnished to and examined by the Designer. Discrepancies between measured and predicted strain or deformation shall be resolved satisfactorily by review of the design, evaluation of measurement tolerances, material variability, and reexamination of the containment.

CC-6520 PRESENTATION OF DATA

Data shall be presented in the final report so that direct comparisons between predicted values and measured values may be made.

Page 155

CC-6530 MINIMUM REPORT REQUIREMENTS

The following minimum information shall be included in the final test report.

- (a) a description of the test procedure and the instrumentation;
- (b) a comparison of the measured displacements and strains with the predicted response including tolerance;
- (c) a summary and discussion of crack measurements;
- (d) an evaluation of the estimated accuracy of the measurements;
- (e) an evaluation of any deviation (such as test results that exceed the allowable limits), the disposition of the deviations, and the need for corrective measures.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 CC-7000

ARTICLE CC-7000 OVERPRESSURE PROTECTION

Page 157

This Article does not provide specific rules for overpressure protection of concrete containments. However, when the use of pressure relief devices is specified by the Design Specification, the relief pressure shall be specified, and the rules of NE-7000

are applicable, except that CC-3000 shall apply rather than NE-3000 as required by NE-7220(k).

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 CC-8000

ARTICLE CC-8000 NAMEPLATES, STAMPING, AND REPORTS

Page 159

CC-8100 GENERAL REQUIREMENTS

The requirements for nameplates, stamping, and reports for components shall be as given in NCA-8000.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 MA APP I

APPENDIX I TABLES OF PRESTRESSING AND LINER
MATERIAL

Page 161

Page 162

[98]

TABLE I-1.1 DELETED

Page 168

**TABLE I-1.2
MATERIAL FOR CONTAINMENT PRESTRESSING
SYSTEMS**

ASME or ASTM Specification	Grade or Type	Product Form
ASTM A 416	250	Strand
	270	Strand
ASTM A 421	BA	Wire
ASTM A 722	150	Bar
	160 [Note (1)]	Bar
ASTM A 779	270	Strand
	260	Strand
	245	Strand

NOTE:

- (1) Bars of Grade 160 (minimum UTS of 160,000 psi), not specifically itemized in ASTM A 722, may be used provided they conform to all other requirements of the ASTM A 722 specification.

TABLE I-1.2 MATERIAL FOR CONTAINMENT PRESTRESSING SYSTEMS

TABLE I-2.2
MATERIAL FOR CONTAINMENT LINERS

ASME Specification	Type, Grade, or Class	Welding P-No.
Plate		
SA-240	TP304, TP304L	8
	TP316, TP316L	8
SA-285	Gr. A	1
	Gr. B	1
	Gr. C	1
SA-299	...	1
SA-516	Gr. 55	1
	Gr. 60	1
	Gr. 65	1
	Gr. 70	1
SA-537	Cl. 1	1
	Cl. 2	1
SA-738	Gr. A	1
	Gr. B	1
	Gr. C	1
Pipe and Tube — Seamless		
SA-106	Gr. A	1
	Gr. B	1
	Gr. C	1
SA-210	Gr. A-1	1
	Gr. C	1
SA-213	TP304, TP304L	8
	TP316, TP316L	8
SA-312	TP304, TP304L	8
SA-333	Gr. 1	1
	Gr. 6	1
SA-334	Gr. 1	1
	Gr. 6	1
SA-376	TP304, TP304H	8
	TP316, TP316H	8
SA-430	FP304, FP304H	8
	FP316, FP316H	8

TABLE I-2.2 (CONT'D)
MATERIAL FOR CONTAINMENT LINERS

ASME Specification	Type, Grade, or Class	Welding P-No.
Pipe and Tube — Welded		
SA-178	Gr. A	1
SA-333	Gr. 1	1
	Gr. 6	1
SA-334	Gr. 1	1
	Gr. 6	1
SA-358	Gr. 304, Gr. 304L	8
	Gr. 316, Gr. 316L	8
Fittings, Forgings, Castings, Bars, and Shapes		
SA-36 [Note (1)]	...	1
SA-105	...	1
SA-181	Cl. 60	1
	Cl. 70	1
SA-216	Gr. WCA	1
	Gr. WCB	1
	Gr. WCC	1
SA-234	Gr. WPB	1
	Gr. WPBW	1
	Gr. WPC	1
	Gr. WPCW	1
SA-266	Cl. 1	1
	Cl. 2	1
	Cl. 3	1
SA-350	Gr. LF1	1
	Gr. LF2	1
SA-351	Gr. CF3	8
	Gr. CF3A	8
	Gr. CF8	8
	Gr. CF8A	8
	Gr. CF3M	8
	Gr. CF8M	8
SA-403	Gr. 304, Gr. 304L	8
	Gr. 316, Gr. 316L	8
SA-420	Gr. WPL-6	1
	Gr. WPL-6W	1
SA-508	Cl. 1	1
SA-541	Cl. 1	1

TABLE I-2.2 (CONT'D) MATERIAL FOR CONTAINMENT LINERS

TABLE I-2.2 (CONT'D)
MATERIAL FOR CONTAINMENT LINERS

ASME Specification	Type, Grade, or Class	Welding P-No.
Reinforced Bar Splice Sleeves Attached to the Liner		
ASTM A 513	1008	1
	1016	1
	1017	1
	1018	1
	1019	1
	1021	1
	1022	1
	1023	1
	1024	1
	1025	1
	1026	1
	1027	1
	1030	1
ASTM A 519	1008	1
	1010	1
	1012	1
	1015	1
	1016	1
	1017	1
	1018	1
	1019	1
	1020	1
	1021	1
	1022	1
	1025	1
	1026	1
	1030	1
Studs		
ASTM A 108	1010	1
	1015	1
	1016	1
	1018	1
	1020	1

NOTE:

(1) May also be used in the form of plate for load bearing attachments.

TABLE I-2.2 (CONT'D) MATERIAL FOR CONTAINMENT LINERS

TABLE I-2.3
MATERIAL FOR EMBEDMENT ANCHORS

Steel Bolting Materials	Grade or Type
SA-36	...
SA-307	B
SA-325	1 2 3
SA-354	BC BD
SA-449	...
ASTM A 490	1 3
SA-540	B21 (Cr-Mo-V) 5 4 3 2 1 B22 (4142-H) 5 4 3 2 1 B23 (E4340-H) 5 4 3 2 1 B24 (4340 MOD) 5 4 3 2 1
SA-563	0 A B C D DH
ASTM A 687	1 & 2
ASTM F 436	...

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 MA APP II

APPENDIX II CONCRETE MULTIAXIAL COMPRESSIVE STRENGTH MODIFICATION

Page 173

ARTICLE II-1000 COMPRESSIVE STRENGTH MODIFICATION

II-1100 C FACTOR

(a) The C factor used in Table CB-3421-1 shall be determined numerically as follows.

(1) In a triaxial compression field, where the smallest of the three compressive stresses has a numerical value greater than $0.15f_{cua}$ and the largest is less than $3f_{cua}$, the procedure outlined below provides safe and conservative values for C .

(2) For cases of triaxial compression where the numerical value of the smallest compressive stress is less than $0.15f_{cua}$ (for cases of essentially biaxial compression), and for triaxial states of stress where biaxial compression is combined with tension in the third direction, the Designer shall justify values of $C \geq 1$ by including in the Design Document appropriate evidence substantiating his values.

(b) *Procedure for Determining C*

(1) Let f_{c1} , f_{c2} , and f_{c3} be the three principal compressive stresses at a point in the concrete (where compressive stresses are taken as positive, and f_{c1} is the largest, f_{c2} the intermediate, and f_{c3} the smallest compressive stress) within the limits of $f_{c1} < 3f_{cua}$ and $f_{c3} > 0.15f_{cua}$. The following procedure may be used to calculate C .

(a) Calculate the ratios f_{c2}/f_{cua} and f_{c3}/f_{cua} .

(b) Enter the ordinate of Fig. II-1 at the value f_{c2}/f_{cua} .

(c) The horizontal line given by f_{c2}/f_{cua} intercepts the curve f_{c3}/f_{cua} . When this horizontal line does not intercept the specified curve stress, augmentation arising from multiaxial loading cannot be assumed, and a value of $C = 1$ must be used.

(d) The higher of the abscissa values of these two intercept points is the C factor, which may be applied to f_{cua} when the compressive concrete stress limits are evaluated.

Page 174

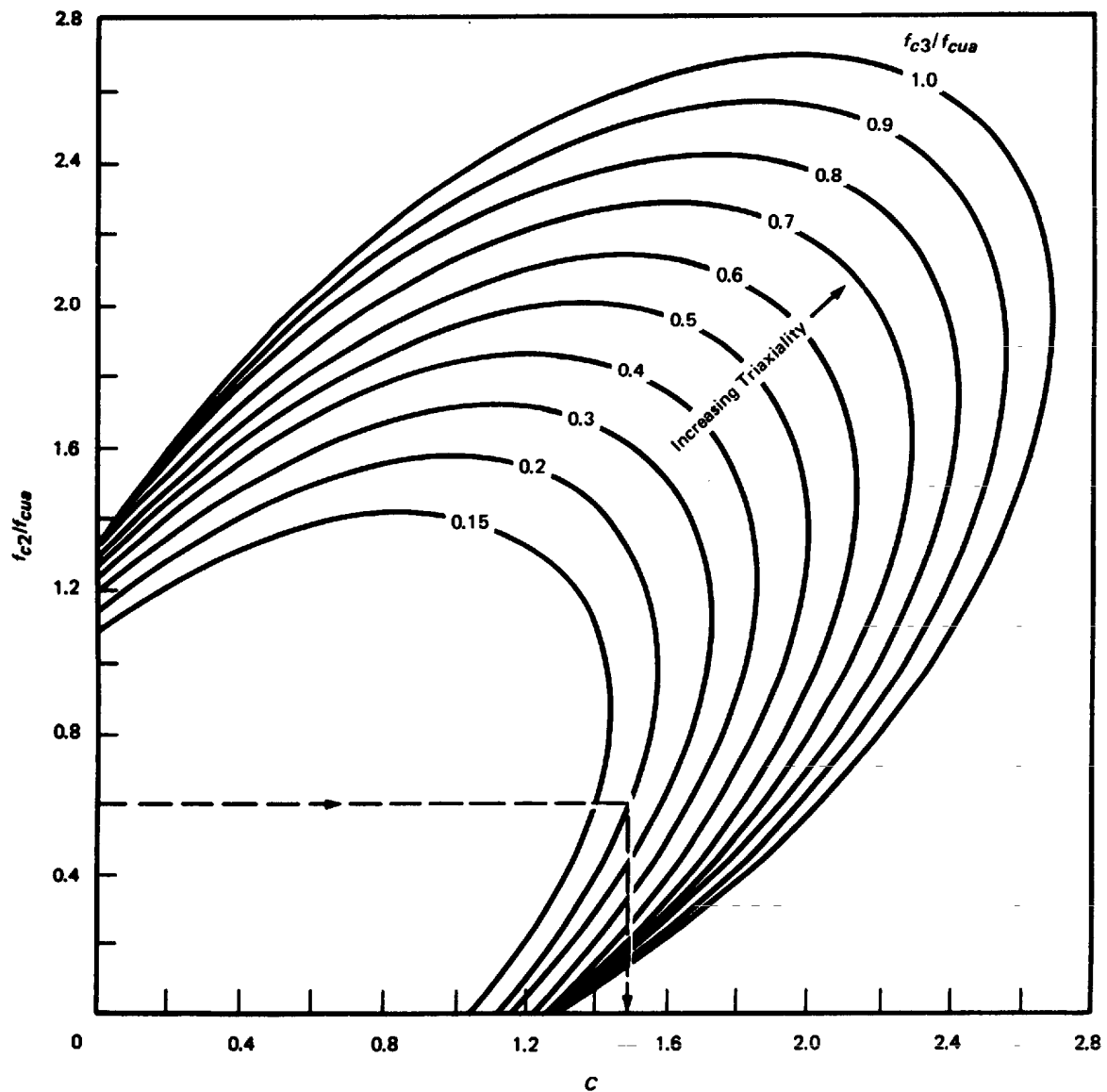


FIG. II-1 C VALUES FOR TRIAXIAL COMPRESSION

FIG. II-1 C VALUES FOR TRIAXIAL COMPRESSION

July 1, 1998
 American Society Of Mechanical Engineers
 SEC III D2 MA APP III

APPENDIX III GLOSSARY OF TERMS AND NOMENCLATURE

Page 175

ARTICLE III-1000 TERMS

For the terms related to cement and concrete not defined herein, refer to ACI 116R, Cement and Concrete Terminology. Terms listed in this Article have a specific meaning applicable to the Code.

anchor, concrete - a member, usually a steel rod with a bend at one end or a headed bolt embedded in the concrete, to which a liner, embedment, or surface-mounted item is attached to prevent that item from pulling away from the hardened concrete

auxiliary systems - features exclusively intended to control or monitor conditions affecting structural integrity that augment the concrete reactor vessel or containment (for example, vessel cooling and insulation, corrosion protection systems, and stress-strain instrumentation)

bending stress - bending stress is the variable component of normal stress; the variation may or may not be linear across the thickness

bulk concrete temperature - the temperature of concrete sufficiently remote from thermal or geometric discontinuities as to be representative of the generalized temperature profile controlling overall structural response. Maximum values are established on the basis of acceptable material behavior for the load category under consideration.

channel - a circumferential recess or groove formed in the external surface of a CRV or containment for the purpose of retaining a circumferential prestressing system

coating-tendon - material used to protect against corrosion or to lubricate the prestressing system

component - a concrete reactor vessel or containment which is governed by the rules of this Division (NCA-1210)

concrete placement - the deposition of concrete or the ingredients for concrete into forms or into members of a structure which serve as forms

coupling - the means by which the prestressing force is permanently transmitted from one portion of the prestressing steel to another to form a complete tendon

ductility - the ratio of the maximum deformation or deflection of the member at the point of collapse to the maximum elastic deformation or deflection at specified minimum yield in the member

effective temperature at liner-concrete interface - the temperature obtained by geometrically projecting the temperature gradient in the bulk of the concrete to the liner-concrete interface

embedment - an item such as an anchor bolt, screed, or conduit encased or partially encased in concrete. Reinforcing systems, liners, and structural members are not considered embedments.

Fabricator - an organization that builds one or more parts (NCA-1231) for the components within the scope of this Division (NCA-3610)

guaranteed ultimate tendon strength (GUTS) - GUTS is the lower of:

(1) the maximum tensioning force that can be applied without breaking more than 2% of the tendon tension members and that can be guaranteed for all tendons

(2) the minimum guaranteed wire, strand, or bar strength times the number of tendon wires, strands, or bars based on test conditions of 70°F (21°C), static loads, and unirradiated samples

leak-chase channel - a channel section permanently installed over a liner weld to permit leak testing of the weld

leak-tight integrity - the ability of a component to maintain a prescribed maximum leakage rate under all service conditions

Page 176

liner - a permanent metal membrane attached to the surface of a concrete reactor vessel, containment, or penetration in order to form a leak-tight enclosure

local hot spots - the maximum local temperature at the liner in any part of the primary coolant due to either discontinuity in the thermal barrier and liner cooling system, or to attachments on the coolant side of the liner which penetrate the thermal barrier or at other locations within the bulk concrete due to radiation heating or other causes. It also includes liner areas subjected to high temperature jet impingement.

membrane stress¹ - the component of normal stress, hoop or meridional, that is uniformly distributed and equal to the average of stress across the thickness of the section under consideration

mineral admixture (fly ash and pozzolans) - a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties

operating basis earthquake - The operating basis earthquake for a site is that which produces the vibratory ground motion for which those features of the power plant necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional. The maximum vibratory ground acceleration of the operating basis earthquake is equal to at least one-half that of the safe shutdown earthquake.

operating basis wind - wind velocities and forces required for the design of a structure in accordance with the uniform building code

peak stress - total stress due to local discontinuities or local thermal stress including the effects of stress concentrations. Its basic characteristic is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or brittle fracture or a localized concrete crack. A stress which is not highly localized falls into this category if it is of a type that cannot cause noticeable distortion. Examples are stresses at a local discontinuity and thermal stresses produced by a local hot spot.

¹ As applied in this Division, membrane stress is not to be substituted for principal stress or stress intensity.

point stress - the maximum apparent stress calculated by adding the membrane stress and the maximum bending stress calculated by elemental beam formulas. When advanced analytical methods (for example, finite element analysis) are used for CRV design, the point stress is defined as the maximum stress across the section under consideration.

primary stress - any normal stress or a shear stress developed by an imposed loading which is necessary to satisfy the laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses which considerably exceed the yield strength in a steel member or gross cracking in concrete will result in failure or in gross distortion. A thermal stress is not classified as a primary stress. Examples are stresses due to internal pressure or to distributed live loads and bending stress in the central portion of a flat slab due to pressure.

safe shutdown earthquake - A safe shutdown earthquake for a site is that which produces the vibratory ground motion for which those features of the power plant necessary to shut down the reactor and maintain the plant in a safe condition without undue risk to the health and safety of the public are designed to remain functional.

secondary stress - a normal stress or shear stress developed by the constraint of adjacent material or by self-constraint of the structure. Its basic characteristic is that it is self-limiting. Local yielding, minor distortions, and concrete cracking can satisfy the conditions that cause the stress to occur, and failure is not to be expected. Examples are general thermal stresses, bending stress at a gross structural discontinuity, and stresses induced by concrete shrinkage and creep.

shear connectors - general term for steel members attached to the liner and embedded in the concrete to provide general compatibility of strains between liner and concrete

structural integrity - the ability of a structure or component to withstand prescribed loads

tendon - the complete assembly consisting of pre-stressing steel and anchorages, and couplings. The tendons impart prestressing forces to the concrete.

ARTICLE III-2000 NOMENCLATURE

A_1

= bearing area of the tendon anchor plate in contact with the concrete, sq in.

A_2	= maximum area of the portion of the anchorage surface that is geometrically similar to and concentric with the area of the tendon anchor plate, sq in.
A_g	= gross area of section, sq in.
A_s	= area of tension reinforcement, sq in.
A_b	= area of individual reinforcement bar, sq in.
A_v	= area of shear reinforcement within a distance t_1 , sq in.
A_{vh}	= area of shear reinforcement parallel to the main tension reinforcement, sq in.
a	= shear span, distance between concentrated load and face of support, in.
b_v	= width of cross section being investigated for shear, in.
D	= dead loads, or their related internal moments and forces, lb
D_c	= construction equipment loads, lb
D_e	= plant fixed equipment load, lb
D_h	= hydrostatic loads
D_i	= weight of internals, lb
	= snow and ice load, lb
D_r	= restraint load, lb
D_s	= soil or embankment load, lb
D_w	= structure and vessel weight, lb
d	= distance from the extreme compression fiber to the centroid of the tension reinforcement, in.
d_b	= nominal diameter of deformed bars or wire, in.
d_s	= distance from the centroidal axis of gross section, neglecting the reinforcement, to the extreme fiber in tension, in.
E_c	= modulus of elasticity, concrete, psi
E_q	= earthquake loads, lb
E_o	= operating basis earthquake, lb
E_s	= modulus of elasticity, steel, psi
E_{ss}	= safe shutdown earthquake, lb
F	= prestressing force loads, lb
F_a	= allowable liner anchor force capacity, lb
F_c	= prestressing force loads during construction staging, lb
F_e	= prestressing force loads at end of plant operational life, lb

F_j	= initial prestressing force loads upon completion of stressing, lb
F_t	= prestressing force loads at time of consideration, lb
F_u	= liner anchor ultimate force capacity, lb
F_y	= liner anchor yield force capacity, lb
f_c	= specified compressive strength of concrete, psi
f_{cc}	= apparent concrete compressive stress
f_{ci}	= compressive strength of concrete at time of initial prestress, psi
f_{cr}	= required average compressive strength of concrete used as the basis for selection of concrete proportions, psi
f_{ct}	= apparent concrete tensile stress, psi
f_{cua}	= compressive strength of concrete at time of test, psi
f_h	= tensile stress developed by a standard hook
f_{pe}	= compressive stress in concrete due to prestress only after all losses, at the extreme fiber of a section at which tensile stresses are caused by applied loads, psi
f_s	= steel stress, psi
f_{sc}	= allowable liner plate compressive stress, psi
f_{st}	= allowable liner plate tensile stress, psi
f_{pu}	= ultimate tensile strength of prestressing steel, psi
f_{py}	= specified tensile yield strength of prestressing or liner steel, psi
f_y	= specified tensile yield strength of reinforcing steel, psi
h	= total depth of section or thickness of wall, in.
I_g	= moment of inertia of gross concrete section about the centroidal axis, neglecting the reinforcing steel, in. ⁴
K	= wobble friction coefficient per ft of prestressing steel
L	= live load, or the related internal moments and forces, lb
L_m	= live load
L_c	= construction live load
l	= length of prestressing steel element from jacking end to any point z, in.
l_d	= reinforcement development length, in.
l_v	= shear span, distance between concentrated load and face of support, in.
M_u	= applied design load moment at a section, in.-lb

N_u	= design axial load normal to the cross section occurring simultaneously with V_u to be taken as positive for compression and negative for tension, and to include the effects of tension due to shrinkage and creep, lb
	= design tensile force on bracket or corbel acting simultaneously with V_u lb
P	= pressure load, lb
P_a	= accident/incident maximum pressure load, lb
P_c	= pressurized crack pressure load, lb
P_d	= differential flow pressure load, lb
P_l	= local pressure buildup load, lb
P_m	= maximum cavity pressure load, lb
P_o	= operational maximum pressure load, lb
P_v	= subatmospheric minimum pressure load, lb
P_s	= steel force at jacking end, lb
P_t	= test pressure load, lb
P_x	= steel force at any point x, lb
p	= pressure, psi
p_a	= accident/incident maximum pressure, psi
p_c	= pressurized crack pressure, psi
p_d	= differential flow pressure, psi
p_l	= local pressure buildup, psi

Page 178

p_m	= maximum cavity pressure, psi
p_o	= operational maximum pressure, psi
p_v	= subatmospheric minimum pressure, psi
p_t	= test pressure, psi
Q	= plant movable equipment loads, lb
R_o	= piping loads during operating conditions, lb
R_a	= piping loads due to increased temperature resulting from the design accident, lb
R_r	= local effects on the containment due to the design basis accident. The local effects shall include the following:
R_{rr}	= load on the containment generated by the design basis accident ² (for example, reaction of a ruptured high energy pipe during the postulated event). The time-dependent nature of the load and the ability of the structure to deform beyond yield shall be considered in establishing the structural capacity

necessary to resist the effects of R_{rr} .

R_{rj}

= load on the containment generated by the design basis accident² (for example, jet impingement from a ruptured high energy pipe during the postulated event). The time-dependent nature of the load and the ability of the structure to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the effects of R_{rj} .

R_{rm}

= effects resulting from the impact of a ruptured high energy pipe on the containment during the design basis accident.² The type of impact (for example, plastic, elastic) together with the ability of the structure to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the impact.

S

= standard deviation, psi

² As defined in U.S. NRC Regulatory Guide 1.70.

s

= spacing of shear reinforcement in a direction parallel to the longitudinal reinforcement, in.

T_a

= accident/incident temperature effects

T_o

= operating temperature effects

T_p

= preoperational heatup temperature effects

T_t

= test temperature effects

V_u

= total applied design shear force at section, lb

V_s

= membrane shear force, lb

W

= wind loads, lb

W_t

= tornado load, lb

W_{tm}

= tornado-generated missile impact effects. The type of impact (for example, plastic, elastic) together with the ability of the structure to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the impact.

W_{tp}

= differential pressure loads due to rapid atmospheric pressure, lb

W_{tq}

= loads due to tornado wind pressure, lb

x

= distance from extreme compression fiber to neutral axis, in.

Y

= dynamic force loads, lb

Y_j

= jet impingement due to fluid discharge, lb

Y_m

= missile impingement load, lb

Y_r

= reaction load due to fluid discharge, lb

Y_w	= water force dynamic load, lb
α	= total angular change of prestressing steel profile in radians from jacking end to any point x; or angle between inclined shear reinforcement and longitudinal axis of member
δ_a	= allowable displacement for liner anchors, in.
δ_u	= ultimate displacement capacity for liner anchors, in.
ϵ_{sc}	= allowable liner plate compressive strain, in./in.
ϵ_{st}	= allowable liner plate tensile strain, in./in.
v_c	= nominal permissible shear stress carried by concrete, psi
v_u	= nominal total design shear stress, psi
ρ	= A_s/bd , sq in./sq in.
μ	= curvature friction coefficient

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 MA APP IV

APPENDIX IV APPROVAL OF NEW MATERIAL

Page 179

ARTICLE IV-1000 PROCEDURE FOR OBTAINING APPROVAL FOR NEW MATERIAL

IV-1100 CODE POLICY

IV-1110 MATERIAL WHICH WILL BE CONSIDERED

It is the policy of the Code to adopt for inclusion in this Division only such specifications that have been adopted by the American Society for Testing and Materials or those others which have been shown by the necessary testing to be suitable for CRV or containment construction.

IV-1200 DATA REQUIRED TO BE SUBMITTED WITH REQUESTS FOR APPROVAL

IV-1210 CONCRETE MATERIAL

IV-1211 Mechanical Properties

The inquirer shall furnish the specification for the concrete material, including any characteristics which deviate from the accepted ASTM standard. In addition, the inquirer shall furnish data on the properties of the proposed concrete mix using this new material inasmuch as the properties deviate from those specified herein. Special attention shall be given to the influence of the new material on concrete compressive and flexural strength, shrinkage, creep, thermal conductivity, coefficient of expansion, and modulus of elasticity. If the properties are dependent upon revised proportions, mixing, placing, or curing procedures, these shall be enumerated.

IV-1212 Additional Considerations

It is important to recognize that the continued durability of the concrete is an essential element in the service life of the structure. Data representing previous experience with the new material showing its influence on concrete durability will be useful to the Code. Also, if the new material results in the limits on chemical contaminants being exceeded, data shall

be furnished on the corrosion potential of embedded metals. Service experience or test data are the type of data to be furnished.

IV-1220 REINFORCING SYSTEM MATERIAL

IV-1221 Mechanical, Physical, and Chemical Properties

Request for acceptance of new reinforcing system material shall include specifications for the material and system characteristics. Any deviation from this Division or accepted standards shall be specifically noted.

Data shall be furnished to demonstrate that the mechanical, physical, and chemical properties of the proposed material meet the specifications. These shall include, but not be limited to, the following.

(a) Mechanical and Physical Properties

- (1) ultimate tensile strength
- (2) yield strength
- (3) elongation at rupture
- (4) specific weight
- (5) coefficient of thermal expansion
- (6) modulus of elasticity
- (7) deformation geometry

(b) Chemical Properties. Complete chemical analysis of material.

IV-1222 System Performance

Documentation shall be furnished to demonstrate that the new material will be physically and chemically compatible when assembled into a reinforced concrete system. The reinforcing system material shall meet the requirements set forth in CB-2300, CB-4300, CB-5300 or CC-2300, CC-4300, and CC-5300.

Page 180

IV-1230 PRESTRESSING SYSTEM MATERIAL

IV-1231 Mechanical, Physical, and Chemical Properties

Request for acceptance of new prestressing system material shall include specifications for the material and system characteristics. Any deviation from this Division or accepted standards shall be specifically noted.

Data shall be furnished to demonstrate that the mechanical, physical, and chemical properties of the proposed material meet the specifications. These shall include, but not be limited to, the following.

(a) Mechanical and Physical Properties

- (1) ultimate tensile strength
- (2) yield strength
- (3) elongation at rupture
- (4) reduction of area
- (5) modulus of elasticity
- (6) hardness (if applicable)
- (7) relaxation properties (if applicable)

(b) *Chemical Properties.* Complete chemical analysis of the material.

IV-1232 System Performance

Documentation shall be furnished to demonstrate that the new material will be physically and chemically compatible when assembled into a prestressed concrete system. The prestressing system material shall meet the requirements set forth in CB-2400, CB-4400, CB-5400 or CC-2400, CC-4400, and CC-5400.

IV-1240 LINER MATERIAL

IV-1241 Mechanical Properties

(a) Together with the specification for the material, the inquirer shall furnish adequate data on which to base allowable stress or strain values for inclusion in the applicable tables. The data shall include values of ultimate strength, yield strength, reduction of area, elongation, and strain fatigue of base metal and welded joints over the range of temperatures at which the material is to be used. Any heat treatment that is required to produce the tensile properties should be fully described. Adequate data on the notch toughness in the proposed service temperatures must be furnished. The brittle fracture characteristics of the material, and particularly of steels which will be subjected to neutron irradiation during service, are especially important. This information is required for both base metal and weld metal, including the weld heat affected zone, in the heat treated condition in which it will be in service. If in the intended service the material will be exposed to neutron irradiation, the effects of such exposure on the nil-ductility transition temperature should be submitted if known. Service experience in the temperature range contemplated will be useful.

(b) If the material is to be used in components to operate under external pressure or load, stress-strain curves (tension or compression) shall be furnished for the range of temperature desired.

IV-1242 Weldability

The inquirer shall furnish complete data on the weldability of material intended for welding, including data on procedure and performance qualification tests made in accordance with the requirements of Section IX. Welding tests shall be made over the range of thickness in which the material is to be used. Pertinent information such as heat treatment required, susceptibility to air hardening, and the amount of experience in welding the material shall be given.

IV-1243 Physical Changes

It is important to know the structural stability characteristics and the degree of retention of properties with exposure of temperature and neutron irradiation of new material. The influence of fabrication practices (such as forming, welding, and thermal treatments on the mechanical properties, ductility, and microstructure of the material) are important, particularly where a degradation in properties may be encountered. Where particular temperature ranges of exposure or heat treatment, cooling rates, combination of mechanical working and thermal treatments, fabrication practices, etc., cause significant changes in the mechanical properties, microstructure, resistance to brittle fracture, etc., it is of prime importance to call attention to those conditions which should be avoided in service or in the manufacture and fabrication of parts or components from the material.

IV-1300 PROPRIETARY MATERIAL

IV-1310 PATENTS AND LICENSES

The inquirer shall state whether or not the material is covered by patents and whether or not it is licensed and, if licensed, the limitations on its manufacture.

Page 181

IV-1400 CODE CASE

In exceptional circumstances, the Code will consider the issuance of a Code Case, effective for a period of 3 years, permitting the use of a material provided the following conditions are met.

- (a) The material is commercially available and can be purchased within the specified range of chemical, physical, and mechanical requirements described in IV-1210 through IV-1240.
- (b) The inquirer shows that there will be a reasonable demand for the material by industry and that there exists an urgency for approval by means of a Code Case.
- (c) The request for approval of the material shall clearly describe it in ASTM specification form for the particular product.
- (d) The inquirer shall furnish all the data specified in IV-1200 and IV-1300.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 MA APP VI

APPENDIX VI ROUNDED INDICATIONS

Page 183

ARTICLE VI-1000 ROUNDED INDICATIONS

VI-1100 ACCEPTANCE STANDARDS FOR RADIOGRAPHICALLY DETERMINED ROUNDED INDICATIONS IN WELDS

VI-1110 APPLICABILITY OF THESE STANDARDS

These standards are applicable to ferritic, austenitic, and nonferrous material.

VI-1120 TERMINOLOGY

VI-1121 Rounded Indications

Indications with a maximum length of three times the width or less on the radiograph are defined as *rounded indications*. These indications may be circular, elliptical, conical, or irregular in shape and may have tails. When evaluating the size of an indication, the tail shall be included. The indication may be from any source in the weld, such as porosity, slag, or tungsten.

VI-1122 Aligned Indications

A sequence of four or more rounded indications shall be considered to be aligned when they touch a line parallel to the length of the weld drawn through the center of the two outer rounded indications.

VI-1123 Thickness t

t is the thickness of the weld, of the pressure retaining material, or of the thinner of the sections being joined, whichever is least. If a full penetration weld includes a fillet weld, the thickness of the fillet weld throat shall be included in t .

VI-1130 ACCEPTANCE CRITERIA

VI-1131 Image Density

Density within the image of the indication may vary and is not a criterion for acceptance or rejection.

VI-1132 Relevant Indications

(See Table VI-1132-1 for Examples)

Only those rounded indications which exceed the following dimensions shall be considered relevant:

- (a) $\frac{1}{10}t$ for t less than $\frac{1}{8}$ in. (3.2 mm);
- (b) $\frac{1}{64}$ in. (0.4 mm) for t equal to $\frac{1}{8}$ in. to $\frac{1}{4}$ in. (3.2 mm to 6 mm), incl.;
- (c) $\frac{1}{32}$ in. (0.8 mm) for t greater than $\frac{1}{4}$ in. to 2 in. (6 mm to 51 mm), incl.;
- (d) $\frac{1}{16}$ in. (1.6 mm) for t greater than 2 in. (51 mm).

VI-1133 Maximum Size of Rounded Indication (See Table VI-1132-1 for Examples)

The maximum permissible size of any indication shall be $\frac{1}{4}t$ or $\frac{5}{32}$ in. (4 mm), whichever is less, except that an isolated indication separated from an adjacent indication by 1 in. (25 mm) or more may be $\frac{1}{32}t$ or $\frac{1}{4}$ in. (6 mm), whichever is less. For t greater than 2 in. (51 mm), the maximum permissible size of an isolated indication shall be increased to $\frac{3}{8}$ in. (10 mm).

VI-1134 Aligned Rounded Indications

Aligned rounded indications are acceptable when the summation of the diameters of the indications is less than t in a length of $12t$ (see Fig. VI-1134-1). The length of groups of aligned rounded indications and the spacing between the groups shall meet the requirements of Fig. VI-1134-2.

Page 184

VI-1135 Spacing

The distance between adjacent rounded indications is not a factor in determining acceptance or rejection, except as required for isolated indications or groups of aligned indications.

VI-1136 Rounded Indication Charts

- (a) The rounded indications as determined from the radiographic film shall not exceed that shown in the charts.
- (b) The charts in Figs. VI-1136-1 through VI-1136-6 illustrate various types of assorted, randomly dispersed, and clustered rounded indications for different weld thicknesses greater than $\frac{1}{8}$ in. (3.2 mm). These charts represent the maximum acceptable concentration limits for rounded indications.
- (c) The chart for each thickness range represents full-scale 6 in. radiographs and shall not be enlarged or reduced. The distributions shown are not necessarily the patterns that may appear on the radiograph, but are typical of the concentration and size of indications permitted.

VI-1137 Weld Thickness t Less Than $\frac{1}{8}$ in. (3.2 mm)

For t less than $\frac{1}{8}$ in. (3.2 mm), the maximum number of rounded indications shall not exceed 12 in a 6 in. (152 mm) length of weld. A proportionally fewer number of indications shall be permitted in welds less than 6 in. (152 mm) in length.

TABLE VI-1132-1
MAXIMUM SIZE OF NONRELEVANT INDICATIONS
AND ACCEPTABLE ROUNDED INDICATIONS—
EXAMPLES ONLY

Thickness t , in.	Maximum Size of Acceptable Rounded Indication, in.		Maximum Size of Nonrelevant Indication, in.
	Random	Isolated	
$<1/8$	$1/4t$	$1/3t$	$1/10t$
$1/8$	0.031	0.042	0.015
$3/16$	0.047	0.063	0.015
$1/4$	0.063	0.083	0.015
$5/16$	0.078	0.104	0.031
$3/8$	0.091	0.125	0.031
$7/16$	0.109	0.146	0.031
$1/2$	0.125	0.168	0.031
$9/16$	0.142	0.188	0.031
$5/8$	0.156	0.210	0.031
$11/16$	0.156	0.230	0.031
$3/4-2$, incl.	0.156	0.250	0.031
>2	0.156	0.375	0.063

TABLE VI-1132-1 MAXIMUM SIZE OF NONRELEVANT INDICATIONS AND ACCEPTABLE ROUNDED INDICATIONS - EXAMPLES ONLY

VI-1138 Clustered Indications

The illustrations for clustered indications show up to four times as many indications in a local area as that shown in the illustrations for random indications. The length of an acceptable cluster shall not exceed the lesser of 1 in. (25 mm) or $2t$. Where more than one cluster is present, the sum of the lengths of the clusters shall not exceed 1 in. (25 mm) in a 6 in. (152 mm) length of weld.

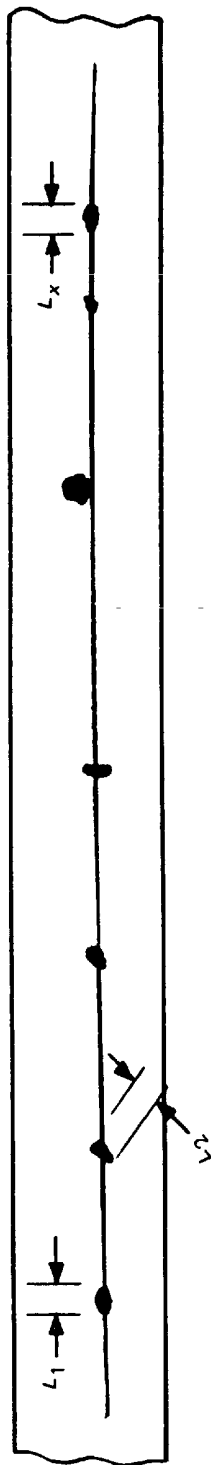
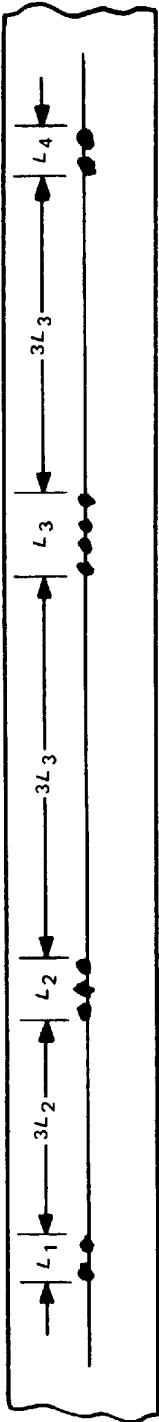


FIG. VI-1134-1 ALIGNED ROUNDED INDICATIONS



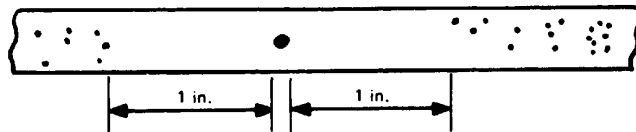
GENERAL NOTE: The sum of the group lengths shall be less than t in a length of $12 t$.

Maximum Group Length	Minimum Group Spacing
$L = 1/4$ in. for t less than $3/4$ in.	$3L$ where L is the length of the
$L = 1/3 t$ for t equal to $3/4$ in. to $2-1/4$ in.	longest adjacent group being
$L = 3/4$ in. for t greater than $2-1/4$ in.	evaluated

FIG. VI-1134-2 GROUPS OF ALIGNED ROUNDED INDICATIONS



(a) Random Rounded Indications
(Typical concentration and size permitted
in any 6 in. length of weld.)



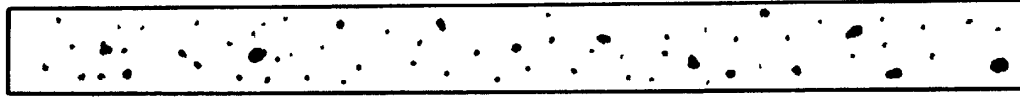
(b) Isolated Indication
(Maximum size per Table VI-1132-1)



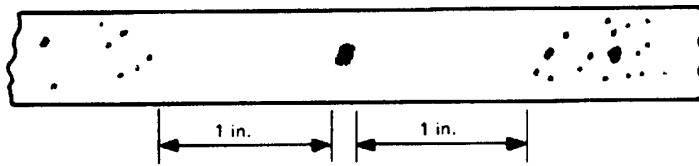
(c) Cluster

FIG. VI-1136-1 CHARTS FOR t EQUAL $\frac{1}{8}$ - $\frac{1}{4}$ in., INCLUSIVE

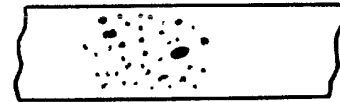
FIG. VI-1136-1 CHARTS FOR t EQUAL $\frac{1}{8}$ - $\frac{1}{4}$ in., INCLUSIVE



(a) Random Rounded Indications
(Typical concentration and size permitted
in any 6 in. length of weld.)



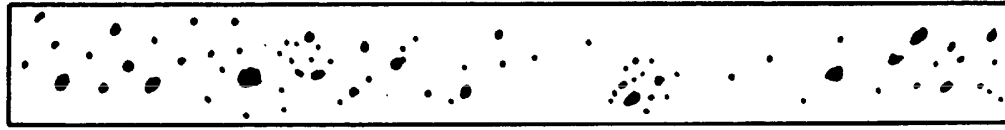
(b) Isolated Indication
(Maximum size per Table VI-1132-1)



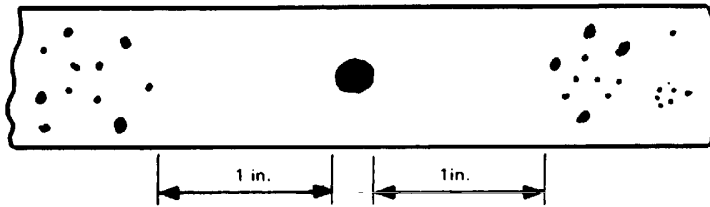
(c) Cluster

FIG. VI-1136-2 CHARTS FOR t OVER $\frac{1}{4}$ – $\frac{3}{8}$ in., INCLUSIVE

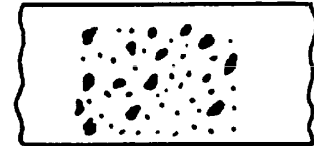
FIG. VI-1136-2 CHARTS FOR t OVER $\frac{1}{4}$ – $\frac{3}{8}$ in., INCLUSIVE



(a) Random Rounded Indications
(Typical concentration and size permitted
in any 6 in. length of weld.)



(b) Isolated Indication
(Maximum size per Table VI-1132-1)



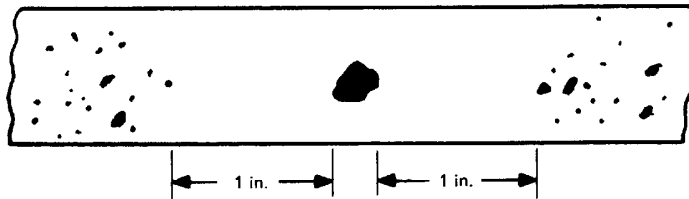
(c) Cluster

FIG. VI-1136-3 CHARTS FOR t OVER $\frac{3}{8}$ - $\frac{3}{4}$ in., INCLUSIVE

FIG. VI-1136-3 CHARTS FOR t OVER $\frac{3}{8}$ - $\frac{3}{4}$ in., INCLUSIVE



(a) Random Rounded Indications
(Typical concentration and size permitted
in any 6 in. length of weld.)



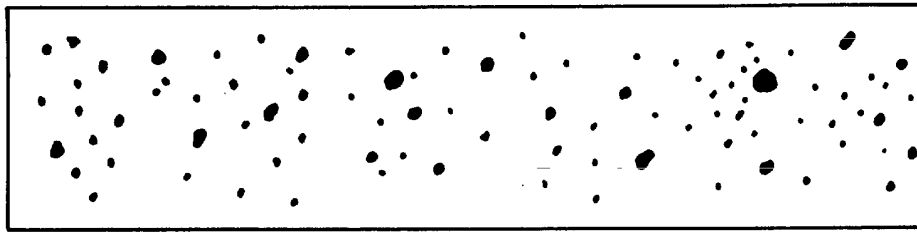
(b) Isolated Indication
(Maximum size per Table VI-1132-1)



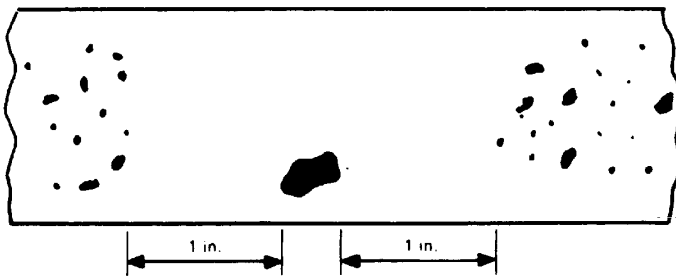
(c) Cluster

FIG. VI-1136-4 CHARTS FOR t OVER $\frac{3}{4}$ -2 in., INCLUSIVE

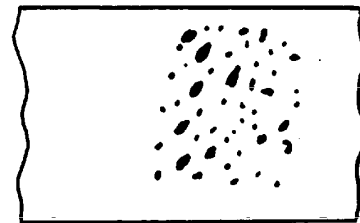
FIG. VI-1136-4 CHARTS FOR t OVER $\frac{3}{4}$ -2 in., INCLUSIVE



(a) Random Rounded Indications
(Typical concentration and size permitted
in any 6 in. length of weld.)



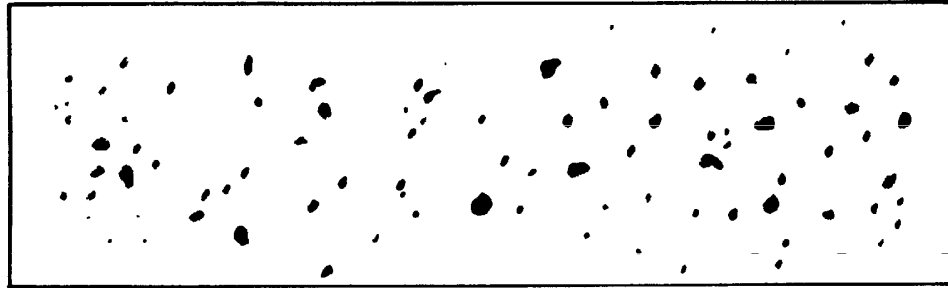
(b) Isolated Indication
(Maximum size per Table VI-1132-1)



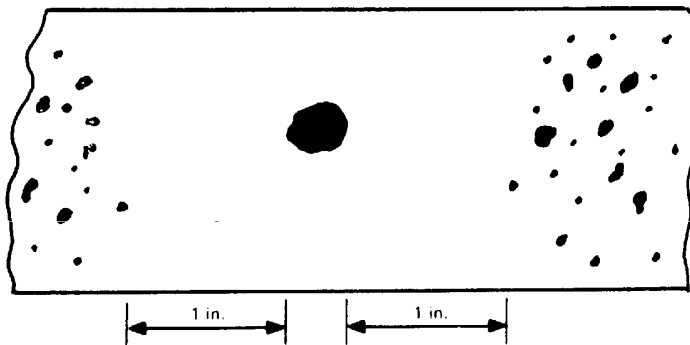
(c) Cluster

FIG. VI-1136-5 CHARTS FOR t OVER 2-4 in., INCLUSIVE

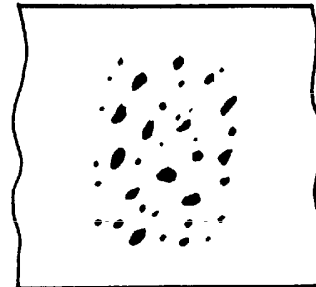
FIG. VI-1136-5 CHARTS FOR t OVER 2-4 in., INCLUSIVE



(a) Random Rounded Indications
(Typical concentration and size permitted
in any 6 in. length of weld.)



(b) Isolated Indication
(Maximum size per Table VI-1132-1)



(c) Cluster

FIG. VI-1136-6 CHARTS FOR t OVER 4 in.

FIG. VI-1136-6 CHARTS FOR t OVER 4 in.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 MA APP VII

APPENDIX VII QUALIFICATIONS OF CONCRETE INSPECTION
PERSONNEL

ARTICLE VII-1000 INTRODUCTION

VII-1100 SCOPE

This Appendix defines the qualifications of personnel, except Authorized Inspectors, who perform concrete inspection and testing.

VII-1200 RESPONSIBILITY

(a) It is the responsibility of the N-type Certificate Holder to ensure that only those personnel who meet the requirements of this Appendix are permitted to perform concrete inspection and testing.

(b) The N-type Certificate Holder responsible for establishing the applicable requirements for personnel performing activities covered by this Appendix shall identify and document the scope of the responsibility of such personnel. The work of establishing training practices and certification procedures and providing the resources in terms of personnel, equipment, and services necessary to implement the requirements of this Appendix may be subcontracted to other organizations, and such contractual relationships shall also be documented.

(c) It is the responsibility of each organization performing concrete inspection and testing to assure that their personnel are certified in accordance with this Appendix.

(d) The organization certifying concrete inspection and testing personnel shall make available for review the detailed methods and procedures used for meeting these requirements. These methods and procedures shall be reviewed and approved by the N-type Certificate Holder.

ARTICLE VII-2000 GENERAL REQUIREMENTS

VII-2100 PLANNING

Plans shall be developed for assigning or staffing and training an adequate number of personnel to perform the required concrete inspections and tests, and these plans shall reflect the schedule of project activity so as to allow adequate time for assignment for selection and training of the required personnel. The need for formal training programs shall be determined, and such training activities shall be conducted as required to qualify personnel responsible for concrete inspection and testing.

VII-2200 CERTIFICATION

Personnel who perform concrete inspection and tests shall be certified by their employer as being qualified to perform the assigned work. This certification shall be supported by appropriate measures such as training, testing, evaluation, and periodic review to assure the initial and continued proficiency of each person.

VII-2210 TRAINING

Training programs shall include indoctrination of personnel with the technical objectives of the project and the codes and standards that are to be used. On-the-job participation shall also be included in the program with emphasis on first-hand experience gained through actual performance of tests, examinations, and inspections. Classroom and on-the-job training may be waived by the Level III Concrete Inspector for concrete inspection and testing personnel with sufficient experience to satisfactorily pass the evaluation (performance or written examination) requirements for the job description.

Page 194

The justification for waiver shall be stated and included in the certification file (VII-2230).

VII-2220 EVALUATION OF PERFORMANCE

(a) The education, experience, and training of Level I and II concrete inspection personnel shall be evaluated prior to initial certification by a Level III Concrete Inspector, and their performance shall also be evaluated at periodic intervals not to exceed 2 years. The N-type Certificate Holder shall review and approve the initial qualifications and periodic

evaluations of concrete inspection and testing personnel.

(b) The qualifications of the Level III Concrete Inspector shall be initially reviewed by the N-type Certificate Holder responsible for designating the Level III Concrete Inspector. The applicant's education, experience, and satisfactory passing of the Level III Concrete Inspector examination shall be evaluated to determine if the results meet the requirements of Appendix VII, the applicant may be certified by his employer.

(c) The performance of Level III Concrete Inspectors shall be reevaluated by the N-type Certificate Holder responsible for designating them at periodic intervals not to exceed 2 years.

(d) A Level III Concrete Inspector who has not been certified or recertified as a Level III Concrete Inspector for a period of 5 years following satisfactory passing of the concrete inspector examinations shall satisfactorily pass another examination to demonstrate current knowledge of concrete practice and this Division.

(e) Level III Concrete Inspectors may file copies of their certification and periodic reevaluation with the American Concrete Institute, Director of Education. This information, together with the original application and notice of passing the Level III examination, would be released, upon request from the individual, to subsequent employers for verification of total experience and performance as a Level III Concrete Inspector.

VII-2230 CERTIFICATION OF QUALIFICATION

(a) The qualifications of Level I and II concrete inspection and testing personnel shall be documented in an appropriate form. The certification file shall include the following information:

(1) employer's name;

(2) name of person being certified;

(3) level of capability;

(4) activity certified to perform, including ASTM test numbers or other test identifications and inspection or testing functions described in VII-4210 or VII-4220;

(5) basis used for certification:

(a) record of education and experience

(b) test results

(c) proficiency demonstration, when applicable

(d) record of training including on-the-job training;

(6) results of periodic evaluation;

(7) results of required physical examinations;

(8) signature of employee's designated Level III Concrete Inspector;

(9) issue date and expiration date of the certification.

(b) The qualifications of Level III Concrete Inspectors shall be documented in an appropriate form. The certification file shall contain the following information:

(1) employer's name;

(2) signature of employer certifying the person as a Level III Concrete Inspector;

(3) signature of the N-type Certificate Holder responsible for reviewing the person's qualifications;

(4) copy of completed application for Level III Concrete Inspector;

(5) proof of satisfactory passing of the Level III Concrete Inspector examination;

- (6) result of required physical examinations;
- (7) results of periodic evaluations;
- (8) certificate issue date and expiration date of the certification.

ARTICLE VII-3000 QUALIFICATIONS

VII-3100 GENERAL REQUIREMENTS

(a) It shall be the responsibility of the N-type Certificate Holder to ensure that all personnel performing concrete inspection and testing operations are competent in and knowledgeable of the applicable or concrete inspection requirements to the degree specified.

(b) All concrete inspections and tests shall be performed and the results evaluated by qualified concrete inspection or testing personnel. The assignment of responsibilities to individual personnel will be at the discretion of the N-type Certificate Holder.

Page 195

VII-3200 QUALIFICATION OF CONCRETE INSPECTION AND TESTING PERSONNEL

VII-3210 QUALIFICATIONS

Three qualification levels for personnel who perform concrete inspection and testing activities are defined below.

VII-3211 Level I Concrete Inspection and Testing Technician

A candidate for Level I Concrete Inspection and Testing Technician must satisfactorily complete each of the following:

(a) Completion with passing grades of at least 2 years of engineering or science study at an accredited university, college, or technical institute, plus 3 months experience in inspection or testing; or high school graduation (GED equivalency) plus six months experience in inspection or testing. At least $\frac{1}{2}$ of the required experience shall be in concrete inspection or testing.

(b) An indoctrination course including subjects such as the requirements of this Division and quality programs applicable to the Candidate.

(c) Combined classroom and on-the-job training for each inspection and testing function to be performed. This training may be reduced for experienced candidates. This training shall be administered by a certified Level II or Level III person. Satisfactory performance shall be documented.

(d) Passing of a written "closed book" examination which includes each inspection and test the Candidate is to perform. The examination content shall be approved by a Level III Concrete Inspector. The examination shall be administered by a certified Level II or Level III person. Satisfactory passing of the examination shall be evaluated for each applicant by a Level III Concrete Inspector.

(e) Passing of a proficiency demonstration for each test the candidate is to perform. The proficiency demonstration shall be administered and evaluated for each candidate by a certified Level II or III person.

VII-3212 Level II Concrete Inspector

A candidate for Level II Concrete Inspector must satisfactorily complete each of the following:

(a) Graduation with an engineering or science degree from a four year accredited engineering or science college or university, plus six months of experience in concrete inspection and testing; or, completion with passing grades of at least 2 years of engineering or science study at an accredited university, college, or technical institute plus one year of experience in concrete inspection and testing; or, high school graduation (GED equivalency) plus 2 years of satisfactory performance as a certified Level I Concrete Inspection Technician.

(b) An indoctrination course including subjects such as applicable quality programs, Code requirements, quality records, duties, and responsibilities that are pertinent to the Candidate's assignment.

(c) Training that includes each inspection and testing function to be performed. This training may be reduced for experienced candidates. This training shall be administered by a certified Level II or Level III person. Satisfactory performance shall be documented.

(d) Passing of a written examination which includes each inspection and test the candidate is to perform. The examination content shall be approved by a Level III Concrete Inspector. The examination shall be administered by a certified Level II or Level III person. Satisfactory passing of the examination shall be evaluated for each applicant by a Level III Concrete Inspector.

(e) Passing of a proficiency demonstration for each test the Candidate is to perform. The proficiency demonstration shall be administered and evaluated for each Candidate by a certified Level II or Level III person.

VII-3213 Level III Concrete Inspector

To be considered for certification, a candidate must satisfy one of the following requirements:

(a) graduation from a 4 year accredited engineering or science college or university, plus 4 years experience in an assignment comparable or superior to that of Level II Concrete Inspector, plus being a registered Professional Engineer, plus satisfactory passing of the Level III Concrete Inspector examination administered by the American Concrete Institute;

(b) completion with passing grades of at least 2 years of engineering or science study at an accredited university, college, or technical institute, plus 7 years or more experience in an assignment comparable or superior to that of Level II Concrete Inspector, plus being a registered Professional Engineer, plus satisfactory passing of the Level III Concrete Inspector examination as administered by the American Concrete Institute;

(c) completion with passing grades of 2 or more years of engineering or science study at an accredited university, college, or technical institute plus 8 years or more experience in an assignment comparable or superior to that of Level III Concrete Inspector, plus

Page 196

satisfactory passing of the Level III Concrete Inspector examination as administered by the American Concrete Institute.

VII-3220 PHYSICAL CAPABILITIES

Personnel who perform concrete inspection and tests shall be physically capable of performing their assigned task. As a minimum, the required characteristics are as follows:

(a) natural or corrected near distance acuity capable of reading J-I letters on standard Jaeger's test type chart for near vision or equivalent test type;

(b) natural or corrected far distance acuity capable of reading 20-40 by the Linear Snellen Scale;

(c) color vision, as applicable.

The required physical characteristics should be verified by examination at intervals not to exceed 2 years.

VII-3230 TECHNICAL

Three levels of technical requirements for personnel who perform concrete inspection and test activities are defined below.

VII-3231 Level I

The person shall have experience or training in the performance of the inspection and tests that he is required to perform. He shall be familiar with the tools and equipment to be employed and shall have demonstrated proficiency in

their use. He shall be familiar with inspection and testing equipment calibration and control methods and shall be capable of verifying that the equipment is in proper condition for use.

VII-3232 Level II

The person shall have experience or training in the performance of required inspections and tests and in the completion and evaluation of the results of the inspections and tests. He shall be capable of supervising or maintaining surveillance over the inspections and tests performed by others and of calibrating or establishing validity of calibration of testing equipment. He shall have demonstrated proficiency in planning and setting up tests and shall be capable of determining the validity of tests results.

VII-3233 Level III

The person shall have broad experience and formal training in the performance of inspections and tests and shall be educated through formal courses of study in the principles and techniques of the inspections and tests that are to be performed. He shall be capable of planning and supervising inspections and tests, reviewing and approving procedures, and evaluating the adequacy of activities to accomplish objectives. He shall be capable of organizing and reporting results and of certifying the validity of results.

ARTICLE VII-4000 PERFORMANCE

VII-4100 CONCRETE INSPECTION AND TESTING FUNCTIONS

Personnel who are assigned the responsibility and authority to perform inspections and tests shall have the level of capability shown in Table VII-4100-1.

VII-4200 CONCRETE INSPECTION AND TESTING FUNCTIONS

VII-4210 LEVEL I

A person performing one or more of the following functions shall hold, as a minimum, Level I certification:

- (a) routine tests of concrete and concrete constituents;
- (b) inspection and testing of mechanical reinforcing bar splices;
- (c) receiving inspection and testing of concrete constituents, reinforcing material, post tensioning systems, and embedments;
- (d) inspection of finishing, patching, and curing of concrete;
- (e) preparation of reports of the above functions.

VII-4220 LEVEL II

A person performing one or more of the following functions shall hold, as a minimum, Level II certification:

- (a) inspection at the batching plant;
- (b) preplacement inspection of forms, reinforcing steel, embedded items, and prestressing systems;
- (c) inspection of concrete handling and placing equipment and its operation;

**TABLE VII-4100-1
MINIMUM LEVELS OF CAPABILITY FOR FUNCTIONS**

Function	Level		
	L-I	L-II	L-III
Recording inspection and testing data	X	X	X
Implementing inspection and testing procedures	X	X	X
Planning inspections and tests: setting up tests including preparation and setup of related equipment		X	X
Evaluating the validity and acceptability of inspection and testing results		X	X
Reporting inspection and testing results		X	X
Supervising equivalent or lower level personnel		X	X
Certifying lower level personnel			X
Evaluating the adequacy of specific programs used to train and test inspection and testing personnel			X
Approve inspection and test procedures			X

TABLE VII-4100-1 MINIMUM LEVELS OF CAPABILITY FOR FUNCTIONS

- (d) inspection of concrete placement including provisions for weather protection;
- (e) inspection of structural repairs to concrete members;
- (f) inspection of insertion, stressing, and greasing of prestressing systems;
- (g) inspection of precasting operations;
- (h) specialized laboratory tests;
- (i) supervision of Level I personnel including review and approval of reports;
- (j) preparation, review, and approval of inspection and test reports prepared by Level I personnel;
- (k) training and administering examinations to Level I and II personnel.

VII-4230 LEVEL III

A person performing one or more of the following functions shall hold Level III certification:

- (a) witnessing and evaluation of laboratory design or testing of concrete mixes as required by the Construction

Specification;

- (b) approval of batching and mixing facilities;
- (c) approval of quality control inspection and test procedures; y
- (d) development of training and certification programs for Level I and II personnel;
- (e) evaluation of Level I and II certification examinations;
- (f) certification of Level I and II personnel.

ARTICLE VII-5000 REVIEW OF QUALIFICATIONS

VII-5100 RECORDS OF QUALIFICATIONS

A file of records of personnel qualifications shall be established and maintained during construction. This file shall contain records of past performance history, training, initial and periodic evaluations, and certification of the qualifications of each person.

Page 198

VII-5200 CERTIFICATION OF CONCRETE INSPECTION PERSONNEL

The Authorized Inspector has the duty to verify the certification of concrete inspection personnel in accordance with VII-3000. He shall have the prerogative to audit the program and require recertification of any inspector when the Authorized Inspector has reason to question the capabilities of that concrete inspector.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 MA APP IX

APPENDIX IX NONDESTRUCTIVE EXAMINATION METHODS

Page 199

ARTICLE IX-1000 INTRODUCTION

IX-1100 SCOPE

This Appendix includes the requirements for those nondestructive examination methods not contained in Section V and the corresponding qualification requirements.

ARTICLE IX-2000 VACUUM BOX EXAMINATION OF WELDS

IX-2100 SCOPE

These rules describe the methods which shall be employed whenever vacuum box examination is specified.

IX-2200 APPLICATION

Vacuum box examination provides for the detection of through-thickness discontinuities in welds. Typical discontinuities detectable by this method are cracks, pores, and lack of fusion. A bubble-forming solution is applied to the surface to be examined. A vacuum box with a viewing window large enough to view the complete area and to allow sufficient light to enter the box for proper examination is then placed over the surface. The box, which by means of its construction and a suitable gasket shall be capable of producing and holding a pressure differential of at least 8 psi, is then evacuated. A calibrated gauge is placed in the system to verify the required pressure differential to detect vacuum seal or other types of leaks in the equipment. The area is then viewed for evidence of through-thickness discontinuities by the formation of bubbles on the surface.

IX-2300 PROCEDURE

IX-2310 SURFACE PREPARATION

In general, satisfactory results may be obtained when the surface is in the as-welded condition.

(a) Prior to vacuum box examination, the surface to be examined shall be cleaned of all slag, scale, grease, paint, or other material which would otherwise interfere with the examination procedure or the interpretation of the results.

(b) Typical cleaning agents which may be used are wire brushes, detergents, organic solvents, descaling solutions, and paint removers.

IX-2320 DRYING AFTER CLEANING

After wet cleaning, the surfaces to be examined may be dried by normal evaporation or with forced hot air. A minimum period of time shall be established and included in the written procedure to ensure that the cleaning solvents have evaporated prior to the application of the bubble solution.

IX-2330 BUBBLE SOLUTION APPLICATION

The bubble solution shall be applied evenly over the entire test area by using brushes or other applicable means.

IX-2340 SOLUTION APPLICATION TIME

Application time is critical, particularly if the surface is warm. At temperatures between 40°F and 100°F,

Page 200

the solution shall not be applied more than 1 min prior to examination.

IX-2350 TEMPERATURE OF SURFACE BEING EXAMINED

As a standard technique, the temperature of the surface of the part to be examined shall not be below 40°F (4°C) nor above 100°F (38°C) throughout the examination. Local heating or cooling is permitted provided temperatures remain in the range of 40°F to 100°F (4°C to 38°C) during examination. Where it is impractical to comply with the foregoing temperature limitations, other temperatures may be used, provided the procedure is qualified as described in IX-2500.

IX-2360 APPLICATION OF VACUUM

The vacuum box shall be placed over the examination area and evacuated to at least 5 psi (35 kPa) pressure differential with respect to atmospheric pressure. The 5 psi (35 kPa) pressure differential shall be verified by the gauge and maintained for a minimum time of 20 sec after the vacuum has been obtained. An overlap of 2 in. (51 mm) shall be used for each subsequent examination along the seam.

IX-2370 VISUAL EXAMINATION

When performing the visual examination, access to the area to be viewed should permit placing the eye within at least 24 in. (610 mm) of the surface being examined. Mirrors may be used to improve the angle of vision, and aids such as magnifying lenses may be used. The lighting in the area to be examined shall be a minimum of 350 lux.

IX-2400 EVALUATION OF INDICATIONS

All indications of bubbles shall be evaluated in terms of the acceptance standards.

IX-2500 PROCEDURE SPECIFICATION REQUIREMENTS

(a) Each Fabricator or Constructor shall certify that the required written examination procedure specification is in accordance with applicable requirements of this Division and IX-2000. The required procedure specification shall record, in detail, at least the following information:

- (1) brand name and specific type (number or letter designation, if available) of bubble solution;
- (2) details of the method of preexamination drying, including cleaning materials used and the time allowed for drying;
- (3) method of assuring that the required differential pressure is present;
- (4) details of the method of bubble solution application, the length of time that the solution remains on the surface prior to examination, and the temperature of the surface during the examination if not within the 40°F and 100°F (4°C to 38°C) range;
- (5) method of postexamination cleaning, if performed.

IX-2600 RECORDS

Copies of procedure and personnel qualifications and examination results shall be maintained in accordance with the requirements of NCA-4134.17(e)(8).

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 MA APP X

APPENDIX X PREPARATION OF TECHNICAL INQUIRIES TO THE BOILER AND PRESSURE VESSEL COMMITTEE

Page 201

X-1000 INTRODUCTION

The ASME Boiler and Pressure Vessel Committee and its Subcommittees, Subgroups, and Working Groups meet regularly to consider revisions of the Code rules, new Code rules as dictated by technological development, Code Cases, and Code interpretations. This Appendix provides guidance to Code users for submitting technical inquiries to the Committee. Technical inquiries include requests for revisions or additions to the Code rules, requests for Code Cases, and requests for Code interpretations.

Code Cases may be issued by the Committee when the need is urgent. Code Cases clarify the intent of existing Code requirements or provide alternative requirements. Code Cases are written as a question and a reply and are usually intended to be incorporated into the Code at a later date. Code interpretations provide the meaning of or the intent of existing rules in the Code and are also presented as a question and a reply. Both Code Cases and Code interpretations are published by the Committee.

The Code rules, Code Cases, and Code interpretations established by the Committee are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design or as limiting in any way the freedom of manufacturers or constructors to choose any method of design or any form of construction that conforms to the Code rules.

As an alternate to the requirements of this Appendix, members of the Committee and its Subcommittees, Subgroups, and Working Groups may introduce requests for Code revisions or additions, Code Cases, and Code interpretations at their respective committee meetings or may submit such requests to the secretary of a Subcommittee, Subgroup, or Working Group.

Inquiries that do not comply with the provisions of this Appendix or that do not provide sufficient information for the Committee's full understanding may result in the request being returned to the inquirer with no action.

X-2000 INQUIRY FORMAT

Submittals to the Committee shall include:

(a) *Purpose.* Specify one of the following:

(1) Revision of present Code rules(s)

(2) New or additional Code rules(s)

(3) Code Case

(4) Code interpretation

(b) *Background*. Provide the information needed for the Committee's understanding of the inquiry, being sure to include reference to the applicable Code Section, Division, Edition, Addenda, paragraphs, figures, and tables. Preferably, provide a copy of the specific referenced portions of the Code.

(c) *Presentations*. The inquirer may desire or be asked to attend a meeting of the Committee to make a formal presentation or to answer questions from the Committee members with regard to the inquiry. Attendance at a Committee meeting shall be at the expense of the inquirer. The inquirer's attendance or lack of attendance at a meeting shall not be a basis for acceptance or rejection of the inquiry by the Committee.

X-3000 CODE REVISIONS OR ADDITIONS

Requests for Code revisions or additions shall provide the following:

Page 202

(a) *Proposed Revision(s) or Addition(s)*. For revisions, identify the rules of the Code that require revision and submit a copy of the appropriate rules as they appear in the Code marked up with the proposed revision. For additions, provide the recommended wording referenced to the existing Code rules.

(b) *Statement of Need*. Provide a brief explanation of the need for the revision(s) or addition(s).

(c) *Background Information*. Provide background information to support the revision(s) or addition(s) including any data or changes in technology that form the basis for the request that will allow the Committee to adequately evaluate the proposed revision(s) or addition(s). Sketches, tables, figures, and graphs should be submitted as appropriate. When applicable, identify any pertinent paragraph in the Code that would be affected by the revision(s) or addition(s) and paragraphs in the Code that reference the paragraphs that are to be revised or added.

X-4000 CODE CASES

Requests for Code Cases shall provide a *Statement of Need* and *Background Information* similar to that defined in V-3000(b) and V-3000(c), respectively, for Code revisions or additions. The proposed Code Case should identify the Code Section and division and be written as a *Question* and a *Reply* in the same format as existing Code Cases. Requests for Section XI Code Cases should also indicate the applicable Code Edition(s) and Addenda to which the proposed Code Case applies.

X-5000 CODE INTERPRETATIONS

Requests for Code interpretations shall provide the following:

(a) *Inquiry*. Provide a condensed and precise question, omitting superfluous background information, and, when possible, composed in such a way that a "yes" or "no" *Reply*, possibly with brief provisos, is acceptable. The question should be technically and editorially correct.

(b) *Reply*. Provide a proposed *Reply* that will clearly and concisely answer the *Inquiry* question. Preferably, the *Reply* should be "yes" or "no" possibly with brief provisos.

(c) *Background Information*. Provide any background information that will assist the Committee in understanding the proposed *Inquiry* and *Reply*.

X-6000 SUBMITTALS

Submittals to and responses from the Committee shall meet the following:

(a) *Submittal*. Inquiries from Code users shall preferably be submitted in typewritten form; however, legible handwritten inquiries will also be considered. They shall include the name, address, telephone number, and fax number, if available, of the inquirer and be mailed to the following address:

Secretary
ASME Boiler and Pressure Vessel Committee
Three Park Avenue
New York, N.Y. 10016-5990

(b) Response. The Secretary of the ASME Boiler and Pressure Vessel Committee or of the appropriate Subcommittee shall acknowledge receipt of each properly prepared inquiry and shall provide a written response to the inquirer upon completion of the requested action by the Code Committee.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 MA APP XI

APPENDIX XI QUALIFICATIONS FOR ARC WELDING REINFORCING BARS

Page 203

ARTICLE XI-1000 INTRODUCTION

XI-1100 SCOPE

This Appendix defines the qualifications of arc welding procedures, welders, and welding operators used to arc weld reinforcing bars to reinforcing bars or to other material.

XI-1200 APPLICATION

Arc welded joints are permissible provided the requirements of CB-2333 or CC-2333, as applicable, are met.

XI-1300 QUALIFICATIONS, RECORDS, AND IDENTIFYING STAMPS

XI-1310 REQUIRED QUALIFICATIONS

Each Constructor or Fabricator is responsible for the welding performed by his organization. The Constructor or Fabricator shall conduct the tests required to qualify the welding procedures and the welders and welding operators who use these procedures.

XI-1320 MAINTENANCE AND CERTIFICATION OF RECORDS

The Constructor or Fabricator shall maintain a record of the qualified welding procedures and of the welders and welding operators qualified and employed by him. These records shall show the date and results of tests and the identification mark assigned to each welder or welding operator. These records shall be reviewed, verified, and signed by the Constructor or Fabricator and shall be accessible to the Owner and to the Inspector.

XI-1330 IDENTIFICATION OF JOINTS WELDED BY WELDERS AND WELDING OPERATORS

The welder or welding operator shall apply the identification mark assigned to him by the Constructor or Fabricator adjacent to each welded joint. As an alternative, the Constructor or Fabricator shall keep a record of permanent welded joints in each item and of the welders and welding operators used in making each of the joints.

XI-1340 WELDING PRIOR TO QUALIFICATION

No production welding shall be performed by a welder or welding operator who has not been qualified in accordance with XI-1540.

XI-1350 TRANSFERRING QUALIFICATIONS

The performance qualification tests for welders and welding operators conducted by one Constructor or Fabricator shall not qualify welders and welding operators to weld for any other Constructor or Fabricator.

XI-1400 GENERAL WELDING REQUIREMENTS

XI-1410 WELDING PROCESS AND MATERIAL

Welding of reinforcing bar shall be restricted to the shielded metal-arc (SMAW), gas metal-arc (GMAW), or flux-cored arc welding (FCAW) processes. Weld metal shall conform to the following requirements.

Page 204

**TABLE XI-1410-1
FILLER METAL REQUIREMENTS**

Base Metal	Electrode Classifications for Welding Processes		
	Shielded Metal-Arc Welding (Low Hydrogen Electrode) (XI-1411)	Gas Metal-Arc Welding (XI-1412)	Flux-Cored Arc Welding (XI-1412)
ASTM A 615 Grade 40	AWS A5.1 or A5.5 E70XX	AWS A5.18 E70S-X, E70U-1	AWS A5.20 E70T-X
ASTM A 706	AWS A5.5 E80XX	AWS A5.28 ER 80S-B2, ER 80S-B2L	AWS A5.20 E80T
ASTM A 615 Grade 60, ASTM A 706	AWS A5.5 E90XX	AWS A5.28 ER90S-B3, ER90S-B3L	AWS A5.20 E90T

TABLE XI-1410-1 FILLER METAL REQUIREMENTS

XI-1411 SMAW Process

The electrode, electrode-gas combination, or grade of weld metal shall be in accordance with Table XI-1410-1. Shielded metal-arc welding shall be performed with low hydrogen electrodes.

XI-1411.1

Low hydrogen electrodes for shielded metal-arc welding shall conform to the requirements of AWS A5.1, Specification for Covered Carbon Steel Arc Welding Electrodes, or to the requirements of AWS A5.5, Specification for Low Alloy Steel Covered Arc Welding Electrodes.

XI-1411.2

All electrodes having low hydrogen coverings conforming to AWS A5.1 shall be purchased in hermetically sealed containers or shall be dried for at least 2 hr at a temperature between 450°F (232°C) and 500°F (260°C) before they are used. Electrodes having a low hydrogen covering conforming to AWS A5.5 shall be purchased in hermetically sealed containers or shall be dried for at least 1 hr at a temperature between 700°F (371°C) and 800°F (427°C) before they are used. Electrodes shall be dried prior to use if the hermetically sealed containers show evidence of damage. After removal from hermetically sealed containers or drying ovens, electrodes shall be stored in ovens held at a temperature of at least 250°F (121°C).

E70XX electrodes that are not used within 4 hr, E80XX within 2 hr, and E90XX within 1 hr after removal from hermetically sealed containers (or removal from a drying or storage oven) shall be redried before use. Electrodes which have been wet shall not be used.

XI-1412 GMAW or FCAW Process

The electrodes and combination of shielding for GMAW or FCAW for producing weld metal with minimum specified yield strengths of 60 ksi (410 MPa) or less shall conform to the requirements of AWS A5.18, Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding, or AWS A5.20, Specification for Carbon Steel Electrodes for Flux Cored Arc Welding, as applicable.

For weld metal having a minimum specified yield strength greater than 60 ksi (410 MPa) for GMAW, the weld material shall conform to AWS A5.28, Specification for Low Alloy Steel Filler Metals for Gas Shielded Arc Welding. For FCAW, each user shall demonstrate that each combination of electrode and shielding proposed for use will produce low alloy weld metal having the mechanical properties listed as follows.

FCAW Grade E80T

Tensile strength, psi (minimum)	80,000
Yield strength, psi (minimum)	65,000
Elongation in 2 in., % (minimum)	18

FCAW Grade E90T

Tensile strength, psi (minimum)	90,000
Yield strength, psi (minimum)	78,000
Elongation in 2 in., % (minimum)	17

TABLE

XI-1412.1

The mechanical properties shall be determined from a multiple-pass weld made in accordance with the test requirements of AWS A5.18, AWS A5.20, or AWS A5.28, as applicable.

Page 205

XI-1412.2 Shielding Gas.

When a gas or a gas mixture is used for shielding in gas metal-arc or flux-cored arc welding, it shall be of a welding grade having a dew point of -40°F (-4°C) or lower.

XI-1420 WELD JOINT DESIGN

Only direct butt splices and attachments to steel elements as shown in Fig. XI-1420-1 are permitted.

A *direct butt splice* is defined as a weld between two steel elements whose axes are essentially in alignment to minimize eccentricities. The steel elements are joined by a full penetration groove weld.

XI-1430 CARBON EQUIVALENT COMPUTATION AND PREHEAT AND INTERPASS REQUIREMENTS

The carbon equivalent (CE) of the heat of reinforcing bar shall be computed from the actual heat analysis using the following formula:

$$CE = \%C + (\%Mn/6) + (\%Cu/40) + (\%Ni/20) + (\%Cr/10) - (\%Mo/50) - (\%V/10)$$

Based on the calculated CE value, the minimum preheat and interpass temperatures shall be those required by Table XI-1430-1.

XI-1500 PROCEDURE QUALIFICATION REQUIREMENTS

XI-1510 GENERAL REQUIREMENTS

The procedure qualification tests shall be made on test joints which simulate the conditions to be used in production. Welding of reinforcing bar joints and reinforcing bars to steel elements shall be performed in accordance with written procedures established for each combination of specification and grade of reinforcing bar and steel elements to be welded.

XI-1520 ESSENTIAL VARIABLES

Welding procedure changes shall require requalification if an essential variable is changed. The qualification joints shall be made using a bar identical to that to be used in production. The largest bar size having the highest carbon equivalent number as determined by XI-1430 shall be used for qualification tests. For arc welding processes, the following changes shall be considered changes in essential variable.

XI-1521 Shielded Metal-Arc Welding (SMAW)

- (a) A change increasing filler metal strength level, e.g., a change from E70XX to E80XX, but not vice versa.
- (b) An increase in the diameter of the electrode used over that called for in the procedure specification.
- (c) A change of electrode amperage and/or voltage that is not within the ranges recommended by the electrode Manufacturer.
- (d) A change in position in which welding is done as defined in Fig. XI-1520-1.
- (e) A change in the type of groove, e.g., a change from a single-Vee to a double-Vee groove.
- (f) A change in the shape of any one type of groove involving the following:
 - (1) a decrease in the included angle of the groove exceeding 5 deg.;
 - (2) a decrease in the root opening of the groove exceeding $\frac{1}{16}$ in.;
 - (3) an increase in the root face of the groove exceeding $\frac{1}{16}$ in.;
 - (4) the omission, but not inclusion, of backing material.
- (g) A decrease of more than 10% in the preheat or interpass temperature. In any case, the preheat or interpass temperature shall not be less than that specified in Table XI-1430-1.
- (h) A change from uncoated to galvanized reinforcing bar.
- (i) An increase of more than one bar size.
- (j) An increase in the carbon equivalent number calculated by XI-1430.

XI-1522 Gas Metal-Arc Welding (GMAW) and Flux-Cored Arc Welding (FCAW)

(a) A change in electrode or method of shielding not covered by AWS A5.18 (GMAW), AWS A5.20 (FCAW), or AWS A5.28 (FCAW).

(b) A change increasing filler metal strength level, e.g., a change from E70S to E80S, but not vice versa.

(c) A change in electrode diameter for GMAW, or an increase in the diameter of electrode used over that called for in the procedure specification for FCAW.

(d) A change from a single gas to any other single gas or to a mixture of gases, or a change in specified composition of gas mixture not covered by AWS A5.18, AWS A5.20, or AWS A5.28.

Page 206

Page 207

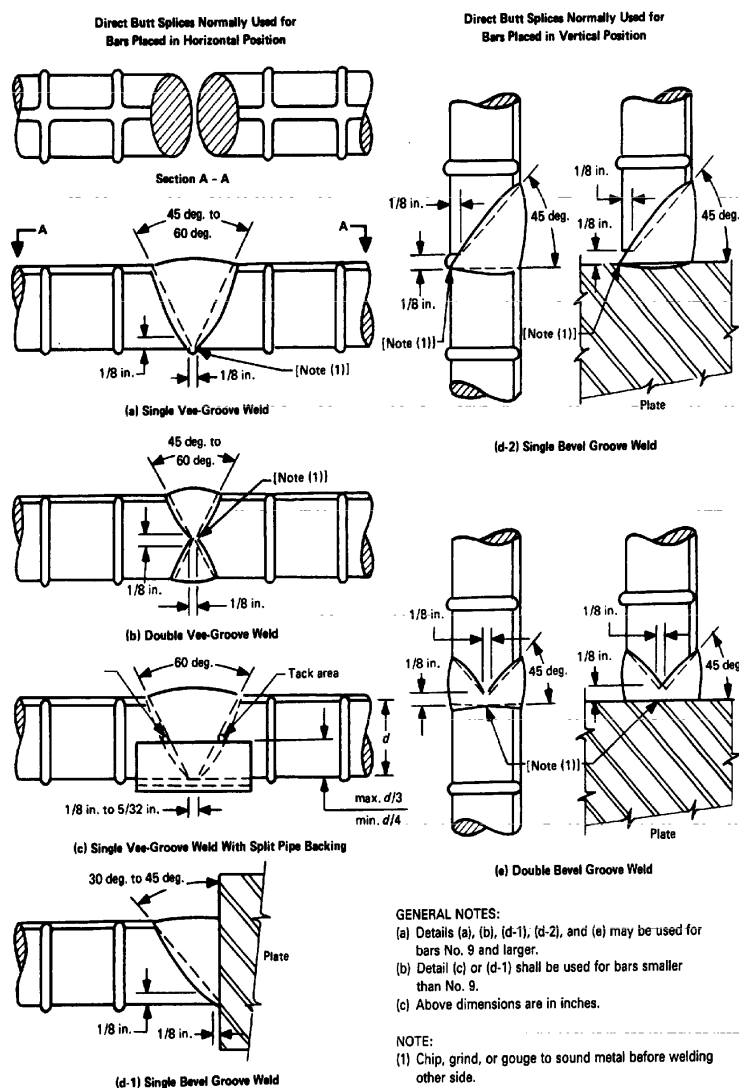


FIG. XI-1420-1 TYPICAL DIRECT BUTT SPLICES

FIG. XI-1420-1 TYPICAL DIRECT BUTT SPLICES

**TABLE XI-1430-1
MINIMUM PREHEAT AND INTERPASS REQUIREMENTS**

Carbon Equivalent Range, %	Size of Reinforcing Bar	Minimum Preheat and Interpass Temperature, °F [Notes (1)–(3)]
0.40 max.	Up to 11, incl. 14 and 18	None [Note (4)] 50
0.41–0.45, incl.	Up to 11, incl. 14 and 18	None [Note (4)] 100
0.46–0.55, incl.	Up to 6, incl. 7 to 11, incl. 14 and 18	None [Note (4)] 50 200

NOTES:

- (1) When reinforcing steel is to be welded to liner plates or other steels permitted by Table I-2.1, the preheat and interpass requirements of both steels shall be considered. The minimum preheat and interpass requirement to apply in this situation shall be the higher requirement of the two materials being joined. When welding reinforcing steel to quenched and tempered steels, the preheat and interpass requirements for both materials must be satisfied or welding shall not be used.
- (2) Welding is not permitted when the ambient temperature is lower than 0°F. When the base metal is below the temperature listed for the welding process being used and the size and carbon equivalent range of the bar being welded, it shall be preheated (except as otherwise provided) in such a manner that the cross section of the bar, for not less than 6 in. on each side of the joint, shall be at or above the specified minimum temperature. Preheat and interpass temperatures must be sufficient to prevent crack formation.
- (3) After welding is complete, bars shall be allowed to cool naturally to ambient temperature. Accelerated cooling is prohibited.
- (4) When the base metal is below 32°F, preheat the base metal to at least 70°F and maintain this minimum temperature during welding.

TABLE XI-1430-1 MINIMUM PREHEAT AND INTERPASS REQUIREMENTS

- (e) A change of more than 10% above or below the specified mean amperage for each size electrode used.
- (f) A change of more than 7% above or below the specified mean arc voltage for each size electrode used.
- (g) A change of more than 10% above or below the specified mean travel speed.
- (h) An increase of 25% or more or a decrease of 10% or more in the rate of flow of shielding gas or mixture of shielding gas.
- (i) A change in the position in which welding is done as defined in Fig. XI-1520-1.
- (j) A change in the type of groove, e.g., a change from a single-Vee groove to a double-Vee groove.
- (k) A change in the shape of any one type groove involving the following:
 - (1) a decrease in the included angle of the groove exceeding 5 deg.;
 - (2) a decrease in the root opening of a groove exceeding $\frac{1}{16}$ in. (1.6 mm);
 - (3) an increase in the root face of a groove exceeding $\frac{1}{16}$ in. (1.6 mm);
 - (4) the omission, but not inclusion, of backing material.

(l) A decrease of more than 10% in the preheat or interpass temperature specified in the welding procedure, provided the resulting preheat or interpass temperature is not less than that specified in Table XI-1430-1.

(m) A change in the type of welding current (ac or dc), polarity, or mode of metal transfer across the arc.

(n) A change from uncoated to galvanized reinforcing bar.

(o) An increase of more than one bar size.

(p) An increase in the carbon equivalent number calculated by XI-1430.

XI-1530 WELD SPECIMEN TESTING

XI-1531 Purpose of Test

The tests listed below are to determine the tensile strength and degree of soundness of welded joints made under a given procedure specification:

(a) full-section tension test (for tensile strength)

(b) macroetch test (for soundness)

XI-1532 Base Metal

The base metal and its preparation for welding shall comply with the Welding Procedure Specification.

XI-1533 Direct Butt Splices

All direct butt splices shall be classified in accordance with definitions of welding positions for groove welds

Page 208

and shall be welded in the position for which the procedure is to be qualified (see Fig. XI-1420-1).

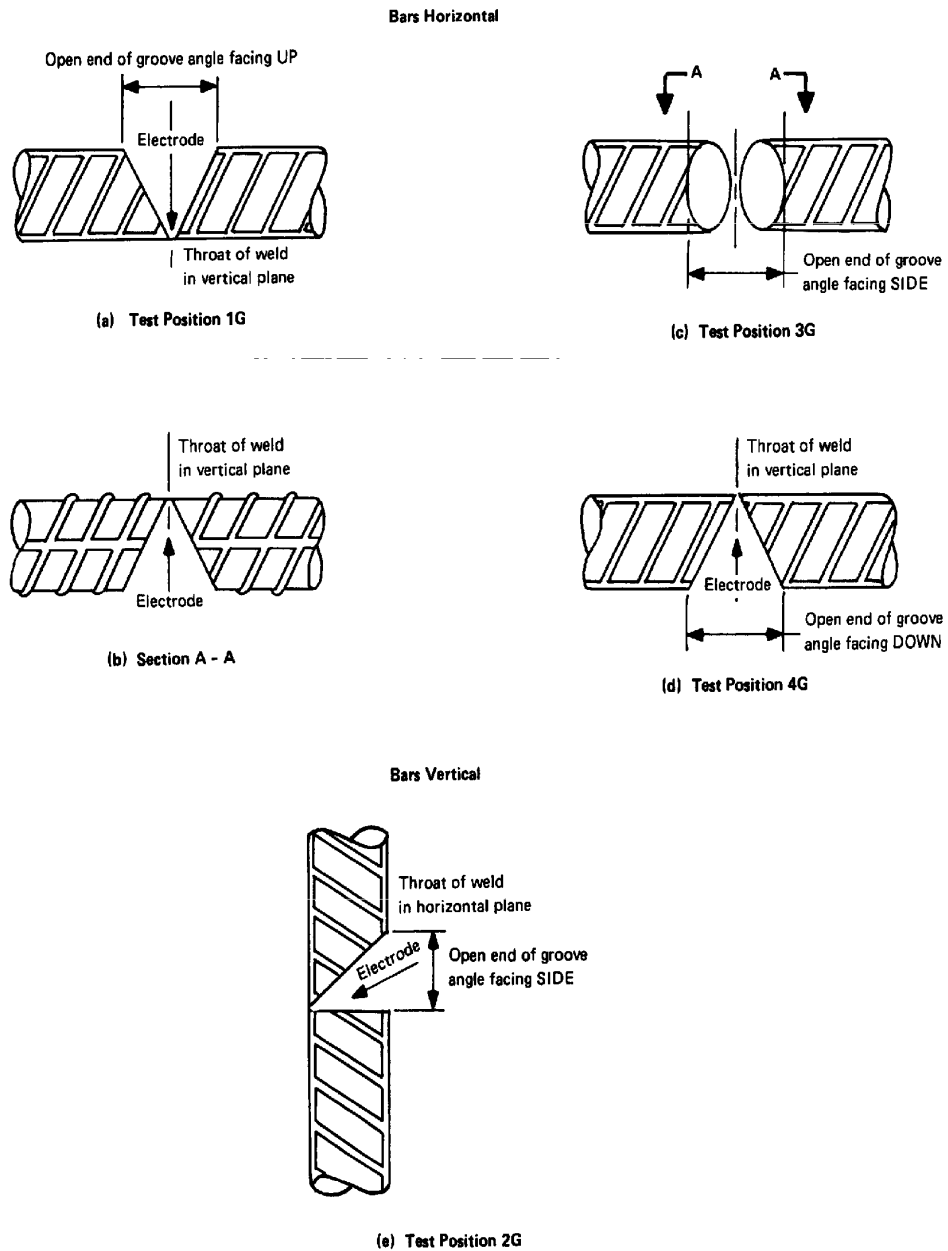
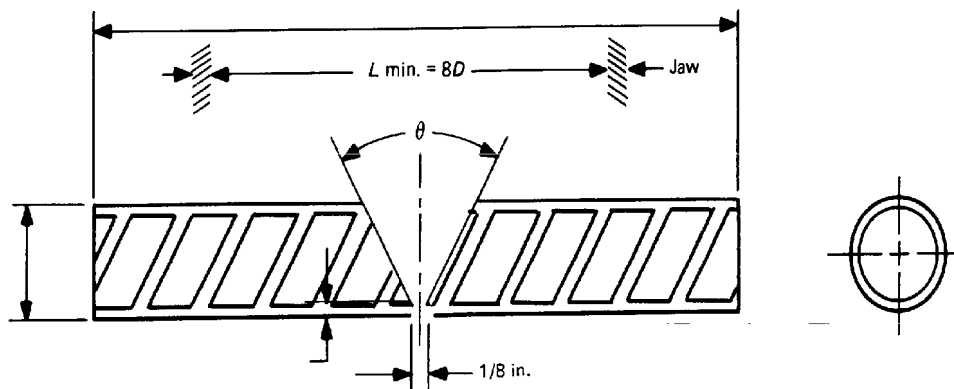


FIG. XI-1520-1 DIRECT BUTT SPLICE TEST POSITIONS FOR GROOVE WELDS

FIG. XI-1520-1 DIRECT BUTT SPLICE TEST POSITIONS FOR GROOVE WELDS



GENERAL NOTES:

- (a) For bars No. 9 or larger, use single Vee- or bevel groove weld ($\theta = 45$ deg.).
- (b) For bars No. 8 or smaller, use single Vee-groove with split pipe backing ($\theta = 60$ deg.).

FIG. XI-1530-1 COMPLETE JOINT PENETRATION GROOVE

FIG. XI-1530-1 COMPLETE JOINT PENETRATION GROOVE

XI-1534 Test Welds

Three test welds shall be made for each procedure specification to be qualified. Unless a greater length is required by the testing agency, the test weld specimens for direct butt splices shall have a minimum length of at least 16 times the diameter of the bar with the weld centrally located (see Fig. XI-1530-1). Two of the three test welds shall be subject to a full-section tensile test. The remaining test weld shall be subjected to the macroetch test.

XI-1535 Method of Testing Specimens

(a) *Full-Section Tensile Test.* The test joints shall be tensile tested in the as-welded condition, i.e., full-size welded joints without machining. The minimum distance between jaws of the testing machine shall be equal to at least eight times the diameter of the bar for direct butt splices. The test specimens shall be ruptured under tensile load. The maximum load, lb, shall be determined. The tensile strength, psi, shall be obtained by dividing the maximum load by the nominal cross-sectional area of the bar.

(b) *Macroetch Test.* The test specimens shall be mechanically cut perpendicular to the direction of welding. The section so obtained shall be polished and show the full longitudinal cross section of the weldment, the root of the weld, and any reinforcement. Etching shall be done by a suitable solution to give a clear definition of the weld.

XI-1536 Test Results Required

(a) *Full-Section Tension Test.* The tensile test results shall comply with the strength requirements of Table CB-4334-1 or Table CC-4334-1, as applicable, for the appropriate grade of reinforcing bar.

(b) *Macroetch Test.* The specimens shall be examined for imperfections and shall comply with the acceptance standards of XI-1622. The etched cross section shall show complete penetration and complete fusion with the base metal.

XI-1540 WELDER AND WELDING OPERATOR PERFORMANCE QUALIFICATION

The requirements for the initial qualification test for welders and welding operators shall be in accordance with XI-1541.

Welders and welding operators shall qualify for each type of weld to be performed by that individual during the course of the work. The completed qualification welds that are tension tested shall satisfy the tensile requirements specified in Table CB-4334-1 or Table CC-4334-1, as applicable.

Page 210

XI-1541 Limitation of Variables

Qualifications established with any of the reinforcing steels shall be considered as qualification to weld any of the other reinforcing steels within the essential variables. Separate qualifications, without reciprocal validity, shall be required for galvanized and uncoated steels. A welder or welding operator shall be qualified for each process to be used in production. A welder or welding operator qualified with an approved electrode and shielding medium combination shall be considered qualified to weld with any other approved electrode and shielding medium combination (see Table XI-1410-1) for the process used in the qualification test. A change in the position of welding to a position for which the welder is not already qualified shall require requalification of the welder or welding operator.

XI-1542 Qualification Tests Required

The qualification test joint shall be a full penetration groove weld made by the SMAW, GMAW, or FCAW process with a single-Vee groove or bevel groove (see Fig. XI-1530-1). Welding on No. 9 bar shall qualify a welder or welding operator for welding all bars greater than No. 9 within the essential variables. If bars smaller than No. 9 are to be welded, the welder or welding operator shall qualify on the smallest bar size to be welded. For bars smaller than No. 9, split pipe backing shall be used (see Fig. XI-1420-1).

XI-1543 Position of Test Welds and Validity of Qualification for Direct Butt Splice Groove Weld Tests

(See Fig. XI-1520-1)

- (a) Qualification in the 1G (flat) position qualifies for welding in the 1G position only.
- (b) Qualification in the 2G (horizontal) position qualifies for welding in the 1G and 2G positions.
- (c) Qualification in the 3G (vertical) position qualifies for welding in the 1G, 2G, and 3G positions.
- (d) Qualification in the 4G (overhead) position qualifies for direct butt welding in the 1G and 4G positions.
- (e) Qualification in the 1G and 2G positions qualifies for welding in the 1G position for diagonal bars.
- (f) Qualification in the 2G and 3G positions qualifies for welding in the 3G position for diagonal bars.

XI-1544 Base Metal

The base metal used shall comply with CB-2310 or CC-2310, as applicable.

XI-1545 Welding Procedure

The welder or the welding operator shall follow the Welding Procedure Specification.

XI-1546 Test Specimens - Number, Type, and Preparation

For each test there shall be two test assemblies welded in accordance with XI-1540 to qualify each welder or welding operator.

Test assemblies welded by GMAW (except short circuiting transfer), SMAW, or FCAW shall be tested by radiography, or one test assembly shall be subjected to the full-section tensile test and the other test assembly to the macroetch test. Direct butt splice test assemblies welded by GMAW short-circuiting transfer methods shall have one test assembly subjected to the full-section tension test and the other to the macroetch test.

Unless a greater length is required by the testing agency, the full-section tension test specimens shall have a minimum length of at least 16 times the diameter of the bar with the weld centrally located (see Fig. XI-1530-1).

XI-1547 Method of Testing Specimens

(a) *Full-Section Tension Test.* The test joints shall be tensile tested in the as-welded condition, i.e., full-size welded joints without machining. The minimum distance between jaws of the testing machine shall be equal to at least eight times the diameter of the bar for direct butt splices. The test specimens shall be ruptured under tensile load. The maximum load, lb, shall be determined. The tensile strength, psi, shall be obtained by dividing the maximum load by the nominal cross-sectional area of the bar.

(b) *Macroetch Test.* The test specimens shall be mechanically cut perpendicular to the direction of welding. The section so obtained shall be polished and show the full longitudinal cross section of the weldment, the root of the weld, and any reinforcement. Etching shall be done by a suitable solution to give a clear definition of the weld.

XI-1548 Test Results Required

(a) *Radiographic Examination.* For acceptable qualification, the weld shall meet the acceptance standards of XI-1622.

(b) *Full-Section Tension Test.* The tension test results shall comply with the strength requirements of Table CB-4334-1

Page 211

or Table CC-4334-1, as applicable, for the appropriate grade of reinforcing bar.

(c) *Macroetch Test.* The specimens shall be examined for imperfections and shall meet the acceptance standards of XI-1622. The etched cross section shall show complete penetration and complete fusion with the base metal.

XI-1549 Retests

If a welder or welding operator fails to meet the qualification requirements of one or more test welds, a retest may be allowed under the following conditions.

(a) An immediate retest may be made consisting of two test welds of each type on which the welder or welding operator failed. All test specimens shall meet all requirements for all such welds.

(b) A retest may be made provided there is evidence that the welder or welding operator has had further training or practice. A complete retest shall be made in this case.

(c) If the Inspector has reason to doubt the qualifications of a welder or welding operator, he may require retest.

XI-1550 PERIOD OF EFFECTIVENESS

The welder's or welding operator's qualifications specified in this Code shall remain in effect indefinitely unless:

(a) the welder or welding operator is not engaged in a given process of welding for which he is qualified for a period exceeding 6 months;

(b) there is some specific reason to question a welder's or welding operator's ability.

XI-1551 Records

Records of the test results shall be kept by the Constructor or Fabricator and shall be available to those authorized to examine them.

XI-1560 CONTINUING JOINT PERFORMANCE TESTS

XI-1561 Introduction

A continuing series of tests shall be made to ensure joints meet the tensile requirements. Nondestructive examination requirements are specified in XI-1600.

XI-1562 Joint Samples

Joint samples may be production joints (i.e., cut directly from in-place reinforcement) or sister joints (i.e., removable joints made in place next to production joints and under the same conditions).

XI-1563 Testing Frequency

Separate test cycles shall be established for joints in horizontal, vertical, and diagonal bars as follows.

XI-1563.1 Production Joints.

If only production joints are tested, the sample frequency shall be as follows:

- (a) 1 of the first 10;
- (b) 1 of the next 90;
- (c) 2 of the next and each subsequent unit of 100.

XI-1563.2 Production and Sister Joints.

If production and sister joints are tested, the sample frequency shall be as follows:

- (a) 1 production joint of the first 10 production joints;
- (b) 1 production and 3 sister joints for the next 90 production joints;
- (c) 1 joint, either production or sister joint, for all subsequent units of 33 joints.

At least one-fourth of the total number of joints tested shall be production joints.

XI-1563.3 Sister Joints.

Straight sister joints shall be substituted for production samples or radius bent bars and for bars arc welded to structural steel elements or the liner.

XI-1564 Tensile Testing Requirements

Joint samples shall be tensile tested using the loading rates set forth in SA-370. The following shall constitute the acceptance standards.

- (a) The tensile strength of each sample shall equal or exceed 125% of the specified yield strength as shown in Table CB-4334-1 or Table CC-4334-1, as applicable.
- (b) The average tensile strength of each group of 15 consecutive samples shall equal or exceed the specified minimum tensile strength as shown in Table CB-4334-1 or Table CC-4334-1, as applicable.
- (c) If any sample joint tested fails to meet the provisions of (a) or (b) above, requirements of XI-1565 shall be followed.

Page 212

XI-1565 Substandard Tensile Test Results

(a) If any production or sister joint used for testing fails to meet the strength requirement of Table CB-4334-1 or Table CC-4334-1, as applicable, and failure occurs in the bar, the cause of the bar break shall be investigated by the Constructor or Fabricator. Any necessary corrective action affecting joint samples shall be implemented prior to continuing the testing frequency of XI-1563.

(b) If any production joint used for testing fails to meet the strength requirement of Table CB-4334-1 or Table CC-4334-1, as applicable, and failure does not occur in the bar, the adjacent production joints on each side of the failed joint shall be tested. If any sister joint used for testing fails to meet the strength requirement of Table CB-4334-1 or Table CC-4334-1, as applicable, and failure does not occur in the bar, two additional sister joints shall be tested. If either of these joints fails to meet the strength requirement of Table CB-4334-1 or Table CC-4334-1, as applicable, welding shall be halted. Welding shall not be resumed until the cause of failures has been corrected.

(c) If the running average tensile strength of 15 consecutive joints fails to meet the strength requirement of Table CB-4334-1 or Table CC-4334-1, as applicable, welding shall be halted. The Constructor or Fabricator shall investigate the cause and make the necessary corrective action.

(d) When welding is resumed, the testing frequency shall be started anew.

XI-1570 RECORDING OF TENSILE TEST RESULTS

The results of all tensile tests obtained from the tests prescribed by XI-1530, XI-1540, and XI-1560, along with all other pertinent data, shall be recorded.

XI-1600 EXAMINATION OF WELDED JOINTS OF REINFORCING BAR

XI-1610 VISUAL EXAMINATION

All completed arc welded joints shall be visually examined for the presence of cracks, undercut, inadequate size, and other visible defects. Welds exhibiting such defects shall be repaired.

**TABLE XI-1620-1
RADIOGRAPH ACCEPTANCE CRITERIA**

Bar Size	Sum of Discontinuity Dimensions, in.	Single Discontinuity Dimension, in.
8	$\frac{3}{16}$	$\frac{1}{8}$
9	$\frac{3}{16}$	$\frac{1}{8}$
10	$\frac{1}{4}$	$\frac{1}{8}$
11	$\frac{1}{4}$	$\frac{3}{16}$
14	$\frac{5}{16}$	$\frac{3}{16}$
18	$\frac{7}{16}$	$\frac{1}{4}$

TABLE XI-1620-1 RADIOGRAPH ACCEPTANCE CRITERIA

XI-1620 RADIOGRAPHIC EXAMINATION

XI-1621 Extent and Procedure Requirements

One joint selected at random from each 25 direct butt production joints made by each welder shall be radiographed from two mutually perpendicular directions. The radiographic examination procedure shall be in accordance with Article 2 of Section V. Ultrasonic examination and inspection may be performed where radiographic examinations are not practical. If ultrasonic examination is used, the examination shall be in accordance with Article 5 of Section V.

XI-1622 Acceptance Standards

Welds shall be free of any type of crack or zone of incomplete fusion or penetration. All craters shall be filled to the full cross section of the weld.

Direct butt splices inspected by radiography shall have a maximum dimension of any single porosity or fusion type discontinuity or the sum of the maximum dimensions of all porosity or fusion type discontinuities not exceeding the limits given in Table XI-1620-1.

Undercutting deeper than $\frac{1}{32}$ in. (0.8 mm) shall not be allowed, regardless of the direction of stress, except that at points where welds intersect the raised pattern of deformations, undercutting less than $\frac{1}{16}$ in. (1.6 mm) deep shall be acceptable. Welds shall be free of all overlaps.

Welds that are shown by radiography to have any of the following types of discontinuities are unacceptable:

- (a) any zone of incomplete fusion, crack, or lack of penetration;
- (b) any other indication which is greater than the limits of Table XI-1620-1.

Page 213

XI-1623 Reexamination

(a) If any of the welded joints are found unacceptable, they shall be replaced and reexamined. Two additional joints from the same group, preferably one on either side of the unacceptable joint, shall also be subject to radiographic examination. If these joints meet the acceptance criteria, all of the remaining joints out of that group of 25 shall be considered acceptable, subject to continuous requalification tests.

(b) If any of the additional joints do not meet the acceptance criteria, all remaining joints of that group shall be reexamined and any unacceptable joints shall be rejected. The operator shall then be requalified in accordance with XI-1540.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 NMA APP C

APPENDIX C TYPICAL CRV LOAD COMBINATIONS (OPTIONAL)

Page 215

ARTICLE C-1000 TYPICAL LOAD COMBINATIONS

A typical CRV load combination example is presented in this Appendix. The notation used is that of Appendix III.

Construction

$$D_{we} + L_c + F_i$$
$$D_{weir} + L_c + F_i + P_i + T_t$$

Normal

$$D_{weir} + L_m + F_t + T_o$$
$$D_{weir} + L_m + F_t + T_o + P_o$$
$$D_{weir} + L_m + F_t + T_o + P_v$$

Abnormal

$$D_{weir} + L_m + F_t + T_o + P_m$$

$$D_{weir} + L_m + F_t + T_a + P_o$$

Severe Environmental

$$D_{weir} + L_m + F_t + T_o + P_o + E_o$$

$$D_{weir} + L_m + F_t + T_o + E_o$$

Extreme Environmental

$$D_{weir} + L_m + F_t + T_o + P_o + E_{ss}$$

$$D_{weir} + L_m + F_t + T_o + E_{ss}$$

$$D_{weir} + L_m + F_t + T_a + P_o$$

Failure

$$D_{wir} + L_m + F_t + P_{mc}$$

$$D_{wir} + L_m + F_t + T_m$$

$$D_{weir} + L_m + F_t + T_o + Y_{jr}$$

$$D_{weir} + L_m + F_t + T_o + P_m + E_{ss}$$

$$D_{weir} + L_m + F_t + Y_{jr} + E_{ss}$$

$$D_{weir} + L_m + 0.5F_t + P_o + T_o$$

NOTE: In the above notation, multiple subscripts on D and Y indicate a combination of the loads represented by all subscripts: for example, D_{we} represents D_w plus D_e .

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 NMA APP D

APPENDIX D NONMANDATORY PREHEAT PROCEDURES

Page 221

ARTICLE D-1000 NONMANDATORY PREHEAT PROCEDURES

D-1100 INTRODUCTION

D-1110 SCOPE

The preheat temperatures given herein are a general guide for the materials listed in P-Numbers of Section IX. Specific rules for preheating are not given, and the minimum preheating temperatures suggested are not mandatory. The Welding Procedure Specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.¹

D-1120 TEMPERATURE MAINTENANCE

(a) Difficulty may be experienced with certain materials if the temperature is allowed to fall below the preheat temperature between passes. It may be desirable to maintain the preheat temperature or to heat the joint to the postweld treatment temperature before allowing it to cool to ambient temperature.

¹ These requirements do not apply to the arc welding of reinforcing bar, the requirements for which are given in XI-1560.

(b) The preheat temperature may be checked by suitable methods, such as temperature-indicating crayons or thermocouple pyrometers, to ensure that the required preheat temperature is maintained during the welding operation. The Fabricator or Constructor should be cautious in the use of temperature-indicating crayons and pellets because some metals may be severely attacked by the chemicals in crayons or pellets at elevated temperatures.

D-1200 FERROUS MATERIAL

D-1210 PREHEAT TEMPERATURES

D-1211 Group P-No. 1

A temperature of 175°F (79°C) is suggested for material which has both a specified maximum carbon content in excess of 0.30% and a thickness in excess of 1 in. (25 mm) This does not apply to fillet welds $\frac{1}{2}$ in. (13 mm) and under in size that are used to attach parts not carrying loadings due to internal pressure. For all other material in this group, 50°F (10°C) is suggested.

It is suggested that stud welding be performed at not less than 0°F (-18°C).² When the ambient temperature is less than 32°F (0°C), it is suggested that the stud welding procedure be tested at the start of each day's production welding period. Testing shall be done by bend testing of two studs to an angle of 15 deg. and returning to their original position.

D-1212 Group P-No. 8

No preheat temperatures are suggested.

² This temperature (0°F) does not mean the ambient environmental temperature but the temperature in the immediate vicinity of the weld. The ambient environmental temperature may be below 0°F, but a heated structure or shelter around the area being welded could maintain the temperature adjacent to the weldment at 0°F or higher.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 NMA APP E

APPENDIX E CERTIFICATION OF LEVEL I AND II CONCRETE INSPECTION PERSONNEL

Page 223

ARTICLE E-1000 INTRODUCTION

E-1100 OBJECTIVE OF CERTIFICATION PROGRAM

The objective of this Appendix is to provide a guide for use by Constructors and Fabricators in the training, evaluation, and certification of Level I and II concrete inspection personnel. Uniformity of duties, training, and evaluation is helpful in facilitating review by the Owner, Authorized Inspectors, regulatory agencies, or independent groups. The contents of this Appendix constitute recommendations and are nonmandatory. The certification program for concrete inspection and testing personnel is designed to provide assurance that personnel have the appropriate technical knowledge, skill, and experience to properly perform the required tests and inspections. Appendix VII presents the Code requirements for qualifications of concrete inspection personnel.

E-1200 ORGANIZATION

The total program includes the following:

- (a) description of duties and responsibilities of concrete inspection and testing personnel;
- (b) determination of the knowledge and skill requirements to perform the duties assigned;

- (c) formulation of the classroom training program and the on-the-job training program;
- (d) provision of a method of verifying that a person has the knowledge and skill to properly perform concrete inspection operations;
- (e) certification of concrete inspection and testing personnel.

E-1300 IMPLEMENTATION

The Constructor or Fabricator has the responsibility for the qualification and certification of concrete inspection and testing personnel. The work of establishing training practices and certification procedures, and providing the resources in terms of personnel, equipment, and services necessary to implement the program may be delegated to other organizations. These inspection personnel are certified as Levels I, II, and III in ascending order of responsibility. The qualification and certification of the Level I and II concrete inspection personnel are under the supervision and control of the Level III Concrete Inspector. The Level III Concrete Inspector has the following duties with regard to certification of Level I and II concrete inspection personnel:

- (a) development of training programs;
- (b) development of evaluation programs;
- (c) preparing and giving examinations;
- (d) certification of concrete inspection and testing personnel.

The Constructor or Fabricator shall conduct a training program, examine his personnel, and certify their qualifications to perform tests and inspections or, alternatively, he may have his personnel trained by others in a school or by taking courses of training; however, the responsibility for certification shall rest with the Constructor or Fabricator and shall be performed by a certified Level III Concrete Inspector who may be his employee or an employee of an outside organization under contract to the Constructor or Fabricator, as applicable.

ARTICLE E-2000 LEVEL I CONCRETE INSPECTION TECHNICIAN

E-2100 GENERAL

A Level I Concrete Inspection Technician should have experience in and shall have satisfactorily completed appropriate training and passed an examination in concrete inspection and testing. He should be familiar with test equipment to be used and should be able to

Page 224

demonstrate proficiency in the use of this equipment. Appendix VII presents the Code requirements for education, experience, and work functions assigned to Level I Concrete Inspection Technicians.

E-2200 ASSIGNMENT AND DESCRIPTION OF DUTIES

The assignment of duties is the responsibility of the Constructor or Fabricator as different organizations and construction projects will require various combinations of functions. It is important that the classroom and on-the-job training, evaluation, and certification match the duties assigned.

E-2210 DESCRIPTIONS OF DUTIES

Two basic Level I descriptions are developed: one for a Reinforcing Material Technician, and the other for a Concrete Material Technician.

E-2211 Reinforcing Material Technician

- (a) Performs receiving and storage inspection of metallic materials used in concrete construction. These include reinforcing steel, embedments, mechanical splice kits, post-tensioning embeds, post-tensioning anchorage components, metallic parts, welding materials, and liner plate materials.

(b) Inspects the installation of mechanical splices, including void determinations, torque values, or other specified criteria.

(c) Performs tensile and bend testing of reinforcing steel.

(d) Performs tensile testing of mechanical splices.

(e) Prepares reports that give the results of the above inspections and tests.

E-2212 Concrete Material Technician

(a) Performs receiving and storage inspection of materials used in the production of concrete. These include materials such as cement, admixtures, and aggregates.

(b) Conducts routine field tests on fresh concrete, such as slump, air content, unit weight, temperature, and preparation of test cylinders.

(c) Inspects finishing, curing, and patching.

(d) Conducts routine jobsite laboratory tests, such as gradation, moisture content, and compressive strength.

(e) Prepares reports that give the results of the above inspections and tests.

ARTICLE E-3000 LEVEL II CONCRETE INSPECTOR

E-3100 GENERAL

A Level II Concrete Inspector should have experience in and shall have satisfactorily completed appropriate training and passed an examination in concrete inspection and testing and in the review and evaluation of the results of the inspection and tests. He shall be capable of supervising or maintaining surveillance over the inspections and tests performed by others and of calibrating or establishing the validity of calibration of testing equipment. He shall have demonstrated proficiency in planning and setting up tests and shall be capable of determining the validity of test results. A Level II Concrete Inspector may also function as a Level I Concrete Inspection Technician in areas in which he is qualified. Appendix VII presents the Code requirements for education, experience, and work functions assigned to Level II Concrete Inspectors.

E-3200 DESCRIPTION OF DUTIES

The duties of the Level II Concrete Inspector involve inspections and tests that are more complex than those performed by a Level I Concrete Inspector. He is required to evaluate and interpret specifications, codes, procedures, documents, tests, and inspection reports. His supervisory duties for Level I personnel include analysis, review, and approval of the reports prepared by Level I Concrete Inspection Technicians.

E-3210 DESCRIPTIONS OF DUTIES

Descriptions of four Level II Concrete Inspectors have been developed and follow. The two basic descriptions suggested are a Preplacement Inspector and a Batching and Placement Inspector. The two specialty descriptions suggested are a Prestressing Systems Inspector and a Laboratory Tester.

E-3211 Preplacement Inspector

(a) Inspects the placement of reinforcing steel, embedments, prestressing bearing plates, tendon ducts, and trumpets for precast and cast-in-place concrete.

(b) Inspects construction joints, water stops, and form work for precast and cast-in-place concrete.

(c) Prepares and interprets reports.

(d) Supervises Level I Reinforcing Material Technician.

E-3212 Batching and Placement Inspector

- (a) Inspects off-site or on-site batching plants.
- (b) Inspects concrete placing equipment, concrete placement, and consolidation for precast and cast-in-place concrete.
- (c) Inspects structural repairs of concrete.
- (d) Prepares and interprets reports.
- (e) Supervises Level I Concrete Material Technician.

E-3213 Prestressing Systems Inspector

- (a) Inspects such activities as insertion, stressing, anchoring, and greasing of prestressing systems.
- (b) Prepares and interprets reports.

E-3214 Laboratory Tester

- (a) Conducts specialized physical laboratory tests, such as shrinkage, creep, and trial batches for concrete, and physical tests for cement.
- (b) Prepares and interprets reports.

ARTICLE E-4000 TRAINING

E-4100 GENERAL

The requirements for Level I and II concrete inspection and testing personnel include a training course covering job related duties. The classroom training providing the facts and knowledge needed for the job should be supplemented by an on-the-job training program to perfect the practical skills necessary to do the work.

E-4110 CLASSROOM TRAINING

Lecture courses should describe the total quality assurance organization and the way each functional organization, i.e., engineering, purchasing, management, works in the implementation of the program. Inspection and testing personnel should be trained in nonconformance reporting, document control, general calibration, and related quality procedures. In addition, the Code requirements applying to their duties should be covered. The duties of the Authorized Inspector and his relationship with concrete inspection personnel should be included in the training course.

E-4200 SUGGESTED CLASSROOM TRAINING COURSES

The training should correspond to the duties assigned to testing and inspection personnel. On the basis of the illustrated Level I and Level II descriptions, suggested classroom hours are shown as indicated below. These hours are based upon typical training times and classes and may be modified to cover class content and needs of their specific assignment. The following classroom training courses are suggested.

E-4210 LEVEL I REINFORCING MATERIAL TECHNICIAN (10 TO 20 hr OF INSTRUCTION)

E-4211 Introduction

- (a) Experience in the use of concrete in nuclear power plants
- (b) Quality requirements for concrete used in reactors and containments
- (c) Basic inspection required for concrete
- (d) Relationships of jurisdictional authorities, Owner, Designer, Constructor, Fabricator, and regulatory agencies

E-4212 Shipping, Receiving, and Storage of Metallic Materials

- (a) Certified Material Test Reports/Certificate of Compliance
- (b) Identification and tagging
- (c) Shipping damage
- (d) Documentation
- (e) Inspection requirements
- (f) Storage requirements
- (g) In-process tests
- (h) Nonconformance procedures

E-4213 Inspection of Mechanical Splices

- (a) Cleanliness of the prepared ends
- (b) Centering
- (c) Assembly of splices
- (d) Inspection of completed splice assembly
- (e) Tension tests of splices as required

E-4214 Arc Welding of Reinforcing Steel

A training course on visual inspection of welding and control of weld filler materials should be provided where welding of reinforcing steel is specified.

Page 226

E-4215 Reports

- (a) Receiving inspection reports
- (b) Splice assembly reports
- (c) Tensile test reporting
- (d) Checklists or quality assurance reports

E-4220 LEVEL I CONCRETE MATERIAL TECHNICIAN (20 TO 40 hr OF INSTRUCTION)

E-4221 Introduction

- (a) Experience in the use of concrete in nuclear power plants
- (b) Quality requirements for concrete used in reactors and containments
- (c) Basic inspection required for concrete
- (d) Relationships of jurisdictional authority, Owner, Designer, Constructor, Fabricator, and regulatory agencies

E-4222 Shipping, Receiving, and Storage of Concrete Materials

- (a) Certified Material Test Reports

- (b) Identification and tagging
- (c) Shipping damage
- (d) Documentation
- (e) Inspection requirements
- (f) Storage requirements
- (g) In-process tests
- (h) Nonconformance procedures

E-4223 Field Tests on Fresh Concrete

- (a) Sampling
- (b) Slump test
- (c) Entrained air
- (d) Unit weight
- (e) Preparation, handling, and storage of concrete cylinders
- (f) Temperature

E-4224 Laboratory Tests

- (a) Sampling
- (b) Sieve analysis
- (c) Moisture content
- (d) Deleterious substances
- (e) Specific gravity
- (f) Compressive strength and curing of concrete cylinders
- (g) Reinforcing steel tensile tests (may also be a Reinforcing Material Technician function)

E-4225 Post-Placement

- (a) Finishing
- (b) Patching
- (c) Curing

E-4226 Reports

- (a) Receiving inspection reports
- (b) Fresh concrete reports
- (c) Laboratory reports
- (d) Post-placement reports
- (e) Checklists or quality assurance reports

E-4230 LEVEL II BATCHING AND PLACEMENT INSPECTOR

(20 TO 40 hr OF INSTRUCTION)

E-4231 Introduction

- (a) Code requirements for concrete, Construction Specifications, and the Construction Report
- (b) Basic inspection plans, procedures, and checklists
- (c) The Authorized Inspection Agency and the duties of the Authorized Inspector
- (d) Coordination of the inspection with the Authorized Inspector

E-4232 Concrete Batching

- (a) Moisture compensation and mix adjustment
- (b) Storing and conveying of materials
- (c) Batching and weighing of materials
- (d) Control of slump, air content, and temperature
- (e) Documentation

E-4233 Transportation and Placement of Concrete

- (a) Transportation equipment
- (b) Placement equipment
- (c) Concrete placement
- (d) Consolidation
- (e) Initial curing

E-4234 Structural Repairs of Concrete

- (a) Detection of areas to be repaired
- (b) Removal of unsatisfactory materials
- (c) Surface preparation

Page 227

- (d) Concrete placement and curing

E-4235 Supervision of Level I Personnel

- (a) Concrete Material Technician duties
- (b) Documentation and report review
- (c) On-the-job training

E-4236 Reports

- (a) Checklists or quality assurance reports
- (b) Batch plant weigh quantity tickets

E-4240 LEVEL II PREPLACEMENT INSPECTOR (10 TO 20 hr OF INSTRUCTION)

E-4241 Introduction

- (a) Code requirements for reinforcing systems, Construction Specifications, and the Construction Report
- (b) Basic inspection plans, procedures, and checklists
- (c) The Authorized Inspection Agency and the duties of the Authorized Inspectors
- (d) Coordination of the inspection with the Authorized Inspector

E-4242 Reinforcing Systems

- (a) Reinforcing steel, size, grade, spacing, and splice locations
- (b) Embedments
- (c) Prestressing systems bearing plates, trumpets, and tendon ducts

E-4243 Formwork

- (a) Alignment, dimensions, bracing, and shoring
- (b) Construction joints, water stops, and joint details
- (c) Cleanliness and form release

E-4244 Supervision of Level I Personnel

- (a) Reinforcing Material Technician duties
- (b) Documentation and report review
- (c) On-the-job training

E-4245 Reports

- (a) Checklists or quality assurance reports
- (b) Preplacement reports

E-4250 LEVEL II PRESTRESSING SYSTEMS INSPECTOR (20 TO 40 hr OF INSTRUCTION)

E-4251 Introduction

- (a) Code requirements for prestressing systems, Construction Specification, and the Construction Report
- (b) Basic inspection plans, procedures, and checklists
- (c) The Authorized Inspection Agency and the duties of the Authorized Inspector
- (d) Coordination of the inspection with the Authorized Inspector

E-4252 Prestressing Systems

- (a) Background and theory
- (b) Comparison of systems
- (c) Assemblies

E-4253 Field Operations and Inspection

- (a) Insertion
- (b) Assembling anchorage components
- (c) Stressing
- (d) Greasing
- (e) Corrosion protection
- (f) Grouting

E-4254 Documentation

- (a) Tendon cards and identification
- (b) Stress-strain recorders
- (c) Checklists or quality assurance reports
- (d) Friction-elongation

E-4260 LEVEL II LABORATORY TESTER (20 TO 60 hr OF INSTRUCTION)

E-4261 Introduction

- (a) Code requirements for concrete
- (b) The Authorized Inspection Agency and the duties of the Authorized Inspector
- (c) Audit responsibilities of the Constructor or Fabricator
- (d) Calibration, documentation, and traceability
- (e) Report preparation

The following is a partial list of tests that may be performed in the laboratory. Training should cover these tests to be performed.

Page 228

E-4262 Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate ASTM C 88

- (a) Scope and apparatus
- (b) Sampling and preparation of samples
- (c) Procedure
- (d) Quantitative examination and report

E-4263 Standard Test Method for Resistance to Degradation of Small Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine ASTM C 131

- (a) Scope and apparatus
- (b) Test sample and abrasive change
- (c) Procedure

(d) Calculation and report

**E-4264 Standard Test Method for Length Change of Hardened Cement Mortar and Concrete
ASTM C 157**

(a) Scope and apparatus

(b) Mixing and molding of specimens

(c) Curing and storage of specimens

(d) Measurement of specimens and report

**E-4265 Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate
Combinations (Mortar-Bar Method)
ASTM C 227**

(a) Scope and apparatus

(b) Mixing and molding of specimens

(c) Storage and measurement of specimens

(d) Examination and calculations

(e) Repeatability, interpretation, and reports

**E-4266 Standard Test Method for Potential Reactivity of Aggregates (Chemical Method)
ASTM C 289**

(a) Scope and apparatus

(b) Selection and preparation of test samples

(c) Dissolved silica by gravimetric method

(d) Dissolved silica by photometric method

(e) Reduction of alkalinity

(f) Repeatability, interpretation, and reports

E-4267 Static Modulus of Elasticity and Poisson's Ratio

(a) scope and apparatus

(b) Procedure and precision

(c) Calculations and reports

E-4268 Laboratory Trial Batches

(a) Scope and apparatus

(b) Moisture control of aggregates

(c) Mixing and molding specimens

(d) Curing and storage of specimens

(e) Tests and reports

E-4269 Physical Tests of Cement

- (a) Fineness
- (b) Time of set
- (c) Air content
- (d) Strength
- (e) Soundness
- (f) Optional physical requirements

E-4270 Physical Tests of Fly Ash and Pozzolans

- (a) Fineness
- (b) Loss on ignition
- (c) Pozzolanic activity index
- (d) Drying shrinkage of mortar bar
- (e) Uniformity requirements
- (f) Reactivity with cement alkalies

E-4300 ON-THE-JOB TRAINING

An on-the-job or laboratory training program should be used to instruct personnel in the practical skills and knowledge necessary for the job. Personnel in a training status should only perform tests or inspections under the direct supervision of certified Level I or II inspection personnel who are present where the work is being performed. The certified person shall prepare and sign reports concerning tests and inspection performed by personnel in a training status. Actual length of on-the-job training for each candidate should be set by the Level III Concrete Inspector.

Page 229

ARTICLE E-5000 EVALUATION

E-5100 EVALUATION

Evaluation should include a written examination, performance demonstration (if applicable), review of education and experience, and periodic performance appraisal.

E-5200 EXAMINATION

The Code requires that all inspection personnel satisfactorily complete an examination prior to certification. Proof of the examination and test results should be maintained. The adequacy of the examination for Level I and II personnel is the responsibility of the certified Level III Concrete Inspector. It is recommended that the evaluation include general questions, specific questions, and (if applicable) a performance demonstration.

E-5210 GENERAL QUESTIONS

General questions should be taken from the classroom course work and should reflect knowledge of the applicable portions of the Code, ACI Standards, ASTM Standards, and typical construction practices. General questions cover the background knowledge necessary to understand the purpose and evaluation of tests and inspections.

E-5220 SPECIFIC QUESTIONS

Specific questions should be taken from the actual tests and inspections to be performed by Level I or II personnel in their work. This testing should be based upon operational and test procedures and should emphasize the knowledge needed to perform tests and inspections properly.

E-5230 PERFORMANCE DEMONSTRATIONS

A performance demonstration should be used (if applicable) to determine the ability to handle test equipment and to perform the required inspections. The objective of the demonstration is to assess the actual hands-on performance of tests or inspections. Performance may be evaluated in a simulated environment or on the jobsite. The demonstration should be scored by subdividing the detailed steps or components of the test and evaluating the applicant upon his performance of each step. A typical test or inspection can generally be subdivided into at least ten detailed steps for scoring.

E-5300 SCOPE OF THE EVALUATION

It is the responsibility of the Level III Concrete Inspector to select questions and prepare the examination. He shall administer and conduct the examination and the performance demonstration. The scoring and length of examination will be dependent upon the extent of the duties and the responsibilities to be assigned. For Level I examinations, it is suggested that the breakdown be approximately 20% for general questions, 30% for specific questions, and 50% for the performance demonstration. For Level II, the percent given for the performance demonstration might be reduced and more weight given to general and specific questions. It is recommended that the percent given to the performance demonstration for any evaluation not exceed 50% of the total score. The overall pass-fail score line should be set at 70% with no individual score less than 60%.

A typical examination for the descriptions outlined in paragraphs E-2200 and E-3200 may have up to 40 multiple-choice closed-book general questions, up to 30 multiple-choice open-book specific questions, and 2 or more performance demonstrations. The general and specific portions of a typical examination might require up to 2 hr and the practical demonstration up to 2 hr.

E-5400 TYPICAL QUESTIONS

To illustrate a typical evaluation, four sample questions have been prepared for the Level I Concrete Material Technician.

E-5410 GENERAL QUESTIONS

E-5411 After cold weather protection is removed, the concrete should be:

- (a) allowed to cool rapidly;
- (b) protected from freezing;
- (c) allowed to cool gradually;
- (d) kept moist for 7 days.

Page 230

E-5412 Water curing, rather than other methods, is specified for mass concrete in warm weather because it can:

- (a) provide rapid curing;
- (b) prevent surface drying;
- (c) harden the surface;
- (d) aid in dissipating the heat of hydration.

E-5420 SPECIFIC QUESTIONS

E-5421 Using normal concrete mixes in weather above 40°F, concrete should be cured for a minimum of:

- (a) 5 days of membrane cure;

- (b) 7 days kept in a moist condition;
- (c) 4 days of water spray cure;
- (d) 14 days kept in a moist condition.

E-5422 In finishing a concrete slab, the floating and troweling operations should take place:

- (a) while water sheen is on the slab surface;
- (b) at least 7 hr after screeding operations;
- (c) when the slab is hard enough to withstand the kick of a man's foot with no apparent damage;
- (d) when water sheen disappears and the slab will support a man's foot with only a slight impression.

E-5430 PERFORMANCE DEMONSTRATION

- (a) Perform a unit weight test on fresh concrete in accordance with ASTM C 138.
- (b) Perform a slump test in accordance with ASTM C 143.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 NMA APP F

APPENDIX F LINER DIMENSIONAL TOLERANCES

Page 231

ARTICLE F-1000 LINER DIMENSIONAL TOLERANCES

F-1100 SCOPE

The dimensional tolerances as given herein are a general guide for constructed liners. These tolerances were established as typical for a liner with a diameter of 150 ft (45.7 m), a hemispherical dome, and a 150 ft (45.7 m) high cylindrical shell. Further consideration should be given to liners with different configurations or that vary significantly from these dimensions. Areas of the liner that visually appear to have significant deviations and do not fall on the check points suggested in this Appendix should also be examined.

F-1200 CYLINDRICAL LINERS

F-1210 GENERAL

The measurements are to be taken at the completion of the work on the circumferential seams above and below the point being measured and prior to supporting reinforcing bar or formwork on this section of the liner. Dimensional tolerances for right circular cylindrical liner shells are established in F-1220 and F-1230.

F-1220 OVERALL DIMENSIONS

(a) At the specified increments of elevation, the difference between the actual radius of the shell and the theoretical radius should not exceed the larger of 3 in. (76 mm) or $\frac{1}{3}$ of 1% of the radius. The radius shall be measured from the theoretical true vertical center line of the cylinder or some offset point. This requirement may be satisfied by measuring radii spaced approximately 30 deg. apart on each shell course. The vertical distance between these measurements should not exceed 12 ft (3.7 m). This requirement may be met by taking measurements within the center $\frac{1}{3}$ of the shell course height.

(b) The average elevation of points on the spring line of the cylinder measured at approximately 30 deg. apart should not

deviate from the theoretical elevation of the spring line of the cylinder by more than the larger of 3 in. (76 mm) or $\frac{1}{6}$ of 1% of the height. Also, these points should be enveloped by two horizontal planes which are no more than 1 in. (25 mm) apart.

(c) An individual liner plate should not deviate from vertical by more than 2 in. (51 mm) in 10 ft (3.0 m). This requirement may be satisfied by taking measurements approximately 30 deg. apart on each shell course. The vertical distance between these measurements should not exceed 12 ft (3.7 m).

F-1230 LOCAL DIMENSIONS

(a) The gap should be measured between the shell and a 15 ft (4.6 m) template curved to the theoretical radius when placed horizontally against the surface of the shell. Measurements may be made on the complete circumference at no greater than 12 ft (3.7 m) increments vertically. These requirements may be met by taking a set of measurements on each shell course. The gap should not exceed 1 in. (25 mm) with a single plate section when the template is not closer than 12 in. (305 mm) to a weld seam. When the template is closer than 12 in. (305 mm) to a weld seam or crosses a weld seam, the gap should not exceed $1\frac{1}{2}$ in. (38 mm). Measurements should be taken and recorded per Fig. F-1230-1.

(b) The gap between the liner shell and a straight edge placed vertically against the liner should not exceed 1 in. (25 mm). The length of the straight edge should be the height of the liner shell course minus 2 ft, and the measurement should not be taken across the weld seam. This requirement may be satisfied by taking measurements approximately 30 deg. apart on each shell course. Measurements should be taken and recorded per Fig. F-1230-1.

Page 232

F-1300 DOME LINERS

F-1310 GENERAL

The dimensional tolerances in this Subarticle are for the final dome configuration prior to supporting reinforcing bar or form work. It is recommended that the elevation and radial location of circumferential seams be checked during the erection so as to ensure that the final dome is within these tolerances.

F-1320 OVERALL DIMENSIONS

The difference between the actual location of the dome and the theoretical location should not exceed 6 in. The horizontal location of the dome should be measured relative to the center line of the top of the as-constructed cylindrical liner, and the vertical location of the dome should be measured relative to the average elevation of the top of the as-constructed cylindrical liner.

This requirement should be satisfied by taking measurements at 15 deg. intervals as shown in Fig. F-1320-1, Section. Measurement shall be taken at approximately 15 deg. in plan (see Fig. F-1320-1, Plan View) along these circles, except that the spacing need not be less than 15 ft (4.6 m).

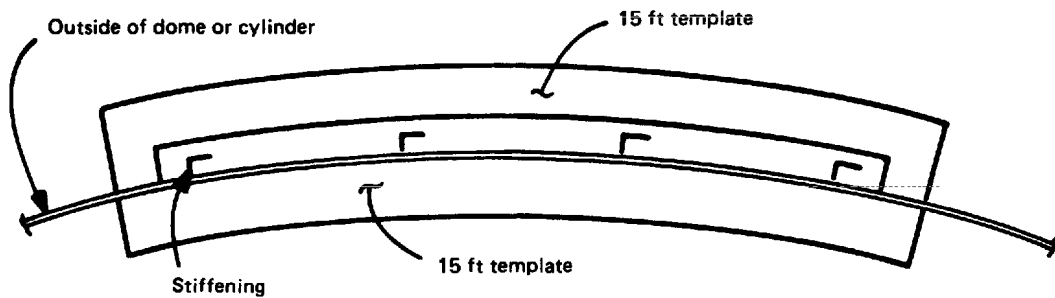
F-1330 LOCAL DIMENSIONS

The gap should be measured between the shell and a 15 ft (4.6 m) template curved to the theoretical radius when placed normal to the shell (see Fig. F-1230-1). The gap should not exceed 1 in. (25 mm) within a single plate section when the template is not closer than 12 in. (305 mm) to a weld seam. When the template is closer than 12 in. (305 mm) to a weld seam or crosses a weld seam, the gap should not exceed $1\frac{1}{2}$ in. (38 mm). A minimum of one meridional and one horizontal template placement check should be made in each 225 sq ft (20.9 m²) of surface area. A suggested method of template placement is shown in Fig. F-1330-1. Measurements should be taken and recorded per Fig. F-1230-1.

When ground assemblies are used in construction, consideration may be given to taking these measurements on the ground after completion of the assembly, provided measurements are taken on the welds joining assemblies.

Page 233

Page 234



GENERAL NOTE:
Record measurements outside of tolerance or, if none are out of tolerance, record the maximum deviation per template placement.

FIG. F-1230-1 MEASUREMENTS OF LOCAL DIMENSIONS PER F-1230

FIG. F-1230-1 MEASUREMENTS OF LOCAL DIMENSIONS PER F-1230

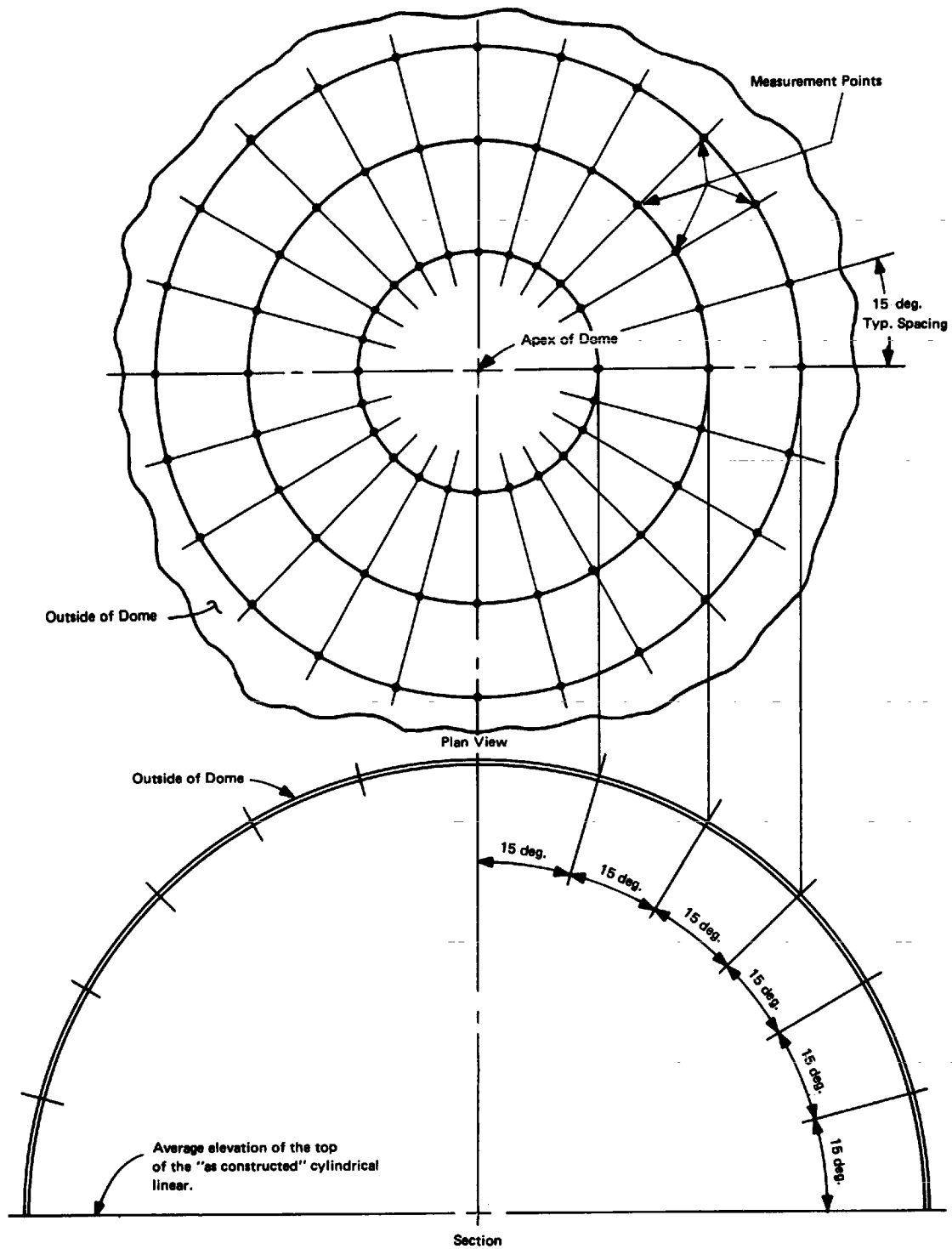


FIG. F-1320-1 MEASUREMENT POINTS PER F-1320

FIG. F-1320-1 MEASUREMENT POINTS PER F-1320

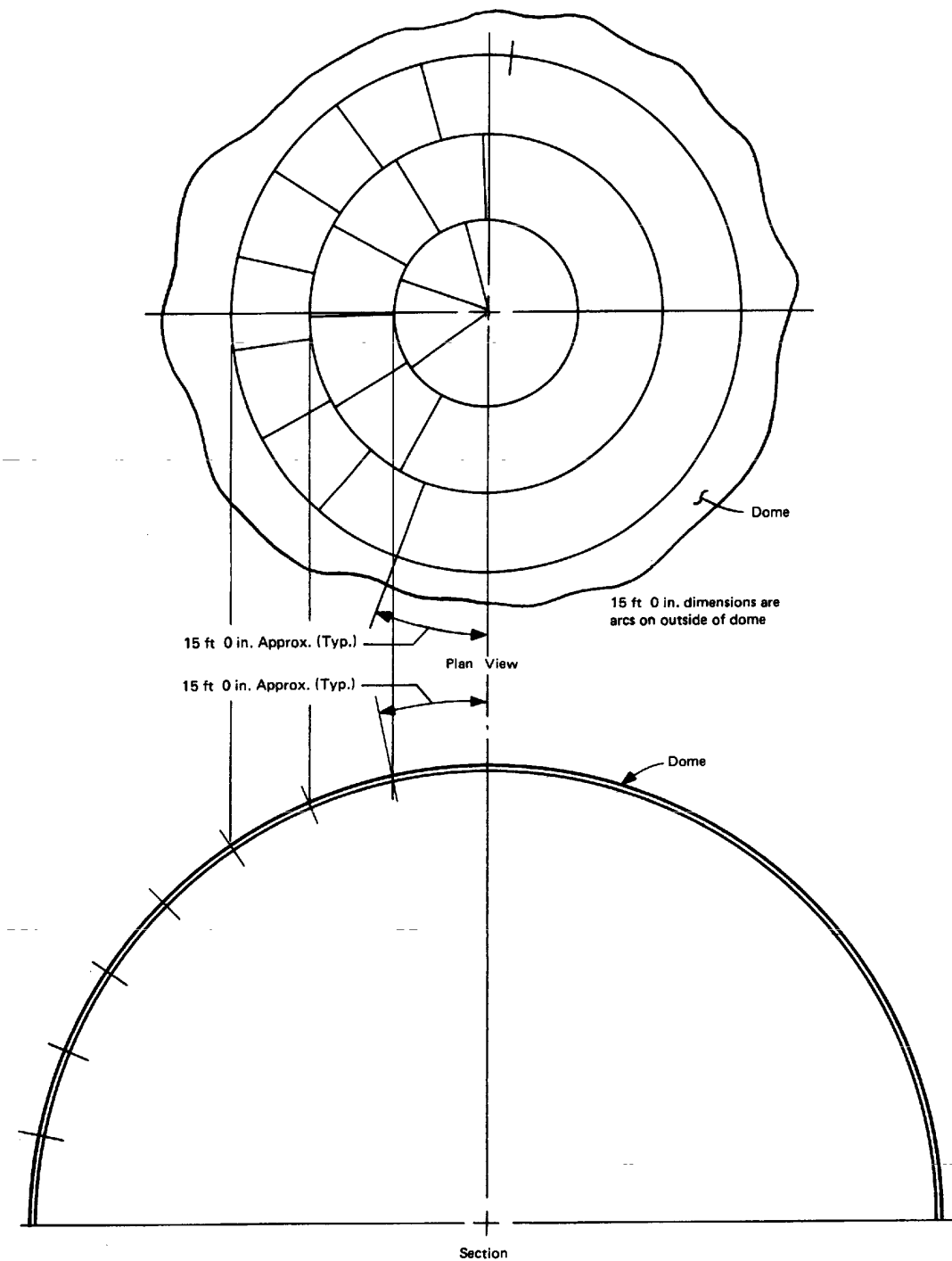


FIG. F-1330-1 MEASUREMENT POINTS PER F-1330

FIG. F-1330-1 MEASUREMENT POINTS PER F-1330

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 NMA APP G

APPENDIX G CERTIFIED MATERIAL TEST REPORTS FOR LINER MATERIALS

Page 237

ARTICLE G-1000 CERTIFIED MATERIAL TEST REPORTS FOR LINER MATERIALS

G-1100 INTRODUCTION

The requirements for a Certified Material Test Report (CMTR) are stated in NCA-3867.4(a). However, the material requirements vary with the class of construction, the product form of material, the requirements of the material specification, and the Manufacturer's procedures. Since changes in any of these requirements may be made by Addenda or new editions of the Code, it is important for the purchaser and the supplier to know the requirements of the applicable edition and Addenda, so that the reported results can be compared with the requirements to determine whether or not the material is in compliance with the Code.

G-1200 GENERAL REQUIRED INFORMATION

The following items of information are required in the CMTR's for material (as defined by CB/CC-2000) used in Section III, Division 2, Construction:

- (a) the Material Manufacturer's or the combination of the Material Manufacturer's and the Material Supplier's name, as applicable;
- (b) the Material Manufacturer's and the Material Supplier's Quality Systems Certificate (Materials) numbers and expiration dates, if the Manufacturer or supplier is a Certificate Holder;
- (c) purchaser's order or contract number;
- (d) description of the material, including specification number, grade, class, type, and nominal size, as applicable. For pipe made to specifications which include both seamless and welded pipe, the report shall designate which type it is.
- (e) description of material identification marking (NCA-3866.6);
- (f) results of chemical analyses, when required by the material specification;
- (g) results of tensile tests, when required by the material specification, including at least ultimate tensile strength and yield strength (or yield point);
- (h) reports of weld repairs performed, if any, as required by CB-2533.5.6, CB-2534.3, CB-2535.8, CC-2533.4.6, CC-2534.4, or CC-2537.8.6, including radiographic films when radiography is required;
- (i) Charpy V-notch (C_v) or drop weight test results required by CB/CC-2523 or CC-2524 when testing is required by CB/CC-2521. When Charpy V-notch impact tests are required, the report shall include the test temperature; the absorbed energy; the lateral expansion; the percent shear; and the location and orientation of specimens used. When drop weight tests are required, the report shall include the test temperature; the type, location, orientation of specimens used; and the results of the tests (break or no break).
- (j) nondestructive examinations performed and accepted as required by CB/CC-2530.

G-1300 INFORMATION REQUIRED UNDER SPECIFIC CIRCUMSTANCES

The following information is required under the specific circumstances given:

(a) heat treatment data as required by NCA-3867.4(a)(2):

(1) temperatures (or temperature ranges) and times at temperature used when the material specification requires specific temperatures and times;

(2) heat treatment conditions when no specific temperatures (or temperature ranges) or times are required by the material specification;

Page 238

(3) the minimum solution annealing temperature used for austenitic stainless steels and high nickel alloys, when required by the material specification;

(4) recorded temperature ranges and actual times at temperature, and heating and cooling rates for postweld heat treatment of materials that are repaired by welding, when postweld heat treatment is required by CB-2533.5.5 and CC-2533.4.5;

(5) recorded temperature ranges and actual times at temperature for postweld heat treatment of materials that are repaired by welding, when postweld heat treatment is required by CB-2534.3, CC-2534.4, and CC-2537.8.5;

(6) recorded temperatures and actual times at temperature for test coupons, when required by CB-2525 and CC-2526 (applicable only when those paragraphs are applicable);

(b) hydrostatic test pressure, when a hydrostatic test is required by the material specification, or notation that the hydrostatic test has not been performed, if it is deferred;

(c) Ferrite Number for all A-No. 8 welding material except type 16-8-2, as required by CB/CC-2613.3;

(d) When a fine grain size is specified for metallic materials, the grain size shall be reported in accordance with ASTM E 112

(e) other tests and test results as given in (1) and (2) below;

(1) results of other tests (such as hardness and cone stripping tests) which have quantitative results shall be included when such tests are required by the material specification;

(2) tests that have been performed and accepted to comply with a material specification shall be enumerated (such as bending, flattening, flaring, and flanging tests);

(f) for welding materials, in addition to the applicable paragraphs above, the process; preheat and interpass temperature; type of chemical analysis (filler metal/undiluted deposit); shielding gas composition; and Ferrite Number shall be reported as required by CB/CC-2600 and as applicable.

G-1400 EXECUTION

All requirements of the material specification and the Code need not be performed by the same organization. Therefore, reports may be executed by more than one organization, provided each organization is identified on the report for the item for which it is responsible.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 NMA APP H

APPENDIX H REINFORCEMENT FABRICATION AND PLACING TOLERANCES

Page 239

ARTICLE H-1000 REINFORCEMENT FABRICATION AND PLACING TOLERANCES

H-1100 SCOPE

The dimensional tolerances as given herein are a general guide for the fabrication and placing of reinforcement. These tolerances are established as guides and further considerations shall be given to the fabrication, placing of reinforcement, concrete placement, and formwork tolerances when determining the tolerance requirements for the Construction Specification.

H-1200 FABRICATION TOLERANCES

H-1210 GENERAL

The fabrication tolerances provided herein are industry standards. The designer shall give consideration to the configuration and location of the bars in the structure when developing fabrication tolerances in the Construction Specification.

H-1220 FABRICATION TOLERANCES FOR BAR SIZES #3 THROUGH #11

Bar sizes #3 through #11 shall be fabricated to meet the tolerances shown in Fig. H-1220-1 for the bend types shown.

H-1230 FABRICATION TOLERANCES FOR BAR SIZES #14 AND #18

Bar sizes #14 and #18 shall be fabricated to meet the tolerances shown in Fig. H-1230-1 for the bend types shown.

H-1300 PLACING TOLERANCES

H-1310 GENERAL

The placing of reinforcement shall be controlled to ensure that the requirements of the design are satisfied; the proper quantity of reinforcement shall be placed such that the design loads are resisted by properly developed reinforcement and concrete can be properly placed and consolidated. The requirements provided herein shall be considered guidelines. Special design requirements shall also be considered in developing the Construction Specification.

H-1320 LOCATION OF REINFORCEMENT

(a) Reinforcement shall be placed within a tolerance of plus or minus one-half the nominal rebar spacing shown on the design drawings, except as stated in (b) and (c) below. In any given run of bars (not to exceed section thickness in length), the total quantity of bars required by design shall be provided (see Fig. H-1320-1).

(b) The reduction of depth d shall not exceed $0.05d$ or 2 in.

(c) The clear distance between reinforcing steel and steel liner shall not be less than 2 in.

H-1330 SPACING

The acceptable spacing tolerances may vary depending on the size and configuration of the structure, the rebar pattern, and the largest size of aggregate to be used. Acceptable tolerances shall ensure proper placing and consolidation of concrete and take into account the design requirements in H-1320.

Page 240

Page 242

Pages 241-241

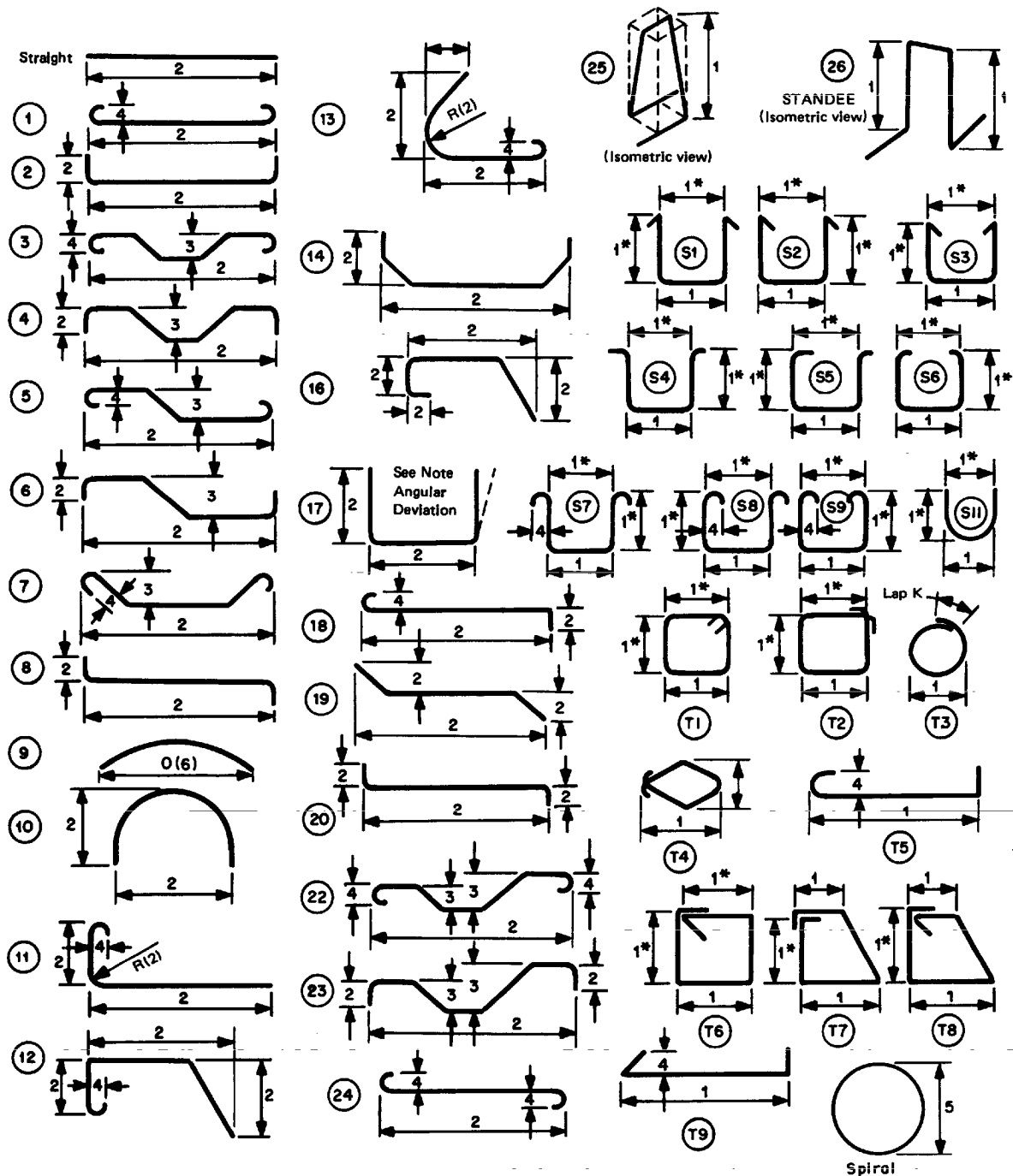


FIG. H-1220-1 STANDARD FABRICATING TOLERANCES FOR BAR SIZES #3 THROUGH #11

FIG. H-1220-1 STANDARD FABRICATING TOLERANCES FOR BAR SIZES #3 THROUGH #11

FIG. H-1220-1 (CONT'D)

GENERAL NOTES:

- (a) Entire shearing and bending tolerances are customarily absorbed in the extension past the last bend in a bent bar.
- (b) Angular Deviation—maximum $\pm 2\frac{1}{2}$ deg. or $\pm 1\frac{1}{2}$ in./ft on all 90 deg. hooks and bends. Saw cut both ends—overall length $\pm \frac{1}{2}$ in. All tolerances single plane and as shown.
- (c) Tolerances for Types S1–S9, T1–T9 apply to bar sizes #3–#5 inclusive only.
- (d) Tolerance Symbols
 - 1 = bar sizes #3, 4, 5 — $\pm \frac{1}{2}$ in. (gross length < 12 ft–0 in.)
 - = bar sizes #3, 4, 5 — ± 1 in. (gross length $\geq$ 12 ft–0 in.)
 - = bar sizes #6, 7, 8 — ± 1 in.
 - 2 = ± 1 in.
 - 3 = +0 in., $-\frac{1}{2}$ in.
 - 4 = $\pm \frac{1}{2}$ in.
 - 5 = diameter $\leq$ 30 in. $\pm \frac{1}{2}$ in.
 - = diameter < 30 in. ± 1 in.
 - 6 = $\pm 1.5\% \times 0$ dimension, ± 2 in. min.**

*Dimensions on this line are to be within tolerance shown but are not to differ from the opposite parallel dimension by more than $\frac{1}{2}$ in.

** If application of positive tolerance to Type 9 results in a chord length equal to or greater than the arc or bar length, the bar may be shipped straight.

FIG. H-1220-1 (CONT'D)

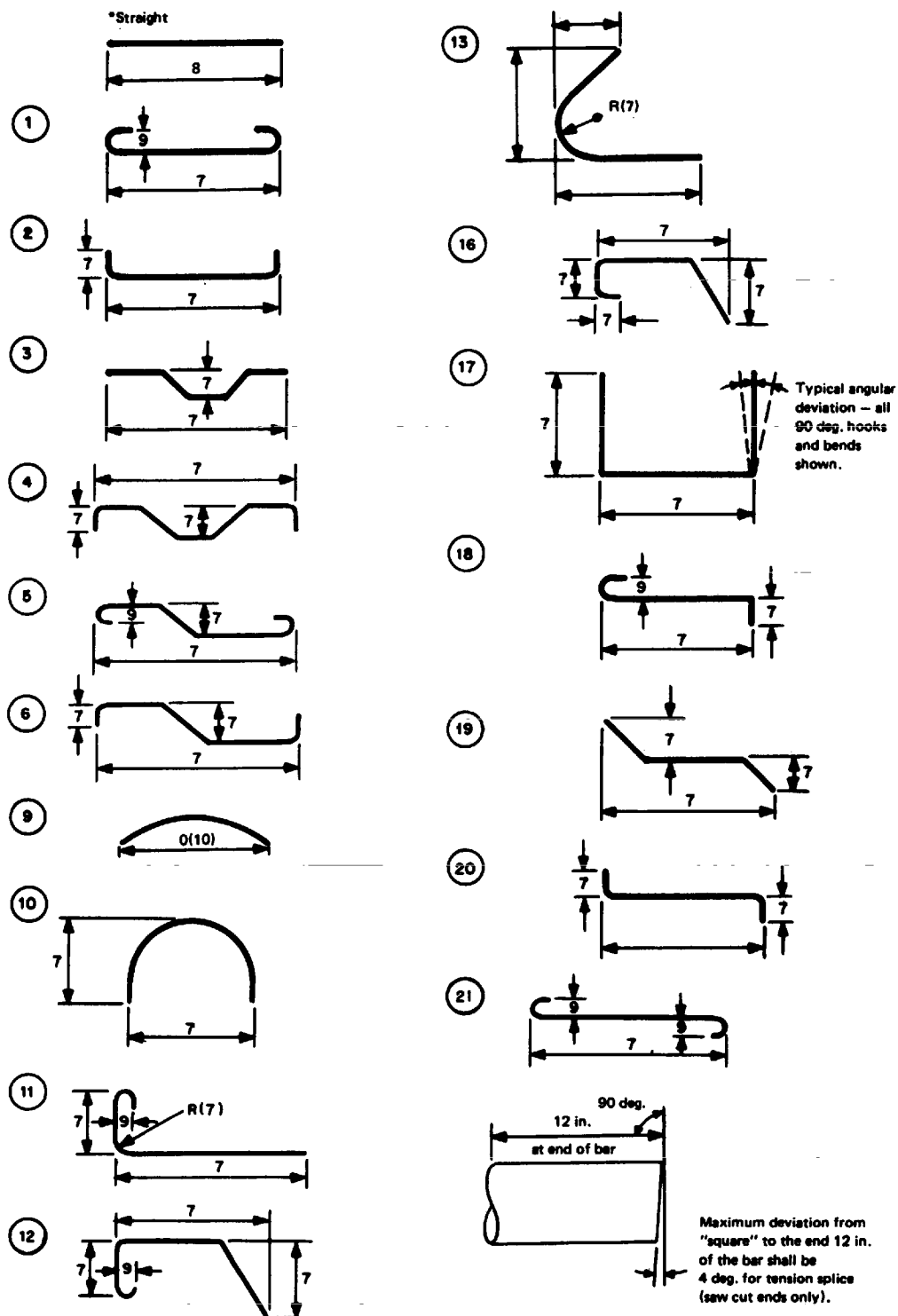


FIG. H-1230-1 STANDARD FABRICATING TOLERANCES FOR BAR SIZES #14 AND #18

FIG. H-1230-1 (CONT'D)

GENERAL NOTES:**(a) Tolerance Symbols**

7 = plus or minus

8 = plus or minus

9 = plus or minus

10 = $\pm 2\% \times 0$ dimension $\geq$

#14

2 1/2 in.

2 in.

1 1/2 in.

 $\pm 2 1/2$ in. min.*

#18

3 1/2 in.

2 in.

2 in.

 $\pm 3 1/2$ in. min.***(b) Angular Deviation** — maximum $\pm 2 1/2$ deg. or $0 \pm 1/2$ in./ft on all 90 deg. hooks and bends.*Saw cut bends — overall length $\pm 1/2$ in.

FIG. H-1230-1 (CONT'D)

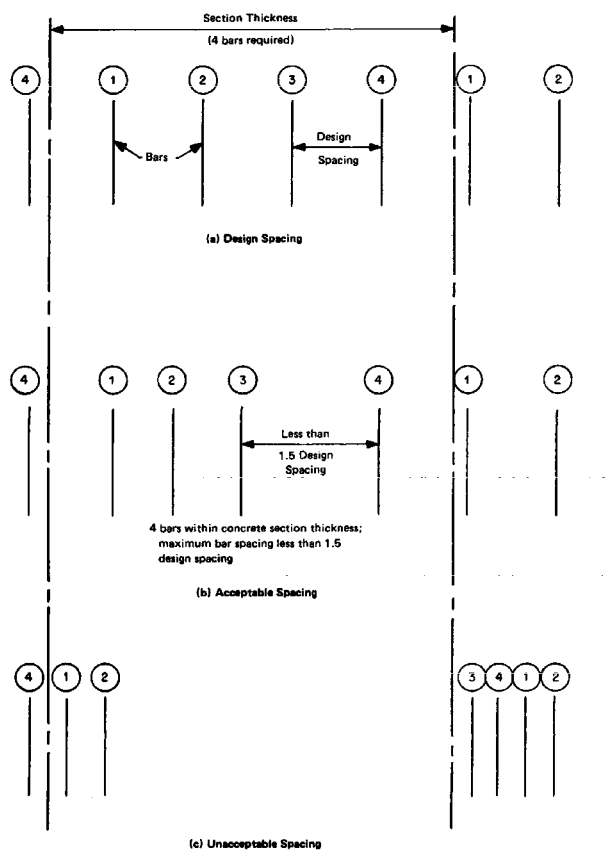


FIG. H-1230-1 LOCATION OF REINFORCEMENT

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 REF MTL

REFERENCE MATERIAL

Page 245

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 CODES

CODES, STANDARDS, AND SPECIFICATIONS REFERENCED
IN TEXT

Page 247

ORGANIZATIONS

American Concrete Institute

American Institute of Steel Construction

American Petroleum Institute

American Public Health Association

American Society of Mechanical Engineers

American Society for Nondestructive Testing

American Society for Testing and Materials

American Water Works Association

American Welding Society

Manufacturer's Standardization Society of the Valve and Fittings Industry

U.S. Army Corps of Engineers

AMERICAN CONCRETE INSTITUTE

ACI 211.1-89

Standard Practice for Selecting Proportions for Normal, Heavy Weight, and Mass Concrete

ACI 214-77 (1983)

Recommended Practice for Evaluation of Strength Test Results of Concrete

ACI 304R-89

Guide for Measuring, Mixing, Transporting and Placing Concrete

ACI 305R-89

Hot Weather Concreting

ACI 306R-88

Cold Weather Concreting

ACI 309R-87

Guide for Consolidation of Concrete

ACI 347R-88

Guide to Formwork for Concrete

AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings, 1978

Specification for Structural Steel Buildings - Allowable Stress Design and Plastic Design, June 1, 1989

Page 248

AMERICAN PETROLEUM INSTITUTE

API 605-1988

Large Diameter Carbon Steel Flanges

[98]

AMERICAN PUBLIC HEALTH ASSOCIATION

APHA-4500-5 17th Edition

Test for Determination of Water Soluble Sulfides (Methylene Blue Method) - Standard Methods for the Examination of Water and Wastewater (1985)

[98]

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

ASME B1.1a-1984

Unified Inch Screw Threads (UN and UNR Thread Form)

ASME B16.5-1988

Steel Pipe Flanges and Flanged Fittings

ASME B16.9-1986

Factory Made Wrought Steel Butt Welding Fittings

ASME B16.11-1980

Forged Steel Fittings, Socket-Welding and Threaded

ASME B16.20-1973

Ring-Joint Gaskets and Grooves for Steel Pipe Flanges

ASME B16.21-1978

Nonmetallic Flat Gaskets for Pipe Flanges

ASME B16.25-1986

Butt Welding Ends

ASME B16.28-1986

Wrought Steel Butt Welding Short Radius Elbows and Returns

ASME B16.34-1988

Valves - Flanged, Threaded, and Welded End

ASME B18.2.1-1978

Square and Hex Bolts and Screws (Inch Series), Including Hex Cap Screws and Lag Screws

ASME B18.2.2-1987

Square and Hex Nuts (Inch Series)

ASME B18.3-1986

Socket Cap, Shoulder and Set Screws (Inch Series)

ASME B1.20.1-1983

Pipe Threads, General Purpose (Inch)

ASME B1.20.5-1978(1980)

Gaging for Dryseal Pipe Threads (Inch)

ASME B36.10M-1985

Welded and Seamless Wrought Steel Pipe

ASME B36.19M-1985

Stainless Steel Pipe

ASME/ANSI N626.3-1988

Qualifications and Duties of Specialized Professional Engineers, including Addenda N626.3a-1989

ASME PTC 25.3-1994

Pressure Relief Devices

AMERICAN SOCIETY FOR NONDESTRUCTIVE TESTING

SNT-TC-1A & Supplements

Recommended Practice - Guidelines for the Qualification and Certification of Nondestructive Testing Personnel & Supplements

AMERICAN SOCIETY FOR TESTING AND MATERIALS

A 416-88b	Standard Specification for Steel Bars, Carbon, Cold-Finished, Standard Quality
A 421-80 (1985)	Standard Specification for Steel Strand, Uncoated Seven-Wire Stress-Relieved for Prestressed Concrete
A 490-90	Standard Specification for Uncoated Stress-Relieved Wire for Prestressed Concrete
A 513-90	Standard Specification for Heat-Treated Steel Structural Bolts, 150 ksi Minimum Tensile Strength
	Standard Specification for Electric-Resistance-Welded Carbon and Alloy Steel Mechanical Tubing
Page 249	
A 519-90	Standard Specification for Seamless Carbon and Alloy Steel Mechanical Tubing
A 576-89b	Standard Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality
A 615-89	Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
A 673-88	Standard Specification for Sampling Procedure for Impact Testing of Structural Steel
A 687-89	Standard Specification for High-Strength Nonheaded Steel Bolts and Studs
A 706-89	Standard Specification for Low-Alloy Steel Deformed Bars for Concrete Reinforcement
A 722-88a	Standard Specification for Uncoated, High-Strength Steel Bar for Prestressing Concrete
A 779-80	Standard Specification for Steel Strand, Seven-Wire, Uncoated, Compacted, Stress-Relieved for Prestressed Concrete
B 117-85	Standard Test Method of Salt Spray (Fog) Testing
C 31-89	Standard Practice for Making and Curing Concrete Test Specimens in the Field
C 33-89	Standard Specification for Concrete Aggregates
C 39-90	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
C 40-84	Standard Test Method for Organic Impurities in Fine Aggregates for Concrete
C 42-87	Standard Methods of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
C 78-84	Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third Point Loading)
C 94-90	Standard Specification for Ready-Mixed Concrete
C 109-88	Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50-mm Cube Specimens)
C 114-88	Standard Test Methods for Chemical Analysis of Hydraulic Cement
C 115-86	Standard Test Method for Fineness of Portland Cement by the Turbidimeter
C 117-87	Standard Test Method for Material Finer than 75- μ m (No. 200) Sieve in Mineral Aggregates by Washing

C 123-83	Standard Test Method for Lightweight Pieces in Aggregate
C 127-88	Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate
C 128-88	Standard Test Method for Specific Gravity and Absorption of Fine Aggregate
C 131-89	Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
C 136-84a	Standard Method for Sieve Analysis of Fine and Coarse Aggregates
C 138-81	Standard Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete
C 142-78	Standard Test Method for Clay Lumps and Friable Particles in Aggregates
C 143-89a	Standard Test Method for Slump of Hydraulic Cement Concrete
C 150-89	Specification for Portland Cement
C 151-89	Standard Test Method for Autoclave Expansion of Portland Cement
C 157-89	Standard Test Method for Length Change of Hardened Cement Mortar

Page 250

	and Concrete
C 172-82	Standard Method of Sampling Freshly Mixed Concrete
C 173-78	Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
C 183-88	Standard Practice for Sampling and the Amount of Testing of Hydraulic Cement
C 191-82	Standard Test Method for Time of Setting Hydraulic Cement by Vicat Needle
C 192-90	Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
C 204-89	Standard Test Method for Fineness of Portland Cement by Air Permeability Apparatus
C 227-87	Standard Test Method for Potential Alkali Reactivity of Cement Aggregate Combinations (Mortar-Bar Method)
C 231-89a	Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
C 260-86	Standard Specification for Air-Entraining Admixtures for Concrete
C 266-89	Standard Test Method for Time of Setting of Hydraulic-Cement Paste by Gillmore Needles
C 289-87	Standard Test Method for Potential Reactivity of Aggregates (Chemical Method)
C 295-85	Standard Practice for Petrographic Examination of Aggregates for Concrete
C 311-90	Standard Test Method for Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete

	Standard Test Method for Potential Volume Change of Cement-Aggregate Combinations
C 430-89	Standard Test Method for Fineness of Hydraulic Cement by the No. 325 (45-µm) Sieve
C 441-89	Standard Test Method for Effectiveness of Mineral Mixtures or Ground Blast-furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction
C 469-87a	Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression
C 494-86	Standard Specification for Chemical Admixtures for Concrete
C 496-86	Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
C 512-87	Standard Test Method for Creep of Concrete in Compression
C 535-89	Standard Test Method for Resistance to Degradation of Large Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
C 566-89	Standard Test Method for Total Moisture Content of Aggregate by Drying
C 586-69 (1986)	Standard Test Method for Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method)
C 595-87	Standard Specification for Blended Hydraulic Cements
C 618-89a	Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
C 637-84	Standard Specification for Aggregates for Radiation Shielding Concrete
C 642-82	Test Method for Specific Gravity, Absorption and Voids in Hardened

Page 251

	Concrete
C 937-80 (1985)	Standard Specification for Grout Fluidifier for Preplaced Aggregate Concrete
C 939-87	Standard Test Method for Flow of Grout for Preplaced Aggregate Concrete
C 940-89	Standard Test Method for Expansion and Bleeding of Freshly Mixed Grouts for Preplaced Aggregate Concrete in the Laboratory
C 943-80	Standard Method for Making Test Cylinders and Prisms for Determining Strength and Density of Preplaced Aggregate Concrete in the Laboratory
C 953-87	Standard Test Method for Time of Setting of Grouts for Preplaced Aggregate Concrete in the Laboratory
C 1017-85	Specification for Chemical Admixtures for Use in Producing Flowing Concrete
C 1077-87	Standard Practice for Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation
D 92-85	Standard Test Method for Flash and Fire Points by Cleveland Open Cup

	Standard Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)
D 512-89	Standard Test Methods for Chloride Ion in Water
D 572-88	Standard Test Method for Rubber Deterioration by Heat and Oxygen
D 609-73 (1980)	Standard Methods for Preparation of Steel Panels for Testing Paint, Varnish, Lacquer, and Related Products
D 610-85 (1989)	Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surface
D 937-87	Standard Test Method for Conce Penetration of Petrolatum
D 938-86	Standard Test Method for Congealing Point of Petroleum Waxes Including Petrolatum
D 974-87	Standard Test Method for Acid and Base Number by Color-Indicator Titration
D 992-71 (1978)	Test for Nitrate Ion in Water
D 1411-82	Standard Test Methods for Water-Soluble Chlorides Present as Admixes in Graded Aggregate Road Mixes
D 1888-78	Tests for Particulate and Dissolved Matter, Solids, or Residue in Water
E 23-88	Standard Test Methods for Notched Bar Impact Testing of Metallic Materials
E 94-89	Standard Guide for Radiographic Testing
E 142-86	Standard Method for Controlling Quality of Radiographic Testing
E 165-80	Standard Practice for Liquid Penetrant Inspection Method
E 186-84 (1989)	Standard Reference Radiographs for Heavy-Walled (2 to 4 ¹ / ₂ in.) Steel Castings
E 208-87a	Standard Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels
E 280-84	Standard Reference Radiographs for Heavy-Walled (4 ¹ / ₂ to 12 in.) Steel Castings
E 328-86	Standard Methods for Stress-Relaxation Tests for Materials and Structures
E 380-89a	Standard Practice for Use of the International System of Units (SI)
E 446-84 (1989)	Reference Radiographs for Steel Castings up to 2 in. in Thickness
E 709-80	Practice for Magnetic Particle Examination
Page 252	
F 436-90	Standard Specification for Hardened Steel Washers
F 788-82 (1989)	Standard Specification for Surface Discontinuities of Bolts, Screws, and Studs

AMERICAN WATER WORKS ASSOCIATION

AWWA C 207-86	Standard for Steel Pipe Flanges for Waterworks Service, 4 in. through 144 in.
---------------	---

AMERICAN WELDING SOCIETY

AWS A4.2-86	Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic Stainless Steel Weld Metal
AWS A5.1-81	Specification for Covered Carbon Steel Arc Welding Electrodes
AWS A5.5-81	Specification for Low Alloy Steel Covered Arc Welding Electrodes
AWS A5.18-79	Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding
AWS A5.20-79	Specification for Carbon Steel Electrodes for Flux Cored Arc Welding
AWS A5.28-79	Specification for Low Alloy Steel Filler Metals for Gas Shielded Arc Welding
AWS D1.1-90	Structural Welding Code

MANUFACTURER'S STANDARDIZATION SOCIETY OF THE VALVE AND FITTINGS INDUSTRY

SP-43-1982(1986)	Wrought Stainless Steel Butt-Welding Fittings
SP-44-1990	Steel Pipeline Flanges
SP-87-1982	Factory Made Butt-Welded Fittings for Class 1 Nuclear Piping Application

U.S. ARMY CORPS OF ENGINEERS

CRD-C 36-73	Test for Thermal Diffusivity of Concrete
CRD-C 39-81	Test for Coefficient of Linear Thermal Expansion of Concrete
CRD-C 44-63	Method for Calculation of Thermal Conductivity of Concrete
CRD-C 119-53	Test for Flat and Elongated Particles in Coarse Aggregate
CRD-C 621-89	Specification for Non-Shrink Grouts
...	Handbook for Concrete and Cement

July 1, 1998

American Society Of Mechanical Engineers

SEC III D2 SI UNITS

SI UNITS

Page 253

The 1998 Edition of the Boiler and Pressure Vessel Code is based on U.S. Customary (ft-lb) units of measurement which are to be regarded as the standard. This supplement is provided as a convenience to the Code user and contains SI conversion factors for units contained in the Code.

Page 254

Page 255

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

Quantity	Unit	Symbol	Other Units or Limitations
Space and Time			
plane angle	radian	rad	degree (decimalized)
length	meter	m	
area	square meter	m ²	
volume	cubic meter	m ³	liter (L) for liquid only (use without prefix other than in milliliter, mL)
time	second	s	minute (min), hour (h), day (d), week, and year
Periodic and Related Phenomena			
frequency	hertz	Hz	revolutions per second (r/s)
rotational frequency	revolutions per second	s ⁻¹	revolutions per minute (r/m)
Mechanics			
mass	kilogram	kg	
density	kilogram per cubic meter	kg/m ³	
moment of inertia	kilogram · meter ²	kg · m ²	
force	newton	N	
moment of force (torque)	newton-meter	N · m	
pressure and stress	pascal	Pa	(pascal = newton per square meter)
energy, work	joule	J	kilowatt-hour (kW · h)
power	watt	W	
impact strength	joule	J	
section modulus	meter ³	m ³	
moment of section (second moment of area)	meter ⁴	m ⁴	
fracture toughness	Pa · $\sqrt{m}$		
Heat			
temperature — thermodynamic [Note (2)]	kelvin	K	degree Celsius (°C)
temperature — other than thermodynamic	degree Celsius	°C	kelvin (K)
linear expansion coefficient	meter per meter-kelvin	K ⁻¹	°C ⁻¹
quantity of heat	joule	J	
heat flow rate	watt	W	
thermal conductivity	watt per meter-kelvin	W/(m · K)	W/(m · °C)
thermal diffusivity	square meter per second	m ² /s	
specific heat capacity	joule per kilogram-kelvin	J/(kg · K)	J/(kg · °C)
Electricity and Magnetism			
electric current	ampere	A	
electric potential	volt	V	
current density	ampere per meter ²	A/m ²	
magnetic field strength	ampere per meter	A/m	

NOTES:

- (1) Conversion factors between SI units and U.S. customary are given in SI-1, "ASME Orientation and Guide for Use of SI (Metric) Units," and ASTM E 380.
- (2) Preferred use for temperature and temperature interval is degrees Celsius (°C), except for thermodynamic and cryogenic work where kelvins may be more suitable. For temperature interval, 1 K = 1°C exactly.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE¹

COMMONLY USED CONVERSION FACTORS
(For Others See ASTM E 380) [See Note (1)]

Quantity	To Convert From	To	Multiply by [Note (2)]	
plane angle	degree	rad	1.745 329	E-02
length	in	m	2.54*	E-02
	ft	m	3.048*	E-01
	yd	m	9.144*	E-01
area	in ²	m ²	6.451 6*	E-04
	ft ²	m ²	9.290 304*	E-02
	yd ²	m ²	8.361 274	E-01
volume	in ³	m ³	1.638 706	E-05
	ft ³	m ³	2.831 685	E-02
	US gallon	m ³	3.785 412	E-03
	Imperial gallon	m ³	4.546 09	E-03
	liter	m ³	1.0*	E-03
mass	lbm	kg	4.535 924	E-01
	ton (metric) (mass)	kg	1.000 00*	E+03
	ton (short 2000 lbm)	kg	9.071 847	E+02
force	kgf	N	9.806 65*	E+00
	lbf	N	4.448 222	E+00
bending, torque	kgf · m	N · m	9.806 65*	E+00
	lbf · in	N · m	1.129 848	E-01
	lbf · ft	N · m	1.355 818	E+00
pressure, stress	kgf/m ²	Pa	9.806 65*	E+00
	lbf/ft ²	Pa	4.788 026	E+01
	lbf/in ² (psi)	Pa	6.894 757	E+03
	kips/in ²	Pa	6.894 757	E+06
	bar	Pa	1.0*	E+05
energy, work	Btu (IT) [Note (3)]	J	1.055 056	E+03
	ft · lbf	J	1.355 818	E+00
power	hp (550 ft · lbf/s)	W	7.456 999	E+02
fracture toughness	ksi $\sqrt{\text{in}}$	Pa · $\sqrt{\text{m}}$	1.098 843	E+06
temperature	°C	K	$t_K = t_C + 273.15$	
	°F	K	$t_K = (t_F + 459.67)/1.8$	
	°F	°C	$t_C = (t_F - 32)/1.8$	
temperature interval	°C	K	1.0*	E+00
	°F	K or °C	5.555 555	E-01

NOTES:

- (1) Care should be taken when converting formulas or equations that contain constant terms or factors. The value of these terms must be understood and may also require conversion.
- (2)(a) Relationships that are exact in terms of the base units are followed by a single asterisk.
- (b) The factors are written as a number greater than 1 and less than 10 with 6 or fewer decimal places. The number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example: 3.523 907 E-02 is $3.523\ 907 \times 10^{-2}$ or 0.035 239 07.
- (3) International Table

COMMONLY USED CONVERSION FACTORS

July 1, 1998
American Society Of Mechanical Engineers
SEC III D3 A98
1998 ADDENDA SUMMARY OF CHANGES

Page xxv

SUMMARY OF CHANGES

Changes given below are identified on the pages by a margin note, **98**, placed next to the affected area.

<i>Page</i>	<i>Location</i>	<i>Change</i>
63	WB-1120	Subparagraph (a) corrected by Errata
84	WB-2432.2	Subparagraph (c) corrected by Errata
121	WB-3227	Paragraph corrected by Errata
	WB-3231.1	Subparagraph (a) revised
197	WB-6221	Subparagraphs (a) and (c) corrected by Errata
198	WB-6321	Subparagraphs (a) and (c) corrected by Errata

July 1, 1998
American Society Of Mechanical Engineers
SEC III D3 INTRODUCTION
INTRODUCTION

**1998 ASME
BOILER &
PRESSURE VESSEL CODE
AN INTERNATIONAL CODE**

III

Division 3

Containment

Systems and

Transport

Packagings

for Spent

Nuclear Fuel

and High

Level

Radioactive

Waste

RULES FOR

CONSTRUCTION

OF NUCLEAR

**OF NUCLEAR
POWER PLANT
COMPONENTS**

[ASME logo] The American Society of
Mechanical Engineers

**IMPORTANT INFORMATION ON THE 1998 BOILER AND PRESSURE VESSEL CODE
ADDENDA DISTRIBUTION SCHEDULE**

There is a change in the way the Addenda to the 1998 Edition of the ASME Boiler and Pressure Vessel Code are distributed. The 1998 Edition, published July 1, 1998, incorporates the 1998 Addenda revisions, additions, or deletions. There will be no separate 1998 Addenda issued in a replacement page format. Two additional Addenda to the 1998 Edition, in the form of replacement pages, will be issued on July 1, 1999 and July 1, 2000.

The Summary of Changes published with the 1998 Edition lists and describes the revisions that are part of the 1998 Addenda. These changes are identified with a margin note, **98**, denoting the affected area.

The Addenda for 1999 and 2000 will also have a Summary of Changes and identifiers printed on the replacement pages. The revisions, additions, or deletions will be incorporated directly into the affected pages. It is advisable to retain the title sheets and all replaced pages for reference.

The effective dates for Code Editions and Addenda are described in the Foreword.

ASME BOILER AND PRESSURE VESSEL CODE
AN INTERNATIONAL CODE

III

**RULES FOR
CONSTRUCTION OF
NUCLEAR POWER
PLANT COMPONENTS**

Division 3

Containment

Systems and

Transport

Packagings

for Spent

Nuclear Fuel

and High

Level

Radioactive

Waste

1998 Edition

July 1, 1998

**ASME BOILER AND
PRESSURE VESSEL
COMMITTEE
SUBCOMMITTEE ON
NUCLEAR POWER**

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
NEW YORK, NEW YORK

Date of Issue - July 1, 1998

(Includes all Addenda dated December 1997 and earlier)

This code or standard was developed under procedures accredited as meeting the criteria for American National Standards. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment which provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not "approve," "rate," or "endorse" any item, construction, proprietary device, or activity.

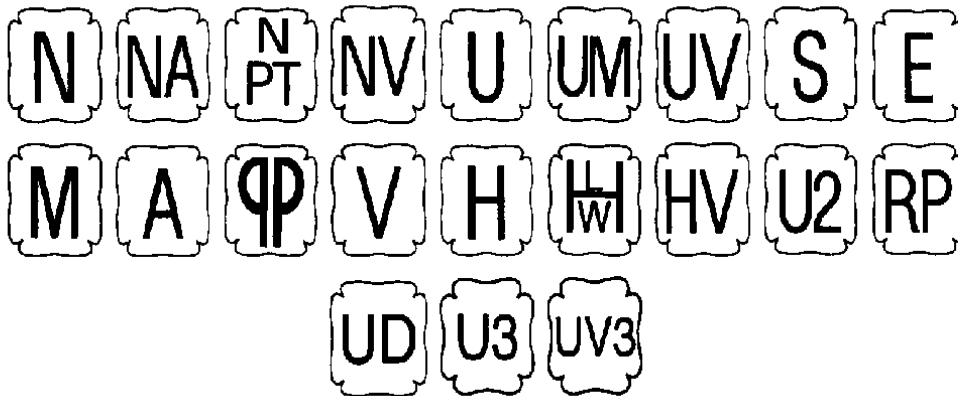
ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of any applicable Letters Patent, nor assume any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations issued in accordance with governing ASME procedures and policies which preclude the issuance of interpretations by individual volunteers.

The footnotes in this document are part of this American National Standard.

[ASME logo] ASME collective membership mark



LOGOS

The above ASME symbols are registered in the U.S. Patent Office.

"ASME" is the trademark of the American Society of Mechanical Engineers.

No part of this document may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Library of Congress Catalog Card Number: 56-3934

Printed in the United States of America

Adopted by the Council of the American Society of Mechanical Engineers, 1914.

Revised 1940, 1941, 1943, 1946, 1949, 1952, 1953, 1956, 1959, 1962, 1965, 1968, 1971, 1974, 1977, 1980, 1983, 1986, 1989, 1992, 1995, 1998

The American Society of Mechanical Engineers
Three Park Avenue, New York, NY 10016-5990

Copyright © 1998 by
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
All Rights Reserved

1998 ASME
BOILER AND PRESSURE VESSEL CODE

SECTIONS

I Rules for Construction of Power Boilers

II Materials

Part A - Ferrous Material Specifications

Part B - Nonferrous Material Specifications

Part C - Specifications for Welding Rods, Electrodes, and Filler Metals

Part D - Properties

III Subsection NCA - General Requirements for Division 1 and Division 2

III Division 1

Subsection NB - Class 1 Components

Subsection NC - Class 2 Components

Subsection ND - Class 3 Components

Subsection NE - Class MC Components

Subsection NF - Supports

Subsection NG - Core Support Structures

Subsection NH - Class 1 Components in Elevated Temperature Service

Appendices

III Division 2 - Code for Concrete Reactor Vessels and Containments

III Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

IV Rules for Construction of Heating Boilers

V Nondestructive Examination

VI Recommended Rules for the Care and Operation of Heating Boilers

VII Recommended Guidelines for the Care of Power Boilers

VIII Rules for Construction of Pressure Vessels

Division 1

Division 2 - Alternative Rules

Division 3 - Alternative Rules for Construction of High Pressure Vessels

IX Welding and Brazing Qualifications

X Fiber-Reinforced Plastic Pressure Vessels

XI Rules for Inservice Inspection of Nuclear Power Plant Components

ADDENDA

Colored-sheet Addenda, which include additions and revisions to individual Sections of the Code, are published annually and will be sent automatically to purchasers of the applicable Sections up to the publication of the 2001 Code. The 1998 Code is available only in the loose-leaf format; accordingly, the Addenda will be issued in the loose-leaf, replacement-page format.

INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code. The Interpretations for each individual Section will be published separately and will be included as part of the update service to that Section. They will be issued semiannually (July and December) up to the publication of the 2001 Code. Interpretations of Section III, Divisions 1 and 2, will be included with the update service to Subsection NCA.

CODE CASES

The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 1998 Code Cases book: (1) Boilers and Pressure Vessels and (2) Nuclear Components. Supplements will be sent automatically to the purchasers of the Code Cases books up to the publication of the 2001 Code.

Page v

FOREWORD

The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety governing the design, fabrication, and inspection during construction of boilers and pressure vessels, and to interpret these rules when questions arise regarding their intent. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property and to provide a margin for deterioration in service so as to give a reasonably long, safe period of usefulness. Advancements in design and material and the evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction,¹ and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

¹ Construction, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However,

designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are responsible for the application of these programs to their design.

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practice as determined by the engineer.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Boiler and Pressure Vessel Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Mandatory Appendix covering preparation of technical inquiries). Proposed revisions to the Code resulting from inquiries will be presented to the Main Committee for appropriate action. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by ASME.

Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute and published in *Mechanical Engineering*

Page viii

to invite comments from all interested persons. After the allotted time for public review and final approval by ASME, revisions are published annually in Addenda to the Code.

Code Cases may be used in the construction of components to be stamped with the ASME Code symbol beginning with the date of their approval by ASME.

Code Editions may be used on or after the date of issue shown in the Edition. After Code revisions are approved by ASME, they may be used beginning with the date of issue shown on the Addenda. Revisions to material specifications are originated by the American Society for Testing and Materials (ASTM) and other recognized national or international organizations, and are usually adopted by ASME. However, those revisions may or may not have any effect on the suitability of material, produced to earlier editions of specifications, for use in ASME construction. ASME material specifications approved for use in each construction Code are listed in the Appendices of Section II, Parts A and B. These Appendices list, for each specification, the latest edition adopted by ASME, and earlier and later editions considered by ASME to be identical for ASME construction.

Owners of nuclear power plants are cautioned that Code Editions, Addenda, and Cases to be used in construction shall be acceptable to the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

Each state and municipality in the United States and each province in Canada that adopts or accepts one or more Sections of the Boiler and Pressure Vessel Code is invited to appoint a representative to act on the Conference Committee to the Boiler and Pressure Vessel Committee. Since the members of the Conference Committee are in active contact with the administration and enforcement of the rules, the requirements for inspection in this Code correspond with those in effect in their respective jurisdictions. The required qualifications for an Authorized Inspector under these rules may be obtained from the administrative authority of any state, municipality, or province which has adopted these rules.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, method of fabrication, inspection, and safety devices. Permission may be granted to regulatory bodies and organizations publishing safety standards to use a complete Section of the Code by reference. If usage of a Section, such as Section IX, involves exceptions, omissions, or changes in provisions, the intent of the Code might not be attained.

Where a state or other regulatory body, in the printing of any Section of the Boiler and Pressure Vessel Code, makes

additions or omissions, it is recommended that such changes be clearly indicated.

The National Board of Boiler and Pressure Vessel Inspectors is composed of chief inspectors of states and municipalities in the United States and of provinces in Canada that have adopted the Boiler and Pressure Vessel Code. This Board, since its organization in 1919, has functioned to uniformly administer and enforce the rules of the Boiler and Pressure Vessel Code. The cooperation of that organization with the Boiler and Pressure Vessel Committee has been extremely helpful.

The Code Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The Scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Code for vessels or components not considered to be within its Scope or may establish additions or deletions in that Scope. Accordingly, inquiries regarding such laws or regulations are to be directed to the issuing enforcement or regulatory body.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the ASME Boiler and Pressure Vessel Committee. ASME is to be notified should questions arise concerning improper use of an ASME Code symbol.

The specifications for materials given in Section II are identical with or similar to those of specifications published by ASTM, AWS, and other recognized national or international organizations. When reference is made in an ASME material specification to a non-ASME specification for which a companion ASME specification exists, the reference shall be interpreted as applying to the ASME material specification. Not all materials included in the material specifications in Section II have been adopted for use in this Section. Usage is limited to those materials and grades listed in at least one of the tables of Section II, Part D, Subpart 1, identified as applicable to this Section. All materials allowed by this Section and used for construction within the scope of these rules shall be furnished in accordance with material specifications

Page ix

contained in Section II or referenced in Appendices A of Section II, Parts A and B except where otherwise provided in Code Cases or in this Section of the Code. Materials covered by these specifications are acceptable for use in items covered by the Code Sections only to the degree indicated in the applicable Section. Materials for Code use should preferably be ordered, produced, and documented on this basis. Material produced to an acceptable specification with requirements different from the requirements of the corresponding specification listed in Appendix A of Part A or Part B may also be used in accordance with the above, provided the material manufacturer or vessel manufacturer certifies with evidence acceptable to the Authorized Inspector that the corresponding ASME specification requirements of specifications listed in Appendix A of Part A or Part B have been met. Material produced to an acceptable material specification is not limited as to country of origin.

When required by context in this Section, the singular shall be interpreted as the plural, and vice-versa; and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

Publication of the SI (Metric) Edition of the ASME Boiler and Pressure Vessel Code was discontinued with the 1986 Edition. Effective October 1, 1986, the SI Edition was withdrawn as an ASME Boiler and Pressure Vessel Code document.

Page xi

STATEMENT OF POLICY ON THE USE OF CODE SYMBOLS AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use Code Symbols for marking items or constructions which have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the symbols,

Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications which might so indicate. An organization holding a Code Symbol and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code."

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified items will carry the symbol. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

The ASME logo, which is the cloverleaf with the letters ASME within, shall not be used by any organization other than ASME.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Code Symbol Stamp described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the various Code Symbols shall not be used on any item which is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME which tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

Page xiii

PERSONNEL ASME Boiler and Pressure Vessel Committee Subcommittees, Subgroups, and Working Groups

As of December 31, 1997

MAIN COMMITTEE

D. A. Canonico, *Chair*

G. G. Karcher, *Vice Chair*

J. S. Brzuszkiewicz, *Secretary*

R. W. Barnes

F. P. Barton

D. L. Berger

M. D. Bernstein

M. N. Bressler

W. J. Carter

T. M. Cullen

J. R. Farr

R. E. Feigel

J. G. Feldstein

M. Gold

O. F. Hedden

A. J. Justin

D. F. Landers
W. M. Lundy
J. R. MacKay
T. J. Mawson
T. G. McCarty
G. C. Millman
R. A. Moen
C. C. Neely
C. J. Pieper
R. F. Reedy
B. W. Roberts
F. J. Schaaf, Jr.
A. Selz
K. K. Tam
D. E. Tanner

EXECUTIVE COMMITTEE (MAIN COMMITTEE)

G. G. Karcher, *Chair*
D. A. Canonico, *Vice Chair*
J. S. Brzuszkiewicz, *Secretary*
F. P. Barton
J. R. Farr
J. G. Feldstein
M. Gold
O. F. Hedden
A. J. Justin
J. R. MacKay
T. G. McCarty
T. P. Pastor
T. E. Quaka
R. F. Reedy
A. J. Spencer

HONORARY MEMBERS (MAIN COMMITTEE)

R. D. Bonner
R. J. Bosnak
H. M. Canavan
L. J. Chockie
J. S. Clarke
W. E. Cooper
W. D. Doty
R. C. Griffin
E. J. Hemzy
E. C. Kistner, Jr.
J. E. Lattan
J. LeCoff
F. N. Moschini

C. E. Rawlins
W. E. Somers
L. P. Zick, Jr.

HONORS AND AWARDS COMMITTEE

J. R. MacKay, *Chair*
A. J. Spencer, *Vice Chair*
F. R. Lyons, *Secretary*
F. P. Barton
W. J. Carter
J. G. Feldstein
M. Gold
F. E. Gregor
E. C. Kistner, Jr.
T. P. Pastor
R. F. Reedy

MARINE CONFERENCE GROUP

J. Tiratto, *Chair*
C. F. Banks
L. W. Douthwaite
J. L. Jones
G. F. Wright

CONFERENCE COMMITTEE

D. E. Tanner - Tennessee (*Chair*)
R. D. Reetz - North Dakota (*Vice Chair*)
A. J. Justin - National Board of Boiler and Pressure Vessel Inspectors (*Secretary*)
R. J. Aben, Jr. - Michigan
J. S. Aclaro - Los Angeles, California
E. A. Anderson - Chicago, Illinois
J. Anderson - South Dakota
R. Barkdoll - Washington
F. P. Barton - Virginia
C. Castle - Nova Scotia, Canada
R. R. Cate - Louisiana
L. Chase - Northwest Territories, Canada
R. A. Coomes - Kentucky
J. Corcoran - Connecticut
M. H. Diehl, Jr. - Maryland
D. A. Douin - Illinois
D. Eastman - Newfoundland and Labrador, Canada
G. L. Ebeyer - New Orleans, Louisiana
F. Ellis - New Hampshire
E. Everett - Georgia
P. C. Hackford - Utah
D. Hanrath - North Carolina
J. B. Harlan - Delaware
K. Hynes - Prince Edward Island, Canada

K. Hynes - Prince Edward Island, Canada
D. T. Jagger - Ohio
D. J. Jenkins - Kansas
M. Kotb - Quebec, Canada
J. P. Larson - Minnesota
K. T. Lau - Alberta, Canada
J. Lemire - California
G. A. Lundberg - Florida
W. C. Lundine - Oregon
M. A. Malek - Maine
I. W. Mault - Manitoba, Canada
H. T. McEwen - Mississippi
A. W. Meiring - Indiana
R. Mile - Ontario, Canada
T. J. Monroe - Oklahoma
Y. Nagpaul - Hawaii
J. D. Payton - Pennsylvania
D. K. Peetz - Missouri
D. C. Price - Yukon Territory, Canada
R. S. Pucek - Wisconsin
T. E. Rennie - Arizona
L. Roussinos - British Columbia, Canada
M. Shuff - West Virginia
R. Snyder - New Jersey
N. Surtees - Saskatchewan, Canada
M. J. Verhagen - Wisconsin
R. B. West - Iowa
M. J. Wheel - Vermont
K. A. White - Nevada
R. K. White - New York
T. F. Wickham - Rhode Island
C. S. Withers - Colorado

SUBCOMMITTEE ON POWER BOILERS (SC I)

J. R. MacKay, *Chair*
M. D. Bernstein, *Vice Chair*
P. D. Stumpf, *Secretary*
D. L. Berger
E. Everett
D. N. French
F. R. Gerety
J. Hainsworth
T. E. Hansen
J. S. Hunter
W. L. Lowry
T. C. McGough
P. A. Molvie

D. K. Parrish
J. T. Pillow
R. G. Presnak
B. W. Roberts
R. D. Schueler, Jr.
R. V. Wielgoszinski
R. L. Williams

Page xiii

Subgroup on Design (SC I)

M. D. Bernstein, *Chair*
R. D. Schueler, Jr., *Vice Chair*
P. A. Molvie, *Secretary*
M. A. Farrugia
J. D. Fishburn
C. F. Jeerings
K. C. Morrison
A. Nassif
N. Surtees
R. V. Wielgoszinski

Subgroup on Fabrication and Examination (SC I)

D. L. Berger, *Chair*
R. E. McLaughlin, *Secretary*
R. W. Boyce
D. N. French
J. Hainsworth
T. E. Hansen
M. H. Iken
J. M. Lyons
J. T. Pillow
M. E. Reese
R. D. Schueler, Jr.
R. F. Slack, Sr.
R. V. Wielgoszinski

Subgroup on General Requirements (SC I)

T. C. McGough, *Chair*
M. D. Bernstein, *Vice Chair*
W. L. Lowry, *Secretary*
D. L. Berger
E. Everett
F. R. Gerety
J. Hainsworth
C. F. Jeerings
J. M. Lyons
R. E. McLaughlin
D. K. Parrish
J. T. Pillow

W. E. Somers
R. L. Williams

Subgroup on Materials (SC I)

B. W. Roberts, *Chair*
C. E. Spaeder, Jr., *Chair*
J. S. Hunter, *Secretary*
T. M. Cullen
D. N. French
J. F. Henry
J. P. Libbrecht
F. Masuyama
J. M. Tanzosh

Subgroup on Piping (SC I)

T. E. Hansen, *Chair*
D. L. Berger
M. D. Bernstein
P. D. Edwards
W. L. Lowry
T. C. McGough
R. G. Presnak
E. Whittle
P. L. Ziegler

SUBCOMMITTEE ON MATERIALS (SC II)

M. Gold, *Chair*
T. M. Cullen, *Vice Chair*
F. R. Lyons, *Secretary*
A. P. Ahrendt
M. N. Bressler
A. Cohen
R. Dirscherl
W. D. Doty
W. D. Edsall
D. Gandy
M. H. Gilkey
J. J. Heger
J. F. Henry
G. C. Hsu
F. Masuyama
E. Michalopoulos
R. A. Moen
R. K. Nanstad
E. G. Nisbett
J. T. Parsons
D. W. Raho
B. W. Roberts

E. Shapiro
C. E. Spaeder, Jr.
R. W. Swindeman
J. M. Tanzosh
B. E. Thurgood
A. W. Zeuthen

Subgroup on External Pressure (SC II)

R. W. Mikitka, *Chair*
D. J. Green
D. S. Griffin
E. Michalopoulos
B. R. Morelock
D. Nadel
C. E. Spaeder, Jr.
C. H. Sturgeon

Subgroup on Ferrous Specifications (SC II)

E. G. Nisbett, *Chair*
B. M. Dingman
W. D. Edsall
T. Graham
W. N. Holliday
E. A. Jonas
D. C. Krouse
J. F. Longenecker
W. C. Mack
A. S. Melilli
J. T. Parsons
E. J. Rozic, Jr.
E. Uptis
A. W. Zeuthen
R. H. Zong

Subgroup on International Material Specifications (SC II)

J. T. Parsons, *Chair*
D. C. Agarwal
J. Cameron
R. Dirscherl
W. D. Doty
D. M. Fryer
M. Gold
M. H. Iken
W. M. Lundy
H. Masahisa
T. F. Miskell
F. Osweiller
A. P. Povilonis

R. D. Schueler, Jr.
R. R. Seeley
E. A. Steen
E. Uptis
E. O. Woolridge

Subgroup on Nonferrous Alloys (SC II)

D. W. Rahoi, *Chair*
D. C. Agarwal, *Secretary*
W. R. Apblett
L. G. Coffee
A. Cohen
R. Dirscherl
M. H. Gilkey
G. C. Hsu
M. Katcher
E. Shapiro
L. E. Shoemaker
R. C. Sutherlin

Subgroup on Strength, Ferrous Alloys (SC II)

B. W. Roberts, *Chair*
J. M. Tanzosh, *Secretary*
A. P. Ahrendt
W. R. Apblett
T. M. Cullen
M. Gold
J. J. Heger
C. L. Hoffmann
A. Iseda
F. Masuyama
R. A. Moen
D. W. Rahoi
C. E. Spaeder, Jr.
R. W. Swindeman
B. E. Thurgood

Subgroup on Strength of Weldments (SC II & SC IX)

C. E. Spaeder, Jr., *Chair*
W. D. Doty
D. W. Rahoi
B. W. Roberts
C. Robino
W. J. Sperko
J. M. Tanzosh
B. E. Thurgood

Subgroup on Toughness (SC II)

J. M. Barsom

D. A. Hansen
A. Selz
R. S. Vecchio
S. Yukawa
R. Zawierucha

Page xv

SUBCOMMITTEE ON NUCLEAR POWER (SC III)

C. J. Pieper, *Chair*
R. M. Jessee, *Vice Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
Y. Asada
R. W. Barnes
J. N. Baysden
W. H. Borter
E. B. Branch
M. N. Bressler
F. C. Cherny
G. D. Cooper
R. P. Deubler
W. D. Doty
F. R. Drahos
K. Ennis
B. A. Erler
D. Hanrath
C. L. Hoffmann
K.-H. Hsu
D. F. Landers
W. C. LaRochelle
T. J. Mawson
W. N. McLean
R. A. Moen
D. B. Nickerson
R. F. Perrin
R. F. Reedy
M. W. Smith
J. D. Stevenson
R. E. Tome
K. R. Wichman

Subgroup on Containment Systems for Spent Fuel and High-Level Waste Transport Packagings (SC III)

J. D. Stevenson, *Chair*
H. H. Chung
R. R. Doggart
E. L. Farrow
K. Goldmann
R. H. Jones

R. H. Jones
W. H. Lake
R. W. Lambert
H. W. Lee
P. McConnell
R. E. Nickell
D. J. Nolan
D. T. Raske
T. Saegusa
R. H. Smith
K. B. Sorenson
P. Turula
N. Urabe
C. R. Witt
S. Yukawa

Subgroup on Design (SC III)

R. W. Barnes, *Chair*
E. B. Branch, *Vice Chair*
R. S. Hill III, *Secretary*
Y. Asada
M. N. Bressler
C. W. Bruny
J. R. Cole
G. D. Cooper
R. P. Deubler
N. W. Edwards
R. E. Gimple
D. Hanrath
R. W. Haupt
T. Iida
B. Jarman
D. F. Landers
W. N. McLean
D. B. Nickerson
E. C. Rodabaugh
J. R. Santangelo
G. C. Slagis
J. D. Stevenson
J. H. Wawrzeniak
K. R. Wichman
R. Wray

Working Group on Administration (SG-D) (SC III)

E. B. Branch, *Chair*
R. W. Barnes, *Vice Chair*
R. S. Hill III, *Secretary*
C. W. Bruny

G. D. Cooper
R. P. Deubler
J. T. Land
D. F. Landers
W. N. McLean
D. B. Nickerson
J. R. Santangelo
R. Wray

Working Group on Core Support Structures (SG-D) (SC III)

J. T. Land, *Chair*
R. H. Hansen
K. B. Larsen
J. F. Mullooly
B. L. Silverblatt

Working Group on Dynamic and Extreme Load Conditions (SG-D) (SC III)

R. Wray, *Chair*
A. E. Meligi, *Secretary*
P. L. Anderson
M. K. Au-Yang
R. D. Blevins
G. J. Bohm
D. L. Caldwell
P.-Y. Chen
A. Hadjian
M. Hartzman
W. S. LaPay
H. Lockert
P. R. Olson
R. F. Perry
J. Wallach

Working Group on Piping (SG-D) (SC III)

D. F. Landers, *Chair*
R. S. Hill III, *Vice Chair*
P. Hirschberg, *Secretary*
T. M. Adams
G. A. Antaki
J. R. Cole
A. B. Glickstein
R. W. Haupt
J. C. Hennart
R. D. Hookway
R. B. Jenkins
K. A. Manoly
J. C. Minichiello
S. E. Moore

A. N. Nguyen
D. B. Nickerson
O. O. Oyamada
R. D. Patel
E. C. Rodabaugh
J. R. Santangelo
M. S. Sills
G. C. Slagis
E. A. Wais

Working Group on Pumps (SG-D) (SC III)

D. B. Nickerson, *Chair*
H. L. Brammer
P. Burchett
R. E. Cornman, Jr.
A. A. Fraser
M. Higuchi
G. R. Jones
J. W. Leavitt
J. E. Livingston
R. A. Schussler
H. Tafarrodi
G. K. Vaghasia

Working Group on Supports (SG-D) (SC III)

R. P. Deubler, *Chair*
R. M. Dulin, Jr., *Secretary*
U. S. Bandyopadhyay
F. J. Birch
M. N. Bressler
J. R. Cole
J. C. Finneran, Jr.
R. W. Haupt
J. C. Hennart
A. S. Laurenson
A. Lee
R. J. Masterson
A. E. Meligi
A. N. Nguyen
J. R. Stinson

Working Group on Valves (SG-D) (SC III)

W. N. McLean, *Chair*
E. A. Bake
R. R. Brodin
W. G. Knecht
R. Koester
J. J. McGavin
S. N. Shields

S. N. Shields
H. R. Sonderegger
J. C. Tsacoyeanes
R. G. Visalli
J. R. Zahorsky

Working Group on Vessels (SG-D) (SC III)

C. W. Bruny, *Chair*
T. K. Burr, Sr.
G. D. Cooper
G. A. Deaver
N. W. Edwards
D. Hanrath
W. J. Heilker
B. Jarman
T. M. Khan
O. Maekawa
K. A. Manoly
A. Merend
G. K. Miller
W. Z. Novak
E. Pelling
H. S. Thornton

Page xvi

Special Working Group on Environmental Effects (SG-D) (SC III)

R. S. Hill III, *Chair*
Y. Asada
W. J. Heilker
C. L. Hoffmann
R. A. Moen
W. Z. Novak
S. Yukawa

Special Working Group on Seismic Piping Rules (SG-D) (SC III)

E. B. Branch, *Chair*
T. M. Adams
G. A. Antaki
R. D. Hookway
J. C. Minichiello
M. S. Sills
E. A. Wais

Subgroup on General Requirements (SC III & SC 3C)

W. C. LaRochelle, *Chair*
K. Ennis, *Secretary*
A. Appleton
J. R. Barbee
J. N. Baysden

L. M. Beason
B. H. Berg
R. E. Kelley
G. S. Korin
A. S. Laurensen
C. Lizotte
M. J. Meyer
M. R. Minick
L. C. Oakes
R. F. Perrin
U. Potapovs
B. B. Scott
D. E. Tanner
D. V. Walshe

Subgroup on Materials, Fabrication, and Examination (SC III)

C. L. Hoffmann, *Chair*
G. P. Milley, *Secretary*
C. W. Allison
D. Doyle
F. R. Drahos
G. M. Foster
G. B. Georgiev
J. E. Harris
R. W. Jackson
R. M. Jessee
C. C. Kim
R. A. Moen
C. J. Pieper
R. R. Seeley
N. M. Simpson
R. C. Soin
W. J. Sperko
K. B. Stuckey
S. Yukawa

Subgroup on Pressure Relief (SC III)

F. C. Cherny, *Chair*
S. F. Harrison, Jr.
E. M. Petrosky
M. W. Smith
A. L. Szeglin
B. S. York
J. R. Zahorsky

Special Working Group on Editing and Review (SC III)

R. F. Reedy, *Chair*
W. H. Borter
M. N. Bressler

R. P. Deubler
B. A. Erler
W. C. LaRochelle
M. W. Smith
J. D. Stevenson
E. O. Woolridge

JOINT ACI-ASME COMMITTEE ON CONCRETE COMPONENTS FOR NUCLEAR SERVICE (SC 3C)

B. A. Erler, *Chair*
C. A. Sanna, *Secretary*
J. P. Allen III
R. M. Attar
A. C. Eberhardt
J. Gutierrez
D. J. Haavik
M. F. Hessheimer
T. E. Johnson
G. R. Murphy
S. F. Putman
B. B. Scott
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Design (SC 3C)

D. G. Adams
A. C. Eberhardt
T. E. Johnson
S. F. Putman
R. E. Shewmaker
J. D. Stevenson
A. Y. Wong

Subgroup on Materials, Construction, and Examination (SC 3C)

D. J. Haavik, *Chair*
J. F. Artuso
R. M. Attar
B. A. Erler
J. Gutierrez

SUBCOMMITTEE ON HEATING BOILERS (SC IV)

F. P. Barton, *Chair*
P. A. Molvie, *Vice Chair*
B. P. Feder, *Secretary*
R. B. Duggan
W. L. Haag, Jr.
W. M. Hiddleston
J. D. Hoh

K. M. McTague
R. I. Mullican
E. A. Nordstrom
J. L. Seigle
D. E. Tanner
S. V. Voorhees
R. H. Weigel
R. V. Wielgoszinski
J. I. Woodworth
T. L. Bedeaux, Alternate

Subgroup on Care and Operation of Heating Boilers (SC IV)

J. I. Woodworth, *Chair*
B. P. Feder, *Secretary*
K. J. Hoey
J. D. Hoh
F. M. Lucas
K. M. McTague
P. A. Molvie
R. I. Mullican
R. H. Weigel
T. F. Wickham
T. L. Bedeaux, Alternate

Subgroup on Cast Iron Boilers (SC IV)

K. M. McTague, *Chair*
R. B. Duggan
R. H. Weigel
T. F. Wickham
J. I. Woodworth
T. L. Bedeaux, Alternate

Subgroup on Water Heaters (SC IV)

W. L. Haag, Jr., *Chair*
T. D. Gantt
W. M. Hiddleston
F. M. Lucas
K. M. McTague
R. I. Mullican
D. Smith
D. E. Tanner
M. A. Taylor

Subgroup on Welded Boilers (SC IV)

P. A. Molvie, *Chair*
T. L. Bedeaux
D. H. Mapes
E. A. Nordstrom
J. L. Seigle

R. F. Slack, Sr.
R. P. Sullivan
D. E. Tanner
R. V. Wielgoszinski

SUBCOMMITTEE ON NONDESTRUCTIVE EXAMINATION (SC V)

T. G. McCarty, *Chair*
J. E. Batey, *Vice Chair*
F. S. Fitzgerald, *Secretary*
A. S. Birks
B. H. Clark, Jr.
W. T. Clayton
R. A. Coomes
N. Y. Faransso
H. C. Graber
O. F. Hedden
G. W. Hembree
F. B. Kovacs
J. F. Manning
W. C. McGaughey
R. D. McGuire

Page xvii

Subgroup on General Requirements/Personnel Qualifications and Inquiries (SC V)

R. D. McGuire, *Chair*
J. E. Batey
W. T. Clayton
N. Y. Faransso
H. C. Graber
G. W. Hembree
J. R. MacKay
J. P. Swezy

Subgroup on Surface Examination Methods (SC V)

H. C. Graber, *Chair*
S. J. Akrin
T. Alexander
A. S. Birks
B. H. Clark
R. A. Coomes
G. W. Hembree

Subgroup on Volumetric Methods (SC V)

J. E. Batey, *Chair*
S. J. Akrin
W. T. Clayton
N. Y. Faransso
H. C. Graber
G. W. Hembree

B. Kellerhall
E. K. Kietzman
F. B. Kovacs
R. W. Kruzic
J. F. Manning
W. C. McGaughey
J. R. Mitchell

Working Group on Acoustic Emissions (SG-VM) (SC V)

B. H. Clark, Jr.
P. M. Horrigan
J. F. Manning
J. R. Mitchell

Working Group on Radiography (SG-VM) (SC V)

G. W. Hembree, *Chair*
S. J. Akrin
T. Alexander
J. E. Batey
N. Y. Faransso
H. C. Graber
F. B. Kovacs

Working Group on Ultrasonics (SG-VM) (SC V)

W. T. Clayton, *Chair*
O. F. Hedden
B. Kellerhall
E. K. Kietzman
J. F. Manning
W. C. McGaughey
R. Paillaman
F. J. Sattler
M. L. Shakinovsky

SUBCOMMITTEE ON PRESSURE VESSELS (SC VIII)

T. P. Pastor, *Chair*
K. Mokhtarian, *Vice Chair*
A. J. Roby, *Secretary*
A. P. Ahrendt
V. Bogosian
S. M. Caldwell
W. J. Carter
S. C. Cyr
R. Dirscherl
R. M. Elliott
J. R. Farr
R. E. Feigel
J. G. Feldstein
G. L. Hollinger

M. J. Houle
W. S. Jacobs
G. G. Karcher
G. B. Komora
K. T. Lau
R. W. Mikitka
U. R. Miller
C. C. Neely
K. J. Schneider
A. Selz
J. R. Sims, Jr.
A. J. Spencer
E. A. Steen
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Design (SC VIII)

U. R. Miller, *Chair*
R. E. Knoblock, *Secretary*
M. R. Bauman
M. R. Breach
S. M. Caldwell
N. W. Edwards
J. R. Farr
J. A. Hayward
G. L. Hollinger
W. S. Jacobs
G. G. Karcher
G. B. Komora
R. W. Mikitka
K. Mokhtarian
T. P. Pastor
M. D. Rana
A. Selz
S. C. Shah
J. W. Stokes
K. K. Tam
E. L. Thomas, Jr.

Subgroup on Fabrication and Inspection (SC VIII)

E. A. Steen, *Chair*
K. Mokhtarian, *Vice Chair*
W. J. Bees
R. W. Boyce
S. C. Cyr
R. E. Feigel
H. E. Gordon
M. J. Houle

W. S. Jacobs
R. A. Johnson
A. S. Lester III
F. C. Ouyang
M. J. Rice
W. P. Webb

Subgroup on General Requirements (SC VIII)

R. M. Elliott, *Chair*
A. P. Ahrendt
V. Bogosian
W. J. Carter
W. P. Crow
J. P. Glaspie
C. R. Good
D. B. Kadakia
J. C. Keenan
W. E. Laveck, Jr.
A. S. Mann
C. C. Neely
A. S. Olivares
K. J. Schneider
A. J. Spencer

Subgroup on Materials (SC VIII)

R. Dirscherl, *Chair*
D. C. Agarwal
A. P. Ahrendt
J. Cameron
W. D. Doty
W. D. Edsall
M. Katcher
W. M. Lundy
E. E. Morgenegg
E. G. Nisbett
J. T. Parsons
D. W. Rahoi
K. K. Tam
B. K. Thakur

Special Working Group on Heat Transfer Equipment (SC VIII)

G. B. Komora, *Chair*
R. P. Zoldak, *Secretary*
C. F. Andreone
D. E. Bolt
S. M. Caldwell
T. K. Haldas
M. J. Holtz

W. G. Jandrasits
R. Mahadeen
U. R. Miller
F. Osweiller
J. E. Soehrens
A. I. Soler
W. A. Treff
S. Yokell

Page xviii

Special Working Group on High-Pressure Vessels (SC VIII)

J. R. Sims, Jr., *Chair*
P. A. Reddington, *Secretary*
L. P. Antalffy
J. E. Baxter
R. C. Biel
T. B. Boyd
D. J. Burns
P. N. Chaku
E. L. Danfelt
R. E. Feigel
D. M. Fryer
J. L. Heck, Jr.
A. H. Honza
V. T. Hwang
M. M. James
P. Jansson
J. A. Kapp
D. P. Kendall
A. K. Khare
S. C. Mordre
G. J. Mraz
E. H. Perez
L. M. Picqueur
E. D. Roll
W. L. Stewart
J. F. Sullivan
F. W. Tatar

Special Working Group on Toughness (SC VIII)

W. S. Jacobs, *Chair*
J. Cameron
W. D. Doty
D. A. Hansen
G. G. Karcher
G. B. Komora
K. Mokhtarian

J. L. Mooney
C. C. Neely
M. D. Rana
J. W. Stokes

SUBCOMMITTEE ON WELDING (SC IX)

J. G. Feldstein, *Chair*
W. J. Sperko, *Vice Chair*
J. Labrador, *Secretary*
R. Barkdoll
D. A. Bowers
M. L. Carpenter
W. D. Doty
P. D. Flenner
M. J. Houle
R. A. Johnson
W. M. Lundy
R. D. McGuire
J. J. Meyer
A. H. Miller
B. R. Newmark
P. P. Norris
S. D. Reynolds, Jr.
W. K. Scattergood
G. W. Spohn III
M. J. Stanko
J. M. Tanzosh
R. R. Young

Subgroup on Brazing (SC IX)

M. J. Houle, *Chair*
A. S. Artayet
M. L. Carpenter
C. F. Jeerings
A. H. Miller
C. Robino

Subgroup on General Requirements (SC IX)

B. R. Newmark, *Chair*
R. Barkdoll
P. R. Evans
P. C. Filean
R. M. Jessee
D. W. Mann
A. S. Olivares
C. E. Wainwright
R. A. Weiss
K. R. Willens

Subgroup on Materials (SC IX)

M. L. Carpenter, *Chair*
L. P. Connor
P. D. Flenner
R. M. Jessee
A. H. Miller
H. A. Sadler
C. E. Sainz
C. E. Spaeder, Jr.
W. J. Sperko
M. J. Stanko
R. R. Young

Subgroup on Performance Qualification (SC IX)

J. J. Meyer, *Chair*
V. A. Bell
D. A. Bowers
L. P. Connor
R. A. Coomes
P. D. Flenner
G. Herrmann
M. J. Houle
W. M. Lundy
R. D. McGuire
S. R. Nordman
P. P. Norris
W. K. Scattergood
G. W. Spohn III

Subgroup on Procedure Qualification (SC IX)

J. J. Meyer, *Chair*
R. K. Brown, Jr.
R. A. Johnson
A. H. Miller
P. P. Norris
A. S. Olivares
F. C. Ouyang
S. D. Reynolds, Jr.
M. J. Rice
W. K. Scattergood
W. J. Sperko
T. C. Wiesner

SUBCOMMITTEE ON FIBER-REINFORCED PLASTIC PRESSURE VESSELS (SC X)

P. J. Conlisk, *Chair*
D. Eisberg, *Vice Chair*
A. J. Roby, *Secretary*
K. M. Agrawal

F. L. Brown
J. L. Bustillos
T. W. Cowley
T. J. Fowler
S. V. Hoa
L. E. Hunt
J. C. Murphy
A. L. Newberry
D. J. Painter
J. A. Rolston
B. F. Shelley
P. R. Wilt

SUBCOMMITTEE ON NUCLEAR INSERVICE INSPECTION (SC XI)

O. F. Hedden, *Chair*
T. J. Mawson, *Vice Chair*
G. L. Fechter, *Secretary*
C. W. Allison
W. H. Bamford, Jr.
R. L. Beverly
J. M. Bloom
R. W. Boyce
C. D. Cowfer
D. D. Davis
R. L. Dyle
T. N. Epps III
R. E. Gimple
F. E. Gregor
L. B. Gross
K. Iida
C. A. Ireland
R. D. Kerr
D. F. Landers
T. F. Lentz
J. T. Lindberg
G. C. Millman
C. R. Osman
P. C. Riccardella
L. Sage
F. J. Schaaf, Jr.
J. E. Staffiera
R. P. Sullivan
R. W. Swayne
R. J. Tamminga
J. C. Tobin
R. A. Yonekawa

Honorary Members (SC XI)

S. H. Bush
L. J. Chockie
J. P. Houstrup
L. R. Katz
R. R. MacCary

Page xix

Subgroup on Evaluation Standards (SC XI)

W. H. Bamford, Jr., *Chair*
M. Kupinski, *Secretary*
J. M. Bloom
R. C. Cipolla
R. M. Gamble
T. J. Griesbach
P. J. Hijeck
K. Iida
Y. Imamura
J. G. Merkle
S. Ranganath
P. C. Riccardella
D. A. Scarth
W. L. Server
C. A. Tomes
W. A. Van Der Sluys
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa

Working Group on Flaw Evaluation (SG-ES) (SC XI)

R. C. Cipolla, *Chair*
W. H. Bamford, Jr.
M. Basol
J. M. Bloom
E. Friedman
T. J. Griesbach
F. D. Hayes
D. N. Hopkins
K. Iida
Y. Imamura
M. Kupinski
H. S. Mehta
J. G. Merkle
J. S. Panesar
R. K. Qashu
S. Ranganath
D. A. Scarth
T. S. Schurman

W. L. Server
F. A. Simonen
K. R. Wichman
G. M. Wilkowski
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Working Group on Operating Plant Criteria (SG-ES) (SC XI)

T. J. Griesbach, *Chair*
W. H. Bamford, Jr.
H. Behnke
B. A. Bishop
W. F. Brady
E. Friedman
S. R. Gosselin
E. M. Hackett
P. J. Hijeck
S. D. Leshnoff
P. Manbeck
J. S. Panesar
W. E. Pennell
J. H. Phillips
S. Ranganath
S. T. Rosinski
W. L. Server
E. A. Siegel
F. A. Simonen
T. D. Spry
K. K. Yoon
S. Yukawa

Working Group on Pipe Flaw Evaluation (SG-ES) (SC XI)

D. A. Scarth, *Chair*
G. M. Wilkowski, *Secretary*
W. H. Bamford, Jr.
J. M. Bloom
R. C. Cipolla
N. G. Cofie
S. K. Daftuar
G. H. De Boo
E. Friedman
D. N. Hopkins
K. Iida
H. S. Mehta
J. G. Merkle

J. S. Panesar
D. Quinones
K. K. Yoon
S. Yukawa
A. Zahoor
V. A. Zilberstein

Subgroup on Liquid-Metal-Cooled Systems (SC XI)

C. G. McCargar, *Chair*
W. L. Chase
S. Hattori
R. Hundal
W. Kwant
J. C. Tobin

Working Group on Liquid-Metal Reactor Covers (SG-LMCS) (SC XI)

W. L. Chase, *Chair*
S. Hattori
R. Hundal
W. Kwant

Subgroup on Nondestructive Examination (SC XI)

R. L. Beverly, *Chair*
N. R. Bentley, *Secretary*
D. C. Adamonis
F. L. Becker
F. T. Carr
C. B. Cheezem
W. T. Clayton
C. D. Cowfer
F. J. Dodd
T. N. Epps III
D. O. Henry
M. R. Hum
S. N. Liu
R. D. McGuire
M. C. Modes
C. R. Osman
F. J. Schaaf, Jr.
J. C. Spanner, Jr.
C. J. Wirtz

Working Group on Personnel Qualification and Surface Visual and Eddy Current Examination (SG-NDE) (SC XI)

C. J. Wirtz, *Secretary*
B. L. Curtis
N. Economos
H. B. Garland
D. O. Henry
H. E. Houserman

J. J. McArdle III
R. D. McGuire
S. A. Redner
M. F. Sherwin
A. L. Smith
D. Spake
J. C. Spanner, Sr.
J. C. Spanner, Jr.
T. V. Tran

Working Group on Pressure Testing (SG-NDE) (SC XI)

G. P. Alexander
T. M. Anselmi
T. B. Basso
J. Boughman
T. R. Bugelhoff
R. J. Cimoch
C. E. Jensen
W. N. Keisler
D. Lamond
F. J. Schaaf, Jr.
D. Terao

Working Group on Procedure Qualification and Volumetric Examination (SG-NDE) (SC XI)

C. D. Cowfer, *Chair*
C. E. Larsen, *Secretary*
D. C. Adamonis
F. L. Becker
N. R. Bentley
B. Bevins
F. T. Carr
C. B. Cheezem
W. T. Clayton
S. R. Doctor
F. J. Dodd
T. N. Epps III
B. Kellerhall
G. A. Lofthus
J. K. McClanahan
M. C. Modes
M. Saporito
T. T. Taylor
S. M. Walker

Subgroup on Repairs, Replacements, and Modifications (SC XI)

R. E. Gimple, *Chair*
W. C. Holston, *Secretary*
R. W. Boyce

M. N. Bressler
S. B. Brown
C. E. Hartz
R. A. Hermann
C. A. Ireland
R. D. Kerr
D. F. Landers
R. S. Lewis
T. J. Mawson
M. S. McDonald
R. R. Stevenson
R. P. Sullivan
R. W. Swayne
R. E. Tome
D. E. Waskey
R. A. Yonekawa

Page xx

Working Group on Design Reconciliation (SG-RR & M) (SC XI)

W. C. Holston, *Chair*
J. T. Conner, *Secretary*
R. W. Boyce
S. B. Brown
J. E. Charnley
T. E. Hiss
E. V. Imbro
D. N. Irvine, Jr.
D. F. Landers
R. W. Swayne
F. Tehranchi
H. J. Thailer
R. E. Tome

Working Group on Responsibilities and Program Requirements (SG-RR&M) (SC XI)

R. A. Yonekawa, *Chair*
R. R. Stevenson, *Secretary*
S. K. Fisher
G. M. Foster
C. E. Hartz
R. S. Lewis
M. S. McDonald
U. Potapovs
S. M. Swilley
A. J. Walcutt
J. Ghergurovich, *Alternate*

Working Group on Welding and Special Repair Processes (SG-RR&M) (SC XI)

D. E. Waskey, *Chair*

R. E. Cantrell, *Secretary*
D. A. Delsignore
A. L. Finney
P. D. Fisher
A. J. Giannuzzi
R. A. Hermann
R. P. Indap
R. D. Kerr
B. R. Newton
P. P. Norris
J. E. O'Sullivan
J. H. Sodergren
K. R. Willens

Subgroup on Water-Cooled Systems (SC XI)

T. F. Lentz, *Chair*
K. Christian, *Secretary*
C. W. Allison
W. J. Briggs
T. R. Bugelholz
D. D. Davis
A. F. Deardorff
R. L. Dyle
L. B. Gross
T. C. Hinkle
S. D. Kulat
M. P. Lintz
J. E. Staffiera
C. W. Tahnk
R. J. Tamminga
D. Terao
S. M. Walker
R. A. West

Working Group on Concrete Containment (SG-WCS) (SC XI)

W. J. Briggs, *Chair*
B. Talmadge, *Secretary*
H. G. Ashar
K. K. N. Chao
M. J. Ferlisi
H. T. Hill
R. D. Hough
C. N. Krishnaswamy
D. Naus
S. C. Petitgout
C. G. Ranganath

Working Group on Implementation of Risk-Based Examination (SG-WCS) (SC XI)

T. J. Mawson, *Chair*

A. McNeill III, *Secretary*

J. Agold

S. A. Ali

B. A. Bishop

J. W. Connor

A. F. Deardorff

H. Q. Do

R. Fougrousse

S. R. Gosselin

J. T. Lindberg

I. Mach

R. K. Mattu

P. J. O'Regan

J. H. Phillips

F. A. Simonen

T. V. Vo

R. A. West

Working Group on Inspection of Systems and Components (SG-WCS) (SC XI)

R. L. Dyle, *Chair*

G. C. Park, *Secretary*

G. L. Belew

T. W. Brombach

R. Fougrousse

T. C. Hinkle

M. R. Hum

S. D. Kulat

J. T. Lindberg

M. P. Lintz

T. K. McLellan

C. Pendleton

C. M. Ross

C. W. Tahnk

K. B. Thomas

E. Throckmorton

R. A. West

J. Whitman

Working Group on Metal Containment (SG-WCS) (SC XI)

J. E. Staffiera, *Chair*

W. E. Norris, *Secretary*

W. J. Briggs

K. K. N. Chao

M. J. Ferlisi

R. W. Hammelmann

M. P. Lintz

S. C. Petitgout

C. G. Ranganath
G. W. Robin
R. T. Zak

Special Working Group on Low-Temperature Heavy Water Reactors (SG-WCS) (SC XI)

C. D. Cowfer, *Chair*
J. M. Morrison, *Secretary*
B. Awadalla
K. F. Schmidt
P. R. Vormelker
S. H. Zaidi

Working Group on General Requirements (SC XI)

A. T. Roberts III, *Chair*
R. G. Edl, *Secretary*
D. A. Graham
L. B. Gross
C. A. Ireland
D. A. Jackson
R. K. Mattu
L. Sage
R. J. Scott
J. C. Shropshire
R. J. Tamminga

Special Working Group on Editing and Review (SC XI)

R. W. Swayne, *Chair*
R. L. Beverly
L. B. Gross
M. P. Lintz
J. E. Staffiera
C. J. Wirtz

Special Working Group on Plant Life Extension (SC XI)

F. E. Gregor, *Chair*
L. B. Gross, *Secretary*
D. D. Davis
D. A. Graham
D. L. Harrison
M. P. Lintz
P. Manbeck
H. W. Massie, Jr.
D. W. Peltola
D. A. Piccione
C. M. Regan
V. N. Shah
R. J. Tamminga

SUBCOMMITTEE ON TRANSPORT TANKS (SC XII)

A. Selz, *Chair*

P. D. Stumpf, *Secretary*
A. N. Antoniou
S. C. Cyr
K. Ennis
M. Hennemand
C. H. Hochman
G. G. Karcher
P. P. Laluc
G. McRae
M. R. Minick
T. P. Pastor
M. D. Rana
C. M. Serratella
G. R. Stoeckinger
N. Surtees
J. P. Swezy
A. P. Varghese
S. V. Voorhees
W. L. White

Page xxi

Subgroup on Design and Materials (SC XII)

M. D. Rana, *Chair*
D. A. Canonico
W. D. Doty
G. G. Karcher
P. P. Laluc
T. P. Pastor
T. A. Rogers
C. M. Serratella
A. P. Varghese
E. Whittle

Subgroup on Fabrication and Inspection (SC XII)

S. V. Voorhees, *Chair*
D. A. Canonico
M. L. Coats
M. Hennemand
D. J. Kreft
G. McRae
M. R. Minick
N. Surtees
J. P. Swezy

Subgroup on General Requirements (SC XII)

C. H. Hochman, *Chair*
T. Alexander
A. N. Antoniou

D. Carter
K. Ennis
M. A. Garrett
J. C. Keenan
F. A. Licari
G. R. Stoeckinger
W. L. White

SUBCOMMITTEE ON BOILER AND PRESSURE VESSEL ACCREDITATION (SC-BPVA)

A. J. Spencer, *Chair*
A. J. Justin, *Vice Chair*
K. I. Baron, *Secretary*
M. B. Doherty
D. A. Douin
P. D. Edwards
R. M. Elliott
C. E. Ford
J. J. Greene
R. C. Howard
B. B. MacDonald
M. L. Sisk
B. C. Turczynski
R. V. Wielgoszinski
R. L. Williams
V. A. Bell, *Alternate*
V. Bogosian, *Alternate*
M. A. De Vries, *Alternate*
J. R. Farr, *Alternate*
R. G. Friend, *Alternate*
W. C. LaRochelle, *Alternate*
A. S. Lester III, *Alternate*
K. M. McTague, *Alternate*
G. P. Milley, *Alternate*
R. E. Muise, *Alternate*
P. G. Scheckermann, *Alternate*
N. Surtees, *Alternate*

SUBCOMMITTEE ON NUCLEAR ACCREDITATION (SC-NA)

T. E. Quaka, *Chair*
R. R. Stevenson, *Vice Chair*
S. Griffin, *Secretary*
C. W. Allison
M. N. Bressler
G. Deily
F. R. Drahos
J. E. Harris
M. Kotb
W. C. LaRochelle

W. C. LaRochelle
U. Potapovs
H. B. Prasse
A. J. Spencer
G. M. Tolson
L. M. Beason, Alternate
R. W. Boyce, Alternate
S. Dasgupta, Alternate
P. D. Edwards, Alternate
J. P. Ellenberger, Alternate
R. E. Feigel, Alternate
D. Hanrath, Alternate
K. A. Huber, Alternate
A. J. Justin, Alternate
N. C. Kist, Alternate
A. A. Lotfi, Alternate
R. P. McIntyre, Alternate
O. E. Trapp, Staff Representative

SUBCOMMITTEE ON DESIGN (SC-D)

W. J. Carter, *Chair*
F. S. Fitzgerald, *Secretary*
R. W. Barnes
C. Becht IV
O. F. Hedden
R. W. Mikitka
K. Mokhtarian
W. J. O'Donnell
R. D. Schueler, Jr.
M. P. Schwartz
A. Selz

Subgroup on Design Analysis (SC-D)

T. P. Pastor, *Secretary*
P. J. Conlisk
A. G. Eggers
J. L. Hechmer
G. L. Hollinger
D. P. Jones
A. Kalnins
W. J. Koves
T. H. Liu
O. Maekawa
A. Merend
T. V. Narayanan
E. L. Thomas, Jr.

Subgroup on Elevated Temperature Design (SC-D)

C. Becht IV, *Chair*

J. M. Corum, *Secretary*

C. R. Brinkman

R. D. Campbell

D. S. Griffin

R. I. Jetter

C. Lawton

W. J. O'Donnell

D. A. Osage

C. C. Schultz, Jr.

L. K. Severud

D. F. Shaw

A. L. Snow

B. E. Thurgood

Subgroup on Fatigue Strength (SC-D)

C. R. Brinkman

P. R. Donavin

J. A. Hayward

J. L. Hechmer

D. P. Jones

G. Kharshafdjian

C. Lawton

A. Merend

H. H. Ziada

Subgroup on Openings (SC-D)

M. P. Schwartz, *Chair*

R. W. Mikitka, *Secretary*

M. R. Breach

V. T. Hwang

S. C. Lou

R. B. Luney

J. P. Madden

K. C. Morrison

D. R. Palmer

M. D. Rana

E. C. Rodabaugh

Special Working Group on Bolted Flanged Joints (SC-D)

R. W. Mikitka, *Chair*

G. D. Bibel

G. Kharshafdjian

D. L. Kurle

E. Michalopoulos

S. N. Pagay

J. R. Payne

R. W. Schneider

R. D. Schueler, Jr.

A. Selz

SUBCOMMITTEE ON SAFETY VALVE REQUIREMENTS (SC-SVR)

E. C. Kistner, Jr., *Chair*

M. D. Bernstein, *Vice Chair*

U. D'Urso, *Secretary*

J. F. Ball

J. A. Cox

R. D. Danzy

R. J. Doelling

D. A. Douin

R. G. Friend

H. I. Gregg

S. F. Harrison, Jr.

C. F. Laitner

H. D. Michael

C. A. Neumann

J. W. Reynolds

M. Robinson

D. J. Scallan

C. M. Schroepfer

A. J. Spencer

J. C. Standfast

E. A. Steen

L. L. Thompson

J. A. West

T. J. Ferrigan, *Alternate*

Page xxii

Subgroup on Design (SC-SVR)

R. G. Friend, *Chair*

J. Cahoon, Jr.

R. D. Danzy

D. B. DeMichael

R. J. Doelling

H. I. Gregg

S. R. Irvin

C. F. Laitner

P. R. Sievert

A. J. Spencer

E. A. Steen

T. R. Tarbay

J. A. West

Subgroup on General Requirements (SC-SVR)

M. D. Bernstein, *Chair*

J. F. Ball

V. M. Deluca

D. A. Douin
H. D. Michael
C. A. Neumann
J. W. Reynolds
M. Robinson
J. C. Standfast
L. L. Thompson

Subgroup on Testing (SC-SVR)

S. F. Harrison, Jr., *Chair*
S. Cammeresi
J. A. Cox
W. F. Hart
D. M. Papa
D. J. Scallan
C. M. Schroepfer
D. E. Snyder

Page xxiii

ORGANIZATION OF SECTION III

1. GENERAL

Section III consists of Division 1, Division 2, and Division 3. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter "N" for Division 1, by the letter "C" for Division 2, and by the letter "W" for Division 3. The following eleven books make up the three Divisions.

Subsection NCA - General Requirements for Division 1 and Division 2

Division 1

Subsection NB - Class 1 Components
Subsection NC - Class 2 Components
Subsection ND - Class 3 Components
Subsection NE - Class MC Components
Subsection NF - Supports
Subsection NG - Core Support Structures
Subsection NH - Class 1 Components in Elevated Temperature Service
Appendices

Division 2 - Code for Concrete Reactor Vessels and Containments

Division 3 - Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste

The Division 2 book includes Subsection CC - Concrete Containments and Division 2 Appendices.

The Division 3 book includes Subsections WA and WB for General Requirements and Class TP (Type B) Containment, respectively.

2. SUBSECTIONS

Subsections are divided into Articles, Subarticles, paragraphs, and, where necessary, subparagraphs and subsubparagraphs.

3. ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections followed by Arabic numbers, such as NB-1000. Where possible, Articles dealing with the same topics are given the same number in each Subsection in accordance with the following general scheme:

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination
6000	Testing
7000	Overpressure Protection
8000	Nameplates, Stamping, and Reports

The numbering of Articles and the material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the rules have been prepared with some gaps in the numbering.

4. SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

5. SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as NB-2130, and generally have no text. When a number such as NB-1110 is followed by text, it is considered a paragraph.

6. PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

7. SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as NB-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

8. SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

Page xxiv

9. REFERENCES

References used within Section III generally fall into one of the following four categories.

A. References to Other Portions of Section III

When a reference is made to another Article, Subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to NB-3000 includes all material in Article NB-3000; reference to NB-3200 includes all material in Subarticle NB-3200; reference to NB-3230 includes all paragraphs NB-3231 through NB-3236.

B. References to Other Sections

Other Sections referred to in Section III are:

Section II, Materials. When a requirement for a material, or for the examination or testing of a material, is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II. These references begin with the letter "S."

Section V, Nondestructive Examination. Section V references begin with the letter "T" and relate to the nondestructive examination of material or welds.

Section IX, Welding and Brazing Qualifications. Section IX references begin with the letter "Q" and relate to welding and brazing requirements.

Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components. When a reference is made to inservice inspection, the rules of Section XI shall apply.

C. Reference to Specifications and Standards Other Than Published in Code Sections

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials. At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E 71-64 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

2 The American National Standards Institute (ANSI) was formerly known as the American Standards Association. Standards approved by the Association were designated by the prefix "ASA" followed by the number of the standard and the year of publication. More recently, the American National Standards Institute was known as the United States of America Standards Institute. Standards were designated by the prefix "USAS" followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the numbers of the standards have remained unchanged.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by the American Society of Mechanical Engineers and approved by the American National Standards Institute.² When a product is to conform to such a standard, for example ANSI B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NB-3132-1, for example ANSI B16.5-1977. Standards published by the American Society of Mechanical Engineers are available from ASME, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300.

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-6, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, 127 Park Street, N.E., Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NB-3132-1, for example MSS SP-6-1963.

(4) Specifications for welding and brazing materials are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33135. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix "SF," for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-620 and API-2000. When documents so designated are referred to in Section III, they are standards published by the American Petroleum Institute.

D. References to Appendices

Two types of Appendices are used in Section III and are designated Mandatory and Nonmandatory.

(1) Mandatory Appendices contain requirements which must be followed in construction; such references are designated by a Roman numeral followed by Arabic numerals. References to II-1100 or XI-3212, for example, relate to the Mandatory Appendices.

(2) Nonmandatory Appendices provide information or guidance for the use of Section III; such references are designated by a capital letter followed by Arabic numerals. A reference to D-1100, for example, relates to a Nonmandatory Appendix.

a capital letter followed by Arabic numerals. A reference to D-1100, for example, relates to a Nonmandatory Appendix.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D3 WA-1000

ARTICLE WA-1000 SCOPE OF DIVISION 3

Page 1

SUBSECTION WA

GENERAL REQUIREMENTS

Page 3

WA-1100 SCOPE

WA-1110 NATURE OF THESE RULES AND COMPONENTS TO WHICH THEY ARE APPLICABLE

The rules of Division 3 constitute requirements for the design and construction of the containment system of a nuclear spent fuel or high level radioactive waste transport packaging.

WA-1120 DEFINITIONS

Definitions of key terms used in Subsection WA are included in WA-9000.

WA-1130 LIMITS OF THESE RULES

(a) The rules of this Division provide requirements for new design construction including consideration of mechanical and thermal stresses due to cyclic operation. They do not cover deterioration which may occur in service as a result of radiation effects, corrosion, erosion, or instability of the material. These effects shall be taken into account with a view to realizing the design or the specified life.

(b) The rules are not intended to be applicable to any item that does not serve a pressure retaining function.

WA-1140 USE OF CODE EDITIONS, ADDENDA, AND CASES

(a)(1) The Design Owner or his designee shall establish the Code Edition and Addenda to be included in the Design Specification. All items shall be designed to a single Code Edition and Addenda.

(2) In no case shall the Code Edition and Addenda dates established in the Design Specifications be earlier than one year prior to the date of filing an application for Certificate of Compliance for a transport package with the Regulatory Authority.

(b) The Class TP Certificate Holder shall construct the containment system under the provisions of a Quality Assurance Program which has been accepted by the Society. The Quality Assurance Program shall meet the requirements of the latest Division 3 Edition and Addenda issued at the time that the containment system is constructed.

(c) Code Cases are permissible and may be used beginning with the date of approval by the ASME Council. Only Code Cases that are specifically identified as being applicable to this Section may be used. Code Cases may be used by mutual consent of the parties involved.

(d) Materials produced and certified in accordance with Code Editions and Addenda other than the one specified in the Design Specification, may be used, provided all of the following requirements are satisfied.

(1) The material (WA-1220) meets the applicable requirements of a material specification permitted by WB-2121 of the

Edition and Addenda specified for construction.

(2) The material meets all the requirements of WB-2000 of the Edition and Addenda specified for construction.

(3) The material was produced under the provisions of a Quality System Program which had been accepted by the Society or qualified by a party other than the Society (WA-3820), in accordance with the requirements of the latest Division 3 Edition and Addenda issued at the time the material was produced. Material exempted from portions of the provisions of WA-3800 by WB-2610 may be used, provided the requirements of (1) and (2) above are met.

WA-1200 GENERAL REQUIREMENTS

WA-1210 COMPONENTS

Piping and valves may form part of the containment system. If piping and valves are included in the containment

Page 6

system they shall be designed and constructed in accordance with Section III, Division 1, Class 1.

WA-1220 MATERIALS

WA-1221 Metallic Materials

Metallic materials shall be manufactured to an SA, SB, or SFA Specification,¹ or any other material specification permitted by WB-2121. Such material shall be manufactured, identified, and certified in accordance with the requirements of this Division. Tubular products and fittings welded with filler metal shall meet the requirements of Section III, Division 1, Class 1.

¹ SA or SB Specifications listed under the heading Bars, Rods, Shapes, Forgings may be used as material for any of these product forms even though not all product forms are listed in the SA or SB Specification.

WA-1222 Metallic Material, ASTM Specification

Metallic materials produced under an ASTM designation may be accepted as complying with the corresponding ASME Specification, provided the ASME Specification is designated as being identical with the ASTM Specification for the grade, class, or type produced and provided that the material is confirmed as complying with the ASTM Specification by a Certified Material Test Report or Certificate of Compliance from the Material Manufacturer.

WA-1223 Welding Material, AWS Specification

Welding material produced under an AWS designation may be accepted as complying with the corresponding ASME Specification, provided the latter Specification is indicated to be identical with the AWS Specification and provided the welding material is confirmed as complying with the AWS Specification by a Certified Material Test Report or Certification from the Material Manufacturer.

WA-1230 PARTS AND PIPING SUBASSEMBLIES

Parts or piping subassemblies may form part of the containment system. The Design Specification and Design Reports for such parts or piping subassemblies shall meet the requirements of WA-3250 and WA-3550, as applicable. If the construction of such parts or piping subassemblies are subcontracted to others, the subcontractor shall possess a valid Class TP Certificate of Authorization or a valid NPT Certificate of Authorization for Class 1 construction.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D3 WA-2000

ARTICLE WA-2000 DESIGN BASIS FOR CONTAINMENT
SYSTEMS FOR TRANSPORT PACKAGINGS

WA-2100 GENERAL REQUIREMENTS

WA-2110 SCOPE

Rules for the design of containment systems for transport packagings are provided in WB-3000. The Design Owner shall be responsible for establishing a Design Specification which identifies design and safety criteria for the design of the containment system in accordance with the rules of Division 3.

WA-2120 DESIGN BASIS

WA-2121 Consideration of Operating Conditions

(a) Containment systems of transport packagings (WA-1110) are subject to operating conditions which are required to be considered in the design of the transport packaging in order to satisfy applicable safety criteria.

(b) Operating conditions for transport packagings are classified as either normal operating conditions or hypothetical accident conditions. Normal operating conditions include normal conditions of transport and in-plant handling conditions.

(c) As a consequence of specified operating conditions, containment systems are subject to pressure, temperature, and mechanical loadings. The resulting stresses in the containment system shall not exceed the Limits provided in this Division.

(d) The selection of operating conditions, and the determination of their significance to the design and operability of the containment system, are beyond the scope of this Division. Appropriate guidance for the selection of operating conditions may be derived from safety criteria documents for transport packagings and the requirements of regulatory and enforcement authorities having jurisdiction.

WA-2122 Consideration of Test Conditions

(a) Each containment system shall be subjected to a pressure test (WB-6000). The minimum test pressure shall not be less than either 1.5 times MNOP¹ or 1.25 times MNIP². The stress produced in the containment system during the test shall not exceed the limits provided in WB-3220 and WB-3330.

(b) Other proof tests may be specified by the Design Owner in the Design Specification. Stresses produced in the containment system by such a test shall not exceed the limits specified for normal operating conditions.

WA-2123 Establishment of Loadings, Stresses, and Limits

(a) In the Design Specification, the Design Owner shall identify all operating and test conditions anticipated or postulated to occur during the intended service life of the transport packaging.

(b) The Design Owner shall determine the resulting loads and combinations of loads on the containment system by considering the entire transport packaging. The Design Owner shall select all critical loads for evaluation of stresses against the Limits provided in this Division.

(c) Stresses are induced by the pressure, temperature, and mechanical loads, and combinations thereof, and shall be classified as either Primary, Secondary or Peak Stresses by the Design Owner in accordance with the requirements of WB-3000.

¹ Maximum Normal Operating Pressure (MNOP) is the maximum pressure that would develop in the containment system in a period of one year under normal conditions of transport without venting.

² Maximum Normal In-plant Handling Pressure (MNIP) is the maximum pressure that would develop in the containment system under the most severe conditions of normal in-plant handling operations.

(d) Normal Limits are those sets of limits which must be satisfied for all normal operating conditions identified in the Design Specification. The stress limits which must be satisfied for normal loads are provided in WB-3220 and WB-3230.

(e) Accident Limits are those sets of limits which must be satisfied for all hypothetical accident conditions identified in the Design Specification. The stress limits which must be satisfied for accident loads are provided in WB-3220 and WB-3230.

WA-2130 SPECIAL REQUIREMENTS

Contractual arrangements between the Design Owner and Packaging Owner and the Class TP Certificate Holder which specify requirements in addition to, or more restrictive than, those specified by the rules of this Division may be applied, provided such requirements do not negate any rules of this Division. Such special contractual requirements are beyond the scope of this Division and shall not apply as conditional requirements for Code construction.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D3 WA-3000

ARTICLE WA-3000 RESPONSIBILITIES AND DUTIES

Page 11

WA-3100 GENERAL

WA-3110 RESPONSIBILITIES VS. LEGAL LIABILITIES

The parties identified in WA-3111, WA-3113, and WA-3114 are involved in the design and construction of containment systems for transport packagings or items which come under the jurisdiction of this Division. Each party has specific duties and responsibilities as set forth in WA-3220, WA-3420, and WA-3520. The responsibilities relate only to Code compliance and are not to be construed as involving contractual or legal liabilities. A single organization may perform one or more of the roles assigned to each party.

WA-3111 DESIGN OWNER

The Design Owner is the organization which obtains a Certificate of Accreditation issued by the Society. The Design Owner or his designee prepares a Design Specification, causes a design to be developed, obtains a Certificate of Compliance or an Amendment to a Certificate of Compliance for a specific design of a transport packaging from the regulatory authority, determines the loads applied to the containment system, designs the containment system, demonstrates the adequacy of the design of the containment system, and issues a Design Report and other Design Documents required by this Division.

WA-3113 PACKAGING OWNER

The Packaging Owner is the organization which assumes title to the transport packaging upon delivery by the Class TP Certificate Holder. The Packaging Owner, or his designee, initiates construction of the containment system through the issuance of a Construction Specification.

WA-3114 CLASS TP CERTIFICATE HOLDER

The Class TP Certificate Holder is the organization which constructs the containment system as part of the transport packaging in accordance with the requirements of the Construction Specification. The Class TP Certificate Holder obtains an N-type Certificate of Authorization issued by the Society, completes the appropriate Data Report Form and applies a Code Symbol Stamp to the completed containment system of a transport packaging.

WA-3120 AUTHORIZATION

WA-3121 Types of Authorization

Table WA-8100-1 lists the types of certificates issued by the Society and indicates the responsibilities assumed by each Certificate Holder. Further details of these responsibilities are contained in this Article.

WA-3122 Subcontracted Services

(a) Services may be subcontracted which are both within and beyond the scope of this Division. There are no requirements for the subcontracting of services beyond the scope of this Division. Services covered by this Division may either be of a type for which the Society issues Certificates, or may be of the type for which the Society does not issue a Certificate. Subcontracts for activities for which Certificates are required shall be made only to Certificate Holders. The Certificate Holder may subcontract to another organization the surveying and auditing of his subcontractors and Material Organizations, but must retain the responsibility for these activities and for the qualification of these subcontractors and Material Organizations.

(b) A Class TP Certificate Holder may subcontract the construction of parts to a Section III, Division 1 Class 1 NPT Certificate Holder provided the scope of

Page 16

work is included in the scope of the subcontractor's N-type Certificate of Authorization.

(c) The Certificate Holder shall describe in his Quality Assurance Manual the manner in which he controls and accepts the responsibility for the subcontracted activities.

WA-3130 WELDING AND SUBCONTRACTING DURING CONSTRUCTION

Division 3 requires that all welding during Code construction be done only by an organization holding the N-type Certificate of Authorization appropriate to the scope of welding to be performed. A Certificate Holder may engage individuals by contract for their services as welders or welding operators at the location shown on the N-type Certificate of Authorization.

WA-3200 DESIGN OWNER'S RESPONSIBILITIES

WA-3210 DEFINITION OF DESIGN OWNER

The term Design Owner, as used in this division, is defined in WA-3111.

WA-3220 CATEGORIES OF THE DESIGN OWNER'S RESPONSIBILITIES

The responsibilities of the Design Owner include the requirements of (a) through (s) below as applicable:

(a) obtaining a Certificate of Compliance or an Amendment to a Certificate of Compliance for a specific design of a transport package from the regulatory authority;

(b) obtaining a Design Owner's Certificate of Accreditation (WA-3230);

(c) documenting a Quality Assurance Program (WA-3272);

(d) obtaining a written agreement with an Authorized Inspection Agency (WA-3230 and WA-8130);

(e) establishing the Code Editions, Addenda, and Code Cases to be used in the Design Specifications, and determining that they are acceptable to the regulatory and enforcement authorities (WA-1140);

(f) providing and correlating Design specification, including establishment of component and system boundaries (WA-3251);

(g) certifying the Design Specification (WA-3255);

(h) providing Design Specification and Design Documents to the regulatory authority, Packaging and Owner and Class TP Certificate Holder, as applicable;

(i) preparing a design of a transport packaging, including the containment system, in accordance with the Design Specification and this Division;

- (j) preparing and certifying Design Documents required by this Division (WA-3260);
- (k) determining the loads applied to the containment system by evaluating the entire transport packaging;
- (l) performing a stress analysis of the containment system and verifying that the limits of this Division are not exceeded (WA-3260);
- (m) providing Design Documents for review and approval (WA-3260);
- (n) performing any of the requirements of (i) through (m) above, with regard to changes to the design after the initial issuance of the Design Documents (WA-3262);
- (o) reviewing Design Reports (WA-3264);
- (p) making available to the Inspector the documents specified by this Division and those requested by the Inspector to ensure compliance with Code requirements (WA-5242);
- (q) designating records to be maintained and providing for their maintenance (WA-3280);
- (r) revising Design Specifications and Design Documents to accommodate construction modifications (WA-3570);
- (s) performing other duties as assigned to the Design Owner throughout this Division.

The activities necessary to provide compliance with responsibilities assigned to the Design Owner above may be performed on behalf of the Design Owner by a designee; however, the responsibility for compliance remains with the Design Owner.

WA-3230 DESIGN OWNER'S CERTIFICATE OF ACCREDITATION

The Design Owner shall obtain a Design Owner's Certificate of Accreditation from the Society prior to the issuance of a Design specification. The information to be supplied by the Design Owner when making applications is given in forms issued by the Society. A written agreement with an Authorized Inspection Agency (WA-8130) is required prior to application.

Page 17

WA-3250 PROVISION OF DESIGN SPECIFICATIONS

WA-3251 Provision and Correlation

It is the responsibility of the Design Owner to prepare, certify, and issue the Design Specification for the containment system. The Design Owner, shall also be responsible for the proper correlation of all Design Specifications. Separate Design Specifications are not required for parts or piping subassemblies, for valves, piping systems and parts that form part of the containment system which are prepared by other organizations when they are included in the Design Specification for a containment system for a transport package (WA-1230).

WA-3252 Contents of Design Specifications

(a) The Design Specifications shall contain sufficient detail to provide a complete basis for design and construction in accordance with this Division. Such requirements shall not result in design or construction which fails to conform with the rules of this Division. All Design Specifications shall include (1) through (6) below:

- (1) the functions and boundaries of the items covered (WA-3254);
- (2) the design requirements (WA-2000);
- (3) the environmental conditions, including radiation;
- (4) material requirements including impact test requirements;
- (5) when operability of a component is a consideration, the Design Specification shall make reference to other appropriate documents which specify the operating requirements;

(6) the effective Code Edition, Addenda, and Code Cases to be used for design and construction.

WA-3254 Boundaries of Jurisdiction

In order to define the boundaries of components with respect to adjacent components and other structures, the Design Specifications shall include:

- (a) the locations of each such boundary within the containment system;
- (b) the structural characteristics of the adjacent and attached components or structures, whether or not they are within this Division's jurisdiction when such components or structures provide constraints to the movement of components;
- (c) the boundary of the Class TP containment system as given in WB-1120.

WA-3255 Certification of the Design Specifications

The Design Specifications shall be certified to be correct and complete and to be in compliance with the requirements of WA-3250 by one or more Registered Professional Engineers, competent in the applicable field of design and related transport packaging requirements and qualified in accordance with the requirements of ANSI/ASME N626.3. Such Registered Professional Engineers are not required to be independent of the organization preparing the Design Specifications.

WA-3260 REQUIREMENTS FOR DESIGN DOCUMENTS

WA-3261 Design Documents

- (a) The Design and the Design Drawings used for construction are the primary Design Documents. The design shown by the Design Drawings shall comply with the Design Specification and the rules of this Division and shall be in agreement with the other Design Documents. The Design Report shall demonstrate the adequacy of the design with regard to the structural integrity of the containment system.
- (b) The Design Owner may subcontract stress analysis or complete design of all or a portion of a component. However, the Design Owner is responsible for the design of the containment system and for the Design Documents.
- (c) The Design Drawings shall be in agreement with the Design Report before it is certified (WA-3263) and shall be identified and described in the Design Report.
- (d) When the design includes parts or piping subassemblies which are to be purchased from an NPT Certificate Holder or valves which are to be purchased from an N Certificate Holder, the Design Owner shall incorporate the Design Documents for the purchased items into the Design Documents of the containment system.
- (e) The Design Owner shall demonstrate the adequacy of the design of any piping subassembly, part, or valve within the boundary of the containment system to meet the requirements of the Design Specification and this Division. This demonstration shall be included the Design Report for the containment system.

WA-3262 Modification of Document and Reconciliation With Design Report

Any modification of any document used for design from the corresponding document used for design analysis,

Page 18

shall be reconciled with the Design Report by the person or organization responsible for the design. A revision or addenda to the Design Report shall be prepared and certified (WA-3263) to indicate the basis on which this has been accomplished. All such revised documentation shall be filed with the completed Design Report.

WA-3263 Certification of Design Report

- (a) The Design Report shall be certified to be correct and complete and to be in accordance with the requirements of WA-3260 by one or more Registered Professional Engineers competent in the applicable field of design and related transport packaging requirements and qualified in accordance with the requirements of ANSI/ASME N626.3. The Design Report shall be certified only after all design requirements of this Division have been met. Such Registered Professional

Report shall be certified only after all design requirements of this Division have been met. Such Registered Professional Engineers are not required to be independent of the organization preparing the design.

(b) It is the intent of this Division that the certification of the Design Report shall in no way relieve the Design Owner of the responsibility for ensuring that the design of the containment system meets the conditions stated in the Design Specification and this Division.

WA-3264 Review of Design Report

(a) The Certified Design Report shall be reviewed by the Design Owner to determine that all Operating Conditions described in the Design Specification have been considered, and that the acceptance criteria established in the Design Specification and in this Division have been met. The Certified Design Report shall be reviewed by the individuals who did prepare the design report.

(b) Documentation shall be provided by the Design Owner to indicate that the review required by (a) above has been completed.

(c) A copy of the documentation required by (b) above shall be attached to, and become part of the Design Report.

(d) A copy of the completed Design Report, including the documentation required by (b) above shall be made available to the Packaging Owner before construction begins.

WA-3270 RESPONSIBILITY FOR QUALITY ASSURANCE

WA-3271 Scope of Responsibilities

(a) The Design Owner shall be responsible for surveying, qualifying, and auditing suppliers of subcontracted services (WA-3122). Subcontractors holding an appropriate Certificate need not be surveyed nor audited for work within the scope of the subcontractor's Certificate.

(b) A Design Owner may qualify vendors of subcontracted services (WA-3122) other than those requiring a Certificate for another Certificate Holder doing work for that Design Owner. The qualification documentation shall be supplied to the other Certificate Holder prior to their use of the subcontracted service.

WA-3272 Documentation of Quality Assurance Program

The Design Owner shall be responsible for documenting its Quality Assurance Program (WA-4134).

WA-3273 Filing of Quality Assurance Manual

The Design Owner shall file with the Authorized Inspection Agency (WA-5121) copies of the Quality Assurance Manual. The Design Owner shall keep a copy on file available to the Inspector (WA-5122).

WA-3280 DESIGN OWNER'S RESPONSIBILITY FOR RECORDS

The Design Owner shall be responsible for designating the records to be maintained (WA-4134.17). The Design Owner shall also be responsible for the maintenance of records required by this Division (WA-4134.17).

WA-3400 PACKAGING OWNER'S RESPONSIBILITIES

WA-3410 DEFINITION OF PACKAGING OWNER

The term Packaging Owner, as used in this Division, is defined in WA-3113.

Page 19

WA-3420 CATEGORIES OF THE PACKAGING OWNER'S RESPONSIBILITIES

The responsibilities of the Packaging Owner include the requirements of (a) through (o) below as applicable:

(a) assuming title to the transport packaging upon delivery by the Class TP Certificate Holder;

- (b) obtaining a Packaging Owner's Certificate of Accreditation (WA-3430);
- (c) documenting a Quality Assurance Program (WA-3471);
- (d) obtaining a written agreement with an Authorized Inspection agency (WA-3430 and WA-8130);
- (e) selecting a Class TP Certificate Holder to construct the containment system;
- (f) establishing the Code Editions, Addenda, and Code Cases to be used in the Construction Specification, and determining that they are consistent with the Design Documents and are acceptable to the regulatory and enforcement authorities (WA-1140);
- (g) verifying that the Code Editions, Addenda, and Code Cases used in the construction of the completed containment system are consistent with the Construction Specification, and Design Documents;
- (h) initiating construction through the issuance of a Construction Specification for the containment system;
- (i) providing the Class TP Certificate Holder with the Design Documents and other applicable documents identified in the Construction Specification (WA-3452);
- (j) making available to the Inspector the documents specified by this Division and those requested by the Inspector to ensure compliance with Code requirements (WA-5242);
- (k) verifying that the Class TP Certificate Holder has prepared, certified and filed the Construction Report;
- (l) reviewing the Construction Report and verifying that it is consistent with the Design Documents and Construction Specification (WA-3460);
- (m) verifying that the Class TP Certificate Holder has prepared and filed the Data Report Form;
- (n) obtaining the Design Owner's approval and appropriate certification for any change to a Design Document after construction has begun;
- (o) performing other duties as assigned to the Packaging Owner throughout this Division.

WA-3430 PACKAGING OWNER'S CERTIFICATE OF ACCREDITATION

The Packaging Owner shall obtain a Packaging Owner's Certificate of Accreditation from the Society prior to the issuance of a Construction Specification. The information to be supplied by the Packaging Owner when making application is given in forms issued by the Society. A written agreement with an Authorized Inspection Agency (WA-8130) is required prior to the application.

WA-3450 PROVISION OF CONSTRUCTION SPECIFICATION

WA-3451 Provision and Correlation

It is the responsibility of the Packaging Owner to prepare, certify, and issue the Construction Specification for the containment system. The Packaging Owner shall be responsible for the proper correlation of all Data Reports for valves, piping systems, and parts that form part of the containment system. Separate Construction Specifications are not required for parts or piping subassemblies when they are included in the Construction Specification of a containment system for a transport packaging (WA-1210).

WA-3452 Contents of Construction Specifications

The Construction Specifications shall be based upon the Design Specifications and associated Design Drawings, and shall contain sufficient detail to provide a complete basis for construction in accordance with this Division. Such requirements shall not result in construction which fails to conform with the Design Specification, Design Documents and the rules of this Division.

WA-3455 Certification of the Construction Specification

The Construction Specification shall be certified to be correct and complete and to be in compliance with the requirements of WA-3450 by one or more Registered Professional Engineers, competent in the applicable field of construction and related transport packaging requirements and qualified in accordance with the requirements of ANSI/ASME N626.3. Such Registered Professional Engineers are not required to be independent of the organization preparing the Construction Specification.

WA-3456 Filing of Construction Specifications

The Construction Specifications in their entirety shall become the principal document governing construction

Page 20

of items. A copy of the Construction Specification shall be made available to the Inspector at the manufacturing site before fabrication begins.

WA-3460 REVIEW OF THE CONSTRUCTION REPORT

(a) The Construction Report which the Class TP Certificate Holder provides shall be reviewed by the Packaging Owner to determine that all requirements described in the Construction Specification and this Division have been met.

(b) Documentation shall be provided by the Packaging Owner to indicate that the review required by (a) above has been completed.

(c) A copy of the documentation required by (b) above shall be attached to, and become part of the Construction Report.

(d) A copy of the completed Construction Report, including the documentation required by (b) above shall be made available to the Class TP Certificate Holder's Authorized Nuclear Inspector before the containment system is stamped.

WA-3470 RESPONSIBILITY FOR QUALITY ASSURANCE

WA-3471 Scope of Responsibilities

The Packaging Owner shall document its Quality Assurance Program (WA-4134) and shall file with the Authorized Inspection Agency (WA-5121) copies of the Quality Assurance Manual. The Packaging Owner shall keep a copy on file available to the Inspector (WA-5122).

WA-3480 PACKAGING OWNER'S RESPONSIBILITY FOR RECORDS

The Packaging Owner shall be responsible for designating the records to be maintained by the Class TP Certificate Holder (WA-4134.17). The Packaging Owner shall be responsible for ensuring that records required by this Division are maintained (WA-4134.17).

WA-3500 DEFINITION AND RESPONSIBILITIES OF A CLASS TP CERTIFICATE HOLDER - DIVISION 3

WA-3510 DEFINITION OF A CLASS TP CERTIFICATE HOLDER

The term Class TP Certificate Holder, as used in this division, is defined in WA-3114.

WA-3520 CATEGORIES OF THE CLASS TP CERTIFICATE HOLDER'S RESPONSIBILITIES

The responsibilities of the Class TP Certificate Holder include the requirements of (a) through (o) below as applicable:

(a) constructing a containment system for a transport packaging in accordance with the Construction Specification and the requirements of this Division;

(b) preparing and certifying the Construction Documents (WA-3550) in accordance with the requirements of this Division;

(c) obtaining an N-type Certificate of Authorization (WA-3530);

- (d) providing the Packaging Owner with information necessary to reconcile Construction with Design Documents;
 - (e) provision of Construction Report to Packaging Owner for review, documentation of review, and filing (WA-3562);
 - (f) qualification of Material Organizations, and suppliers of subcontracted services (WA-3581);
 - (g) documenting a Quality Assurance Program (WA-3582);
 - (h) filing the Quality Assurance Manual (WA-3583);
 - (i) prepare and file the proper Data Reports forms (WA-3590);
 - (j) obtaining an agreement with an Authorized Inspection Agency (WA-8130);
 - (k) making available to the Inspector the documents specified by this Division and those requested by him to assure compliance with Code requirements;
 - (l) review of Certified Material Test Reports and Certificates of Compliance for materials (WA-1220);
 - (m) preparation, accumulation, control, and protection of required records while in his custody (WA-4134.17);
 - (n) documentation of review and approval of material as permitted by WA-1140(d).
 - (o) performing other duties as assigned to the Class TP Certificate Holder throughout this Division.
-

Page 21

WA-3530 CLASS TP CERTIFICATE OF AUTHORIZATION

A Class TP Certificate of Authorization (WA-8100) shall be obtained for the construction of any item intended to be in compliance with the requirements of this Division and to be stamped with a Class TP Code Symbol.

WA-3540 COMPLIANCE WITH THIS DIVISION

The Class TP Certificate Holder has the responsibility for assuring that the construction of the item meets the Construction Specification and complies with the construction requirements of this Division, furnishing a Construction Report, and completing the appropriate Data Report Form.

WA-3550 REQUIREMENTS FOR CONSTRUCTION DOCUMENTS

WA-3551 Construction Procedures

Procedures describing methods of construction to satisfy the Construction Specification shall be provided. Such procedures shall give sufficient detailed information about the methods of construction to enable those reviewing the procedures to determine whether the requirements of the Construction Specification will be satisfied. Construction Procedures will include test procedures to be performed by the Class TP Certificate Holder that are needed to establish conformance with the Construction Specification and this Division.

WA-3552 Shop Drawings

The Class TP Certificate Holder shall provide Shop Drawings describing construction details, physical dimensions, and any significant engineering features needed to establish conformance with the Construction Specification and this Division.

WA-3553 Material Documentation

The Class TP Certificate Holder shall assemble records to verify that materials comply with the requirements of the Construction Specification and this Division.

WA-3560 CONSTRUCTION REPORT

WA-3561 Content of Construction Report

The Class TP Certificate Holder shall provide a Construction Report which confirms and verifies that the completed containment system complies with the requirements of the Construction Specification and this Division. The Construction Report shall include the following:

- (a) a list of all Construction Documents which were used for the construction of the containment system, including as-built drawings, showing the revision used for construction and date;
- (b) a summary of deviations (nonconformances) giving a brief description of the nature of the deviations (nonconformances) and the corrective actions and the date when the corrective actions were taken;
- (c) a complete, detailed record of all containment system acceptance testing;
- (d) quality assurance records (WA-4134.17).

WA-3562 Submittal of Construction Report to Packaging Owner for Review

The Class TP Certificate Holder shall submit to the Packaging Owner a copy of the completed Construction Report for the containment system for review and documentation of the review to the extent required by WA-3460.

WA-3570 MODIFICATION OF CONSTRUCTION DOCUMENTS AND RECONCILIATION WITH DESIGN REPORT

If the as-constructed condition of a containment system is not in accordance with the Construction Specification, that containment system may not be Code symbol stamped unless the Design Specification, the Design Report, and the Construction Report have been supplemented by the organization responsible for those documents to reconcile the differences. Any supplement to these documents shall receive the same approvals and certifications as the original document.

WA-3580 RESPONSIBILITY FOR QUALITY ASSURANCE

WA-3581 Scope of Responsibilities

- (a) The Class TP Certificate Holder shall be responsible for surveying, qualifying, and auditing suppliers of

Page 22

subcontracted services (WA-3122), including nondestructive examination contractors, and Material Organizations or Material Organizations holding Quality System Certificates (Materials), and Certificate Holders whose scope includes supply or manufacture supply of materials, need not be surveyed nor audited for work or material covered by the scope of their Certificate. Subcontractors holding an appropriate Certificate need not be surveyed nor audited for work within the scope of the subcontractor's Certificate.

(b) A Class TP Certificate Holder may qualify vendors of subcontracted services (WA-3122) other than those requiring a Certificate, such as Material Organizations, for another Certificate Holder doing work for that Class TP Certificate Holder. The qualification documentation shall be supplied to the other Certificate Holder prior to their use of the subcontracted service, or Material Organization.

WA-3582 Documentation of Quality Assurance Program

The Class TP Certificate Holder shall be responsible for documenting its Quality Assurance Program (WA-4134).

WA-3583 Filing of Quality Assurance Manual

The Class TP Certificate Holder shall file with the Authorized Inspection Agency (WA-5121) copies of the Quality Assurance Manual. The Class TP Certificate Holder shall keep a copy on file available to the Inspector (WA-5122).

WA-3590 DATA REPORT

The Class TP Certificate Holder shall certify compliance with this Division by signing the appropriate Data Report

The Class TP Certificate Holder shall certify compliance with this Division by signing the appropriate Data Report including stamping (WA-8000).

WA-3800 METALLIC MATERIAL QUALITY SYSTEM PROGRAM

WA-3810 EXCLUSIONS

Material falling within the small products exclusion of WB-2610 or material which is allowed by this Section to be furnished with a Certificate of Compliance, is exempted from the requirements of WA-3800, except:

- (a) Certified Material Test Reports or Certificates of Compliance shall meet the requirements of WA-3862.1.
- (b) For construction of components meeting the requirements of this Division, material identification and marking shall meet the requirements of WA-3856.3.

WA-3820 ACCREDITATION OR QUALIFICATION OF MATERIAL ORGANIZATIONS

- (a) A Material Organization shall be accredited by obtaining a Quality System Certificate issued by the Society verifying the adequacy of the Material Organization's Quality System Program.
- (b) Alternatively, the Certificate Holder (WA-3461, WA-3561, WA-3661, or WA-3761) or, when included in its scope of activities, the accredited Material Organization [WA-3820(a)] may qualify Material Organizations not accredited by the Society by evaluation of the organization's Quality System Program in accordance with the requirements of WA-3842.
- (c) A Certificate Holder may furnish material when stated in the scope of its Certificate. In this case, a Quality System Certificate is not required, nor is the user of the material required to survey, qualify, or audit such a Certificate Holder.

WA-3830 RESPONSIBILITIES OF MATERIAL ORGANIZATIONS

The Material Organization shall be responsible for establishing, documenting, implementing, and maintaining a Quality System Program in accordance with the requirements of WA-3850, and as applicable to its scope of activities:

- (a) establishing and maintaining measures for the traceability of material or source material while under its control (WA-3856);
- (b) controlling quality during manufacture, including control of testing, examination, repair, and treatment of the material or source material (WA-3857, WA-3858);
- (c) evaluating, qualifying, and auditing Material Organizations (WA-3842), as provided by WA-3820(b), except when the party holds a Quality System Certificate which covers the operations performed;
- (d) approving and controlling operations performed by suppliers of source material and subcontracted services (WA-3855);
- (e) preparing Certified Material Test Reports and Certificates of Compliance (WA-3860).

Page 23

WA-3840 EVALUATION OF THE PROGRAM

WA-3841 Evaluation by the Society

(a) The Society, when requested by the applicant on forms issued by the Society, will arrange for a survey of the Material Organization's Quality System Program for the scope of activities on the application. The Program will be evaluated on the basis of its compliance with the applicable material requirements of this Division and the requirements of this Division. The Quality System Certificate, which is issued for a three year period, will describe and specify the scope and limits of work for which the accredited Material Organization is qualified and will be subject to a planned audit program by the Society. Not later than six months prior to the expiration of the Certificate, the accredited Material Organization shall apply for a renewal evaluation and for issuance of a new Certificate.

- (b) The applicant shall supply all information required by forms provided by the Society.
- (c)

(d) A controlled copy of the accredited Material Organization's Quality System Manual shall be filed with the Society. The Manual shall be the Society's guide for surveying and auditing the accredited Material Organization's continued compliance with the accepted Quality System Program.

(e) The accredited Material Organization shall make available for on-site review by the Society any procedures, process sheets, or drawings as are necessary to understand the Program. Detailed technical procedures will not be approved by the Society. The accredited Material Organization shall keep a controlled copy of the Manual on file and in a place and manner readily available to the Society's audit team.

(f) The accredited Material Organization shall obtain the Society's review and acceptance of proposed modifications to the Quality System Manual prior to implementation.

(g) When the applicant requests that the scope of the Quality System Certificate include qualification of non-accredited Material Organizations (WA-3842), this activity shall be included in the Manual, and will be reviewed by the Society.

(h) When the applicant requests that the scope of the Quality System Certificate include implementation of WA-3855.5, Utilization of Unqualified Source Material, this activity shall be included in the Manual and will be reviewed by the Society.

(i) When the applicant requests that the scope of the Quality System Certificate include approval and control of suppliers (WA-3855.3), this activity shall be included in the Manual and will be reviewed by the Society.

WA-3842 Evaluation by Parties Other Than the Society

WA-3842.1 Qualification of Material Organizations.

The qualification of Material Organizations by parties other than the Society shall be limited to the furnishing of source material, material, or subcontracted services to the accredited Material Organization or Certificate Holder performing the evaluation, or their designee.

WA-3842.2 Evaluation of the Qualified Material Organization's Program by Accredited Material Organizations or Certificate Holders.

Evaluation of a Material Organization's Quality System Program by parties other than the Society, as provided by WA-3820(b), shall be performed in accordance with the requirements of WA-3842.2(a) through (h) below.

(a) The Quality System Program shall be surveyed, accepted, and audited by the party performing the evaluation on the basis of its compliance with the applicable material requirements of this Division and the requirements of WA-3850.

(b) The Quality System Manual (WA-3853.1) shall be the party's guide for surveying and auditing the qualified Material Organization's continued compliance with the accepted Quality System Program.

(c) The qualified Material Organization shall make available for on-site review by the party performing the evaluation any procedures, process sheets, or drawings as are necessary to understand the Program. The qualified Material Organization shall keep a controlled copy of the Manual on file and in a place and manner readily available to the party performing the audit.

(d) The qualified Material Organization shall notify purchasers of material, source material, or subcontracted services accepting its Program of proposed modifications to its Quality System Manual. The party accepting the Program shall evaluate and accept such modifications prior to the implementation of the modifications on purchased materials or services.

(e) When the qualified Material Organization's scope of activities includes utilization of unqualified source material (WA-3855.5), this activity shall be included in the Quality System Manual, and shall be reviewed by the party accepting the Program.

(f) When the qualified Material Organization's scope of activities includes approval and control of suppliers (WA-3855.3), this activity shall be included in the Quality System Manual, and shall be reviewed by the

party accepting the Program. During surveys or audits of qualified Material Organizations, the party performing the evaluation shall review objective evidence that the qualified Material Organization's control of suppliers is adequate to assure compliance with the applicable material requirements of this Division.

(g) Audits by parties performing evaluations of qualified Material Organizations shall meet the following requirements:

(1) The party performing the evaluation shall include audit frequency in their Manual.

(2) Audit frequencies shall be commensurate with the schedule of production or procurement, but shall be conducted at least once triennially during the interval in which materials are controlled or services are performed by the Material Organization being evaluated.

(3) Audits shall meet the requirements of WA-3859.1(a) through (c).

(h) The party performing the evaluation shall supplement triennial audits with annual audits or performance assessments documenting the effectiveness of the qualified Material Organization's Quality System Program. Performance assessments shall meet the following requirements:

(1) Assessment frequencies shall be commensurate with the schedule of production or procurement, but shall be conducted at least once annually during the interval in which materials or source materials are controlled, or services are supplied by the Material Organization being evaluated.

(2) Assessments shall include a documented review of the qualified Material Organization's history of conditions adverse to quality, nonconformances, and corrective actions.

(3) Assessments shall include a documented review of periodic testing performed since the last assessment to demonstrate conformance of sample materials to selected requirements of the material specification. Such testing shall be conducted during the period since the last assessment by the party performing the evaluation.

WA-3850 QUALITY SYSTEM PROGRAM REQUIREMENTS

WA-3851 Responsibility and Organization

WA-3851.1 General

(a) The Material Organization shall establish a Quality System Program for the control of quality during manufacture or during other work it proposes to perform, and for the traceability of material or source material under its control. The Program shall be planned, documented, implemented, and maintained in accordance with the requirements of WA-3850.

(b) The establishment of the Program shall include consideration of the technical aspects and provide for planning and accomplishment of activities affecting quality. The Program shall provide for any special controls, processes, test equipment, tools, and skills to attain the required quality and for verification of quality.

WA-3851.2 Scope and Applicability

(a) The Quality System Manual shall define the specific activities included in the scope of the work the Material Organization proposes to perform, including any combination of:

(1) Operations performed during the melting and heat analysis, affecting the mechanical properties, conversion from one product form into another product form including applicable dimensional requirements, and certification to the applicable material specification.

(2) Testing, examination, repair, or treatments required by the material specification or the specific applicable material requirements of this Section and certification of the results of such tests, examinations, repairs, or treatments.

(3) Receipt, identification, verification, handling, storage, and shipment of material or source material.

(4) Qualification of Material Organizations permitted by WA-3820(b).

(5) Approval and control of suppliers of source material or subcontracted services (WA-3855.3).

(6) Utilization of unqualified source material (WA-3855.5).

(b) The Program shall include measures to comply with all requirements of this Division, to the extent necessary to assure compliance with the requirements of this Division.

WA-3851.3 Organization

(a) The organizational structure for executing the Program may take various forms, provided the persons and organizations assigned the quality assurance functions have the required authority and organizational freedom.

(b) Persons or organizations responsible for defining and measuring the overall effectiveness of the Program shall:

(1) be designated;

(2) be sufficiently independent from the pressures of production;

(3) have direct access to responsible management at a level where appropriate action can be initiated;

(4) report regularly on the effectiveness of the Program.

Page 25

(c) The organizational structure, functional responsibilities, levels of authority, and lines of communication for activities affecting quality shall be documented. Persons or organizations responsible for assuring that an appropriate Quality System Program has been established and verifying that activities affecting quality have been correctly performed shall have sufficient authority, access to work areas, and organizational freedom to:

(1) identify quality problems;

(2) initiate, recommend, or provide solutions to quality problems through designated channels;

(3) verify implementation of solutions;

(4) assure that further processing, delivery, or use is controlled until proper disposition of a nonconformance, deficiency, or unsatisfactory condition has occurred.

(d) Individuals or groups assigned the responsibility of checking, auditing, or otherwise verifying that production and quality control activities have been correctly performed, shall be independent of the individual or group directly responsible for performing the specific activity. Such persons shall not report directly to the supervisor with immediate responsibility for the work being verified.

(e) Management shall regularly review the status and adequacy of the Program.

WA-3852 Personnel

WA-3852.1 Indoctrination, Training, and Qualification of Personnel

(a) Measures shall be established to assure that all personnel performing or managing activities affecting quality are indoctrinated and trained. The assignment of personnel shall be at the discretion of the organization's management. Indoctrination and training measures shall reflect the following requirements:

(1) Personnel to be indoctrinated or trained shall be identified.

(2) The extent of indoctrination and training shall be commensurate with the scope, complexity, and nature of the activity as well as the education, experience, and proficiency of the person.

(3) Personnel shall be indoctrinated in the general criteria, applicable codes, standards, company procedures, Quality System Program requirements, job responsibilities and authority as they relate to a particular function.

(4) Training shall be provided, as needed, to achieve initial proficiency, maintain proficiency, and adapt to changes in technology, methods, and job responsibilities.

(b) All nondestructive examination personnel shall be qualified in accordance with para. WB-5521 of the applicable Subsection.

(c) Personnel who lead audits shall be qualified on the basis of education, experience, training, audit participation, and examination in accordance with the organization's Quality System Program.

WA-3852.2 Personnel Records

(a) Records shall be maintained of the implementation of indoctrination and training of personnel. Records of indoctrination and training may take the form of attendance sheets, training logs, or personnel training records.

(b) Qualification records of all nondestructive examination personnel shall be documented and maintained.

(c) Qualification records of personnel who lead audits shall be documented and maintained and shall include education, experience, audit training and examination, and audit participation used as the basis of qualification.

WA-3853 Program Documentation

WA-3853.1 Quality System Manual

(a) The Quality System Program shall be described and summarized in a Quality System Manual which shall be a major basis for demonstration of compliance with the rules of this Division.

(b) The Program documented in the Manual shall be implemented by written procedures which are maintained either separately or in the Quality System Manual.

(c) Detailed technical procedures and processes, such as those for nondestructive examination, are not considered part of the Manual; however, the controls of such procedures and processes shall be covered by the Manual.

WA-3853.2 Procedures, Instructions, and Drawings

(a) Activities affecting quality shall be prescribed by and performed in accordance with documented instructions, procedures, or drawings of a type appropriate to the circumstances.

(b) These documents shall include or reference appropriate acceptance criteria for determining that the prescribed activities have been satisfactorily completed.

WA-3853.3 Document Control.

The preparation, issue, and change of documents that specify quality requirements or prescribe activities affecting quality, such as Quality System Program Manuals, purchase specifications, instructions, procedures, and drawings shall be controlled to assure that the correct documents are being used at the location where the activity is

Page 26

performed. Such documents, including changes thereto, shall be reviewed for adequacy and approved for release by authorized personnel.

WA-3853.4 Quality Assurance Records.

Records that furnish documentary evidence of quality shall be specified, prepared, controlled, and maintained. Records shall be legible, identifiable, and retrievable. Records shall be protected against damage, deterioration, or loss. Requirements and responsibilities for record transmittal, distribution, retention, maintenance, and disposition shall be established and documented.

WA-3853.5 Records of Examinations and Tests.

All characteristics required to be reported by the material specification and this Division shall be verified and the results recorded. Records shall be traceable to the document and revision to which an inspection, examination, or test was performed.

WA-3855 Control of Purchased Materials, Source Materials, and Services

WA-3855.1 General

(a) Measures shall be established to assure that all purchased material, source material, and subcontracted services conform to the requirements of this Division.

(b) Welding material used in the repair of material or source material shall be controlled in accordance with this Division.

(c) These measures shall be designed to prevent the use of incorrect or defective material or source material, or materials which have not received the required examinations or tests.

WA-3855.2 Sources of Material, Source Material, and Services

(a) Material shall be furnished by a Material Organization [WA-3820(a) or WA-3820(b)], or by a Certificate Holder [WA-3820(c)].

(b) Except as provided in WA-3855.5, source material shall be furnished by a Material Organization, by an approved supplier (WA-3855.3), or by a Certificate Holder.

(c) Services including performance and certification of operations, processes, the results of tests, examinations, repairs, or treatments required by the material specification or by this Division shall be furnished by a Material Organization, by an approved supplier, or by a Certificate Holder.

WA-3855.3 Approval and Control of Suppliers of Source Material and Services

(a) The Material Organization or Certificate Holder shall be responsible for the approval of and control of activities performed by suppliers of source materials and subcontracted services. Such control shall provide for source evaluation and selection, evaluation of objective evidence of quality, audit, and examination of items and services upon delivery, in accordance with requirements documented in the Material Organization's or Certificate Holder's Program.

(b) The Material Organization or Certificate Holder shall be responsible for establishing and verifying that the supplier's controls applicable to the activities performed are adequate by:

(1) surveying and auditing the supplier's established quality system which is consistent with the requirements of this Division, or

(2) having the supplier perform the activities in accordance with controls established by the Material Organization's or Certificate Holder's Program.

(c) The Material Organization or Certificate Holder shall be responsible for assuring that all material and activities conform to all applicable requirements of this Division.

WA-3855.4 Procurement Document Control

(a) Procurement documents shall include requirements necessary to assure compliance with the requirements of this Division.

(b) Except as provided in WA-3855.5, procurement documents shall require material, source material, or subcontracted services to be furnished in accordance with the applicable requirements of this Division.

(c) Procurement documents shall require approved suppliers to reference the accepted quality system or controls established by the Material Organization or Certificate Holder on documentation that accompanies the source material or services furnished.

(d) Procurement documents that specify quality requirements or prescribe activities affecting quality shall be reviewed for adequacy and approved for release by authorized personnel.

WA-3855.5 Utilization of Unqualified Source Material

(a) As an alternative to WA-3855.2(b), when included in its scope of activities as permitted by the provisions of this Division, a Material Organization may accept certification of the requirements of the material specification which must be performed during the melting, heat analysis, and heat treatment of the material, and may use or furnish unqualified source material, provided the requirements of WA-3855.5(a)(1) through (4) below are met:

(1) No welding with filler metal has been performed on the unqualified source material.

Page 27

(2) The Material Organization performs or subcontracts a product analysis to verify the chemical composition of each piece of unqualified source material.

(3) The Material Organization performs or subcontracts all other requirements of the material specification on each piece of unqualified source material. Where Certificates of Compliance [WA-3862.1(g)] are acceptable, testing of each piece is not required. Alternatively, the Material Organization may perform or subcontract all other requirements of the material specification on each heat and lot of unqualified source material provided:

(a) A Certified Material Test Report is provided with the unqualified source material.

(b) The unqualified source material is traceable to the Certified Material Test Report.

(c) Procurement documents require that suppliers of unqualified source material establish written procedures for identifying source materials in a manner that provides traceability to the Certified Material Test Report.

(d) The Material Organization reviews and accepts the supplier's identification and traceability procedures and verifies compliance with the procedures at a frequency commensurate with the schedule of production or procurement, but at least once triennially.

(e) Upon receipt, the Material Organization shall verify by review of objective evidence, that the requirements of the procurement document have been met.

(4) The provisions of (a)(1) through (a)(3) above are performed in accordance with the Material Organization's Quality System Program.

(b) The provisions of (a)(1) through (a)(3) above may be performed by the Certificate Holder in accordance with his Quality Assurance Program.

WA-3856 Identification, Marking, and Material Control

WA-3856.1 General

(a) Control shall be established to assure that only correct and accepted material or source material is used. Identification shall be maintained on these materials or on documents traceable to these materials, or in a manner which assures that the identification is established and maintained.

(b) Measures shall be established for controlling and identifying material or source material, including that which is partially processed, throughout the manufacturing process, during the performance of tests, examinations, repairs, and treatments, and during receipt, storage, handling, and shipment.

(c) Identification marking shall be transferred to all pieces when material or source material is divided.

WA-3856.2 Marking Method.

Materials and source materials shall be marked by any method acceptable to the purchaser which will not result in harmful contamination or sharp discontinuities and will identify these materials in accordance with the material specification.

WA-3856.3 Identification of Completed Material

(a) The identification of completed material shall consist of marking the material with the applicable specification and

grade of the material, the heat number or heat code of the material, and any additional marking required by this Division to facilitate traceability of the material to reports of the results of all tests and examinations performed on the material.

(b) For those materials where Certificates of Compliance [WA-3862.1(g)] are allowed, heat-number identification need not be indicated on the material or the Certificate.

(c) A marking symbol or code may be used which identifies the material, provided such code or symbol is explained in the Certified Material Test Report (WA-3862.1) or Certificate of Compliance [WA-3862.1(g)], as applicable.

(d) All requirements of the material specification shall be met except where specifically exempted or superseded by a provision of this Division. When special requirements or provisions of this Division conflict with the requirements of the material specification, the material specification and grade number shall be followed with an asterisk (*) to indicate that the material specification has been modified as shown on the material certification.

(e) For nonferrous materials manufactured in accordance with material specifications which do not provide for heat identification, the material shall be marked with a symbol or code that identifies the lot, as defined in the material specification, with the Certified Material Test Report.

(f) Except as required by the material specification, bolts and nuts 1 in. (25 mm) nominal diameter and smaller and other products where the largest space available for marking is less than 1 in. (25 mm) in any one direction need not be individually marked, provided they are packed in packages or containers which shall be clearly identified by legible marking to ensure positive identification of the material. The markings on the containers shall identify the material with the Certificate of Compliance [WA-3862.1(g)] or Certified Material Test Report (WA-3862.1), as applicable.

Page 28

WA-3856.4 Welding and Brazing Materials Identification.

Welding and brazing materials shall be clearly identified by legible marking on the package or container to ensure positive identification of the material. The marking shall include the heat or lot number as applicable, a control marking code which identifies the material with the Certified Material Test Report (WA-3862.1), and other information such as specification, grade and classification number, Material Organization's name, and trade designation.

WA-3857 Process Control

WA-3857.1 General.

Processes affecting quality of materials, source materials, or services shall be controlled. Special processes that control or verify quality, such as those used in welding, heat treating, or nondestructive examination, shall be performed by qualified personnel using qualified procedures in accordance with specific requirements.

WA-3857.2 Manufacturing Process Control.

Operations shall be performed under a controlled system such as process sheets, shop procedures, checklists, travellers, or equivalent procedures. Measures shall be established to ensure that processes, including heat treatment, are controlled in accordance with the material specification and the rules of this Division.

WA-3857.3 Welding.

When welding is required in the repair of material or source material, it shall be performed in accordance with procedures and by welders or welding operators qualified in accordance with this Division and Section IX. The qualification of procedures and welders or welding operators shall be documented.

WA-3857.4 Handling, Storage, Shipping, and Preservation.

Instructions shall be established for handling, storage, shipping, and preservation of material or source material to prevent damage or deterioration.

WA-3858 Control of Examinations, Tests, and Nonconforming Material

WA-3858.1 Inspection, Examination, and Test Control

(a) Inspections, examinations, and tests shall be established to assure conformance with the requirements of the material specification and this Division.

(b) Inspections or examinations required to verify conformance of material, source material, or an activity to specified requirements shall be planned. Characteristics to be inspected or examined, and inspection or examination methods to be employed, shall be specified. Inspection or examination results shall be documented.

(c) Tests required to verify conformance to specified requirements shall be planned. Characteristics to be tested and test methods to be employed shall be specified. Test results shall be documented and their conformance with acceptance criteria shall be evaluated.

WA-3858.2 Control of Measuring and Test Equipment

(a) Procedures shall be in effect to assure that tools, gages, instruments, and other measuring and testing devices used to verify compliance with the material specification and this Division are calibrated and properly adjusted at specific periods or use intervals to maintain accuracy within necessary limits. Periodic checks on equipment may be performed to determine that calibration is maintained.

(b) Calibration shall be against certified equipment having known valid relationships and documented traceability to nationally recognized standards, where such standards exist. If no known nationally recognized standards exist, the basis for calibration shall be documented.

(c) Control measures shall include provisions for measuring and test equipment identification and for determining calibration status by equipment marking or on records traceable to the equipment.

WA-3858.3 Discrepancies in Measuring or Testing Equipment

(a) When discrepancies in excess of tolerances for measuring or testing equipment are found at calibration, appropriate corrective action shall be taken, and material measured or tested since the previous calibration shall be reviewed to determine that all applicable requirements have been met.

(b) When periodic checks on equipment are performed to determine that calibration is maintained, potential material or source material discrepancies need only be resolved to the previous check, provided:

- (1) the methods used and frequency of periodic checking are described in calibration procedures; and
- (2) the calibration discrepancy was found by periodic check.

WA-3858.4 Inspection and Test Status.

Measures shall be established so that the status and results of any required inspections, examinations, or tests can be determined at any time. Status shall be maintained through indicators such as physical location and tags, marking, shop travellers, stamps, inspection records, or other suitable means. The authority for application and removal of such indicators shall be specified.

Page 29

WA-3858.5 Control of Nonconforming Material

(a) Adequate control measures shall be established to prevent the use of material that does not conform to the requirements of the material specification and this Division.

(b) Material or source material with nonconformances shall be identified, segregated when practical, and reviewed for acceptance, rejection, or repair in accordance with documented procedures. The responsibility and authority for the disposition of nonconformances in these materials shall be defined.

(c) Repaired material or source material shall be reexamined in accordance with applicable procedures.

(d) Measures which control further processing of nonconforming or defective material or source material, pending a decision on its disposition, shall be established and maintained. These control measures shall extend to notification of other affected organizations, as appropriate.

WA-3859 Audits and Corrective Action

WA-3859.1 Audits

(a) Audits shall be performed in accordance with written procedures or checklists by personnel not having direct responsibility in the areas being audited.

(b) Audit results shall be documented by auditing personnel for review by management having responsibility in the area being audited.

(c) Procedures shall include provisions for documentation of corrective action taken in response to deficiencies. Follow-up action, including re-audit of deficient areas where indicated, shall be taken to verify implementation of such corrective actions.

(d) In addition to audits of Material Organizations and suppliers, a comprehensive system of planned and periodic internal audits shall be carried out to assure compliance with all aspects of the Quality System Program and to determine the effectiveness of the Program.

(e) Internal audits shall be performed in accordance with the requirements of (a) through (c) above.

WA-3859.2 Corrective Action

(a) Measures shall be established to assure that conditions adverse to quality such as failures, malfunctions, deviations, defective material and equipment, nonconformances, and quality system deficiencies, are promptly identified and reported to appropriate levels of management. The measures shall also assure that the cause of conditions adverse to established quality levels be determined and corrected.

(b) The identification of significant or recurring conditions adverse to quality, the cause of condition, and the corrective action taken shall be documented and reported to appropriate levels of management.

(c) These requirements shall also extend to the performance of the approved supplier's corrective action measures.

WA-3860 CERTIFICATION REQUIREMENTS

WA-3861 Certification Requirements for Material Organizations

(a) The Material Organization whose scope of activities includes WA-3830 shall provide a Certified Material Test Report or Certificate of Compliance, as applicable (WA-3862), for the material.

(1) The certification affirms that contents of the report are correct and accurate and that all test results and operations performed by the Material Organization or its subcontractors are in compliance with the material specification and the specific applicable material requirements of this Division.

(2) Chemical analyses, tests, examinations, and heat treatments required by the material specification that were not performed shall be listed on the Certified Material Test Report or Certificate of Compliance, as applicable, or may be listed on an identified attachment.

(3) When the Material Organization's scope of activities includes product form conversion, the Material Organization shall also certify that the material conforms to the applicable dimensional requirements.

(b) The Material Organization shall transmit all certifications received from other Material Organizations or approved suppliers in accordance with (a) above, to the purchaser at time of shipment.

(c) The Certificate Holder shall complete all operations not completed by the Material Organization and shall provide a Certified Material Test Report for all operations performed by him or his approved suppliers. The Certificate Holder shall certify that the contents of the report are correct and accurate and that all test results and operations performed by the

Certificate Holder or his approved suppliers are in compliance with the requirements of the material specification and this Division. Alternatively, the Certificate Holder shall provide a Certified Material Test Report for the operations it performed and at least one Certified Material Test Report from each of its approved suppliers for the operations they performed.

WA-3862 Certification of Material

WA-3862.1 Material Certification

(a) The Certified Material Test Report shall include the actual results of all required chemical analyses, tests, and examinations.

(b) When required chemical analyses (including melting mill heat analysis), heat treatment, tests, examinations, or repairs are subcontracted, the approved supplier's certification for the operations performed shall be furnished as an identified attachment to the Certified Material Test Report.

(c) The Certified Material Test Report shall also include a report of all weld repairs performed on the material as required by this Division. Radiographic film required for the examination of material repair welds shall be included as a part of the Certified Material Test Report, except for those radiographs required for the testing of welding or brazing materials.

(d) When specific times or temperatures (or temperature ranges) of heat treatments are required by material specifications, they shall be reported. When specific times and temperatures (or temperature ranges) are not required by the material specification, a statement of the type of heat treated condition shall be reported. In any case, a statement of the minimum solution annealing temperature is adequate for austenitic stainless steels and high nickel alloys. Additionally, the times and temperatures of postweld heat treatments of weld repaired materials as required by the fabrication requirements of this Division shall be reported.

(e) Reporting of actual dimensions and visual examination results is neither required nor prohibited by this paragraph.

(f) Notarization of the Certified Material Test Report is not required.

(g) A Certificate of Compliance with the material specification, grade, class, and heat treated condition, as applicable, may be provided in lieu of a Certified Material Test Report for material NPS $\frac{3}{4}$ (DN 20) and less (pipe, fittings, flanges, materials for valves and tubes except heat exchanger tubes), bolting 1 in. (25 mm) and less, as applicable.

(h) Material identification shall be described in the Certified Material Test Report or Certificate of Compliance, as applicable. Heat or lot traceability to the Certificate of Compliance is not required.

WA-3862.2 Quality System Program Statement

(a) When the Material Organization holds a Quality System Certificate, the Material Organization's Quality System Certificate number and expiration date shall be shown on the Certified Material Test Report or Certificate of Compliance, as applicable, or on a certification included with the documentation that accompanies the material.

(b) When the Material Organization has been qualified by a party other than the Society, the revision and date of the applicable written Quality System Program shall be shown on the Certified Material Test Report or Certificate of Compliance, as applicable, or on a certification included with the documentation that accompanies the material.

(c) The inclusion of the Quality System Certificate number and expiration date or reference to revision and date of the applicable written Quality System Program shall be considered the Material Organization's certification that all activities have been performed in accordance with the applicable requirements of this Division.

July 1, 1998

American Society Of Mechanical Engineers
SEC III D3 WA-4000

ARTICLE WA-4000 QUALITY ASSURANCE

Page 31

Page 33

WA-4100 REQUIREMENTS

WA-4110 SCOPE AND APPLICABILITY

(a) This Article sets forth the requirements for planning, managing, and conducting Quality Assurance Programs for controlling the quality of activities performed under this Division and the rules governing the evaluation of such Programs prior to the issuance of Certificates for the design, construction, fabrication, and manufacture of Class TP items. The Quality Assurance requirements for Material Organizations are provided in WA-3800. Certificate Holders are advised to consult other regulations for quality assurance requirements governing activities beyond the scope of this Division.

(b) N-Type Certificate Holders shall comply with the Basic Requirements and Supplements of ASME NQA-1-1994, as modified and supplemented in WA-4134.

WA-4120 DEFINITIONS

(a) The definitions in WA-9000 shall apply.

(b) The terms and definitions of NQA-1-1994, Supplement S-1 shall apply except for those listed in (1) through (7) below. For the following terms, the definitions in WA-9000 shall apply:

- (1) *item*
- (2) *Owner*
- (3) *quality assurance*
- (4) *repair*
- (5) *rework*
- (6) *service*
- (7) *use-as-is*

WA-4130 ESTABLISHMENT AND IMPLEMENTATION

WA-4131 Material Organizations, Division 3

The requirements of WA-3800 apply.

WA-4134 Design Owners, Class TP Certificate Holders, and Packaging Owners

WA-4134.1 Organization.

The provisions of NQA-1-1994, Basic Requirement 1 and Supplement 1S-1, shall apply.

WA-4134.2 Quality Assurance Program

(a) The provisions of NQA-1-1994, Basic Requirement 2 and Supplements 2S-1 and 2S-3, shall apply and the system used to meet these requirements shall be described in the Quality Assurance Manual. The Quality Assurance Manual shall also include a statement of policy and authority indicating management support. The specific responsibilities of the quality assurance organization of the Certificate Holder shall also include the review of written procedures and monitoring of the activities concerned with the Quality Assurance Program as covered in this Article.

(b) In lieu of Supplement 2S-2, the qualification of nondestructive examination personnel shall be as required by WB-5520.

(c) The controls used in the Quality Assurance Program shall be documented in the Quality Assurance Manual. The Program need not be in the same format or sequential arrangement as the requirements in this Article, as long as all applicable requirements of this Article have been covered. A copy, including all changes that are made, shall be made available to the Inspector. The Certificate Holder shall make available to the Inspector such drawings and process sheets as are necessary to make the Quality Assurance Program intelligible.

(d) The Certificate Holder shall be responsible for advising its Authorized Inspection Agency of any significant changes which are proposed to be made to the Quality Assurance Manual, and shall have acceptance of the Authorized Inspection Agency's Authorized Nuclear Inspector Supervisor before putting such changes into effect. The Certificate Holder shall be responsible for promptly notifying the Inspector of such accepted changes, including evidence of acceptance by the Authorized

Page 34

Inspection Agency, and for simultaneously reconciling copies of the Quality Assurance Manual.

WA-4134.3 Design Control

(a) The provisions of NQA-1-1994, Basic Requirement 3 and Supplement 3S-1, shall apply.

(b) Measures shall be established to ensure that applicable requirements of the Design Specifications and of this Division for items are correctly translated into specifications, drawings, procedures, and instructions.

(c) Design documents shall be verified for adequacy and compliance with the Design Specification and this Division.

WA-4134.4 Procurement Document Control.

The provisions of NQA-1-1994, Basic Requirement 4 and Supplement 4S-1, shall apply, except that procurement documents shall require Suppliers to provide a Quality Assurance Program consistent with the applicable requirements of this Division.

WA-4134.5 Instructions, Procedures, and Drawings.

The provisions of NQA-1-1994, Basic Requirement 5, shall apply.

WA-4134.6 Document Control.

The provisions of NQA-1-1994, Basic Requirement 6 and Supplement 6S-1, shall apply.

WA-4134.7 Control of Purchased Items and Services.

The provisions of NQA-1-1994, Basic Requirement 7 and Supplement 7S-1, shall apply, except that:

(a) Supplement 7S-1, 8.3 is not applicable to the procurement of Authorized Inspection Agency services as required in WA-8130;

(b) the decision to perform bid evaluation for materials to confirm conformance to procurement documents, required in 7S-1, 4.0, shall remain the responsibility of the Certificate Holder;

(c) changes, waivers, or deviations permitted by 7S-1, 8.2.1(b) shall not be acceptable if they do not meet the requirements of this Division;

(d) resolution of nonconformances identified in 7S-1, 8.2.1(c) shall be in conformance with the requirements of this Division; and

(e) documentary evidence that items conform to the requirements of this Division shall be available at the site before use. Requirements for documentary evidence are satisfied for material when the applicable rules of WA-3800 for material certification are met. For stamped items, the requirements are satisfied by a Data Report.

WA-4134.8 Identification and Control of Items

(a) The provisions of NQA-1-1994, Basic Requirement 8 and Supplement 8S-1, shall apply.

(b) Welding and brazing materials shall be controlled.

(c) All characteristics required to be reported by the material specifications and by this Division shall appear on checklists, and each such characteristic shall be examined by accepted procedures as required and the results recorded. Characteristics included on Certified Material Test Reports or Certificates of Compliance need not be duplicated in the checklists. Checklists shall provide for a record that the Certified Material Test Reports and Certificates of Compliance have been received, reviewed, and found acceptable. When the results of the examination or test procedure conducted by the Certificate Holder are necessary to show compliance with material specification or other requirements, the checklists shall show the required range of values. The checklists shall include spaces for: inclusion of document number and revision to which examination or tests were made; a signature, initials, or stamp; the date of the examination performed by the Certificate Holder's representative; an Authorized Nuclear Inspector's signature, initials, or stamp; and the date on which those activities were witnessed.

WA-4134.9 Control of Processes

(a) The provisions of NQA-1-1994, Basic Requirement 9 and Supplement 9S-1, shall apply.

(b) The Certificate Holder shall prepare instructions, procedures, drawings, checklists, travelers, or other appropriate documents, including the document numbers and revisions to which the process conforms, with space provided for reporting results of completion of specific operations at checkpoints of fabrication, manufacture, or installation. The documents shall include space for: a signature, initials, or stamp; the date that the activity was performed by the Certificate Holder's representative; the Authorized Nuclear Inspector's signature, initials, or stamp; and the date on which those activities were witnessed.

WA-4134.10 Inspection

(a) The provisions of NQA-1-1994, Basic Requirement 10 and Supplement 10S-1, shall apply, except for para. 2 and the requirements of Inservice Inspection.

(b) The Certificate Holder shall prepare process sheets, travelers, or checklists, including the document numbers and revision to which the examination or test is to be performed, with space provided for recording results of examinations and tests. The documents shall include space for: a signature, initials, or stamp; the date that the activity was performed by the Certificate Holder's representative; the Authorized Nuclear Inspector's signature, initials, or stamp; and the date on which those activities were witnessed. The examination checklist for construction of items shall be filled in

Page 35

and completed by the Certificate Holder who applies the appropriate Code Symbol Stamp to the item.

(c) Mandatory hold points at which witnessing is required by the Certificate Holder's representative or the Authorized Nuclear Inspector shall be indicated in the controlling documents (WA-4134.9). Work shall not proceed beyond mandatory hold points without the consent of the Certificate Holder's representative or the Authorized Nuclear Inspector, as appropriate.

WA-4134.11 Test Control.

The provisions of NQA-1-1994, Basic Requirement 11 and Supplement 11S-1, shall apply.

WA-4134.12 Control of Measuring and Test Equipment

(a) The provisions of NQA-1-1994, Basic Requirement 12 and Supplement 12S-1, shall apply.

(b) The Certificate Holder may perform periodic checks on equipment to determine that calibration is maintained. When periodic checking is used, discrepancies need only be resolved to the prior check, provided the discrepancy is discovered by the periodic check. The methods and frequency of periodic checking, when used, shall be included in the Certificate Holder's Quality Assurance Program.

WA-4134.13 Handling, Storage, and Shipping.

The provisions of NQA-1-1994, Basic Requirement 13 and Supplement 13S-1, shall apply.

WA-4134.14 Inspection and Test Status.

The provisions of NQA-1-1994, Basic Requirement 14, shall apply for inspections and tests, but not for operating status.

WA-4134.15 Control of Nonconforming Items.

The provisions of NQA-1-1994, Basic Requirement 15 and Supplement 15S-1, shall apply, except that the definition of *repair* given in this Division shall apply in lieu of *repair* and *rework* given in NQA-1-1994.

WA-4134.16 Corrective Action

- (a) The provisions of NQA-1-1994, Basic Requirement 16, shall apply.
- (b) The requirements shall also extend to the performance of the subcontractor's corrective action measures.

WA-4134.17 Quality Assurance Records

(a) *General.* The provisions of NQA-1-1994, Basic Requirement 17 and Supplement 17S-1, shall apply, except that the requirements for classification in 17S-1, 2.7, retention of records in 17S-1, 2.8, and facility in 17S-1, 4.4 are not applicable. Such records shall be classified and maintained as required by this Division.

(b) *Records Index.* The records shall be indexed. The records and the indices thereto shall be accessible to the Packaging Owner, or his designee, and Authorized Nuclear Inspector.

(c) *Reproduction of Radiographs.* Radiographs may be reproduced provided the following requirements are met:

- (1) the reproduction process shall be subject to the Packaging Owner's approval;
- (2) when radiographs are reproduced for either a Packaging Owner or Class TP Certificate Holder, the Quality Assurance Program of the Class TP Certificate Holder responsible for the reproduction process shall include a system for controlling and monitoring the accuracy of the process so that the image, when reproduced to its original size, will provide the same information retrieval capability as the original radiograph;
- (3) procedures shall contain applicable requirements pertaining to exposure, scanning, focusing, contrast, resolution, and distinguishing film artifacts that might appear as material discontinuities in the reproduced image.

(d) *Lifetime Records.* For Class TP, the records listed in Table WA-4134.17-1 shall be classified as lifetime records. The Design Owner and Packaging Owner shall be responsible for their retention for the life of the item as indicated in the Table.

(e) *Nonpermanent Records.* For Class TP, the records listed in Table WA-4134.17-2 shall be classified as nonpermanent records. The Design Owner and Packaging Owner shall be responsible for their retention for the period specified in Table WA-4134.17-2. In no case need nonpermanent records be retained for longer than 10 years after completion of applicable Code Data Report, CMTR, or Certificate of Compliance.

WA-4134.18 Audits

- (a) The provisions of NQA-1-1994, Basic Requirement 18 and Supplement 18S-1, shall apply.
 - (b) Results of audits shall be made available to the Authorized Nuclear Inspector.
 - (c) The audit frequency shall be specified in the Certificate Holder's Quality Assurance Manual. The Certificate Holder's audit frequency shall be commensurate with his schedule of activities and shall be such that each ongoing Code activity is audited at least once annually.
-

**TABLE WA-4134.17-1 [Note (1)]
LIFETIME QUALITY ASSURANCE RECORDS**

Record	Record
1. Index to lifetime records (WA-4134.17) [DO, PO] [Note (2)]	9. Final nondestructive examination reports; Final radiographs for the containment system [PO]
2. Code Data Reports (WA-8400) [PO]	10. Repair records when required by Code (WB-4130) [PO]
3. Design Specification (WA-3250) [DO, PO]	11. Weld procedures [PO]
4. Design Documents (WA-2550) [DO, PO]	12. Audit and survey reports (WA-4121 and WA-4134.18) [DO, PO]
5. As-built drawings (WA-3554) [PO]	13. Process sheets, travelers, or checklists (WA-4134.10) [PO]
6. Certified Material Test Reports (CMTR) and documentation providing traceability to location used, if required (WB-4122) [PO]	14. Joint-welder identification records when such records are used in lieu of physical marking of welds (WB-4322) [PO]
7. Heat treatment records [PO] [Note (3)]	
8. Final hydrostatic and pneumatic test results (WA-5280) [PO]	

NOTES:

- (1) Nonconformance reports that affect those records listed shall be incorporated into the record or be retained with the records.
- (2) Letters in brackets identify organization responsible for record retention: DO = Design Owner, PO = Packaging Owner.
- (3) Either heat treatment charts or certified summaries of time and temperature data may be provided. These data may be included as part of the CMTR.

TABLE WA-4134.17-1 [Note (1)] LIFETIME QUALITY ASSURANCE RECORDS

**TABLE WA-4134.17-2 [Note (1)]
NONPERMANENT QUALITY ASSURANCE RECORDS**

Record	Retention Period
1. QA Program Manual [DO, PO] [Note (2)]	3 years after superseded or invalidated
2. Design procurement and QA procedures (WA-4134.5) [DO, PO]	3 years after superseded or invalidated
3. Installation and NDE procedures WB-5112 [PO]	10 years after superseded or invalidated
4. Personnel qualification records (WB-5520 and WB-4322) [DO, PO]	3 years after superseded or invalidated
5. Purchase orders [DO, PO]	10 years after superseded or invalidated
6. Final radiographs not covered in Table WA-4134.17-1 [PO]	10 years after completion
7. Calibration records (WA-4134.12) [PO]	Until recalibrated

NOTES:

- (1) Nonconformance reports which affect those records listed and are not incorporated into the record shall be retained for the retention period applicable to the record the nonconformance report affects.
 (2) Letters in brackets identify organization responsible for record retention: DO = Design Owner, PO = Packaging Owner.

TABLE WA-4134.17-2 [Note (1)] NONPERMANENT QUALITY ASSURANCE RECORDS

July 1, 1998

American Society Of Mechanical Engineers

SEC III D3 WA-5000

ARTICLE WA-5000 AUTHORIZED INSPECTION

Page 37

Page 39

WA-5100 INTRODUCTION

WA-5110 APPLICABILITY

This Article provides the requirements for inspection by the Authorized Inspection Agency.

WA-5120 PERFORMANCE OF INSPECTION

WA-5121 Authorized Inspection Agency

(a) An Authorized Inspection Agency is one designated by, or is one acceptable to, the appropriate Enforcement Authority of a state of the United States or a province of Canada. The Authorized Inspection Agency shall be accredited by the Society in accordance with the provisions set forth in ASME QAI-1-1995.

(b) The Authorized Inspection Agency shall notify the Society when it enters into an agreement with a Design Owner or Class TP Certificate Holder, or whenever an existing agreement is terminated. The Authorized Inspection Agency shall also notify the Enforcement Authority whenever an agreement with a Design Owner, Packaging Owner, or Class TP

also notify the Enforcement Authority whenever an agreement with a Design Owner, Packaging Owner, or Class TP Certificate Holder is written or a Design Owner's, Packaging Owner, or Class TP Certificate Holder agreement is terminated.

WA-5122 Authorized Nuclear Inspector Supervisor

The Authorized Inspection Agency shall employ Authorized Nuclear Inspection Supervisors qualified in accordance with ASME QAI-1-1995, to supervise the Inspectors.

WA-5123 Authorized Nuclear Inspector

The Authorized Inspection Agency shall also employ Authorized Nuclear Inspectors qualified in accordance with ASME QAI-1-1995, to perform inspections required by this Division. The inspections required by this Division shall be performed by an Authorized Nuclear Inspector. Any reference to Inspector throughout this Division shall mean Authorized Nuclear Inspector. The Authorized Nuclear Inspector shall not be in the employ of a Design Owner, Packaging Owner, or Class TP Certificate Holder.

WA-5125 Duties of Authorized Nuclear Inspector Supervisors

(a) Supervisors, in conjunction with Inspectors employed by the same Authorized Inspection Agency (WA-5121), shall participate in the Society's review of the applicant's Quality Assurance Program (WA-8160). In those cases where the Supervisor performs the functions of the Inspector, he may represent both during the review of the Program. A Supervisor designated by the Authorized Inspection Agency shall review and accept any proposed modifications to Quality Assurance Manuals before they are put into effect. The Authorized Nuclear Inspector Supervisor shall audit the Inspector's performance at least twice per year at locations where the Class TP Certificate Holder is actively engaged in Section III work. The Supervisor shall be available as needed for consultation and support of the local inspection staff. The Supervisor shall maintain supervisory control over one or more Authorized Nuclear Inspectors and shall perform all of the functions and maintain the records required of him in ASME QAI-1-1995.

(b) The portion of a Class TP Certificate Holder's Quality Assurance Program that involves supply or manufacture and supply of materials [WA-3820(c)] shall be audited by the Supervisor at least once each year.

Page 40

WA-5130 ACCESS FOR INSPECTION AGENCY PERSONNEL

WA-5131 Access to the Class TP Certificate Holder's Facilities

(a) The Certificate Holder shall arrange for the Inspection Agency Personnel to have free access at all times to those locations where Code activities, including those concerned with supply or manufacture of materials, are being performed on an item, when so requested. The Class TP Certificate Holder shall keep the Inspector informed of the progress of the work and shall notify him reasonably in advance when the item will be ready for any required tests or inspections.

(b) The Class TP Certificate Holder shall provide personnel to accompany the Authorized Nuclear Inspector Supervisor during his required audits.

WA-5132 Access to the Design Owner's and Packaging Owner's Facilities

The Design Owner and Packaging Owner shall arrange for the Authorized Inspection Agency Personnel to have free access to the Design Owner's and Packaging Owner's facilities as required to perform duties under the Design Owner's and Packaging Owner's Agreement with the Authorized Inspection Agency (WA-5121).

WA-5200 DUTIES OF INSPECTOR

WA-5210 GENERAL INSPECTION DUTIES

(a) The Inspector who performs the detailed inspections in compliance with this Division shall witness or otherwise verify all examinations and make all inspections required by this Division. He shall also make any other inspections and witness or verify (including making measurements) any other examinations and additional investigations which, in his judgment, are

necessary to ascertain whether the item being inspected has been constructed (WA-1110) in compliance with the rules of this Division. Parts and piping subassemblies shall be in accordance with the accepted documents (WA-3251).

(b) The duties of the Inspector shall not be interpreted by virtue of these rules to extend to any construction requirements beyond those of this Division which may be set forth in the Construction Specifications (WA-3451). However, such requirements shall not result in construction which fails to conform with the requirements of this Division (WA-3570).

WA-5220 CATEGORIES OF INSPECTOR'S DUTIES

The duties of the Inspector shall include but not necessarily be limited to those given in (a) through (i) below:

(a) verifying the scope of work to be performed [WA-5230(a)];

(b) monitoring of the Design Owner's, Packaging Owner's, and Class TP Certificate Holder's Quality Assurance Program including subcontracted activities (WA-5240);

(c) reviewing of Design Owner's, Packaging Owner's, and Class TP Certificate Holder's qualification records (WA-5250);

(d) verifying materials (WA-5260);

(e) witnessing or verifying in-process fabrication, nondestructive examination, and tests (WA-5270);

(f) witnessing final pressure tests (WA-5280);

(g) certifying Data Reports and Construction Reports (WA-5290);

(h) reviewing drawings and inspecting in accordance with them;

(i) performing all other duties specifically required in ASME QAI-1-1995.

WA-5230 SCOPE OF WORK, DESIGN SPECIFICATIONS, DESIGN REPORTS, CONSTRUCTION SPECIFICATIONS, AND CONSTRUCTION REPORTS

(a) The Inspector shall verify that the scope stated in the N-type Certificate of Authorization includes the work to be performed.

(b) The Inspector shall verify that the Design Specification, Design Reports, Construction Specifications, and Construction Reports, when required (WA-3456 and WA-3561), are on file and that they have been properly certified in accordance with WA-3255 and WA-3455.

(c) The Inspector shall not be held responsible for the scope or adequacy of the Design Specifications, for the completeness or accuracy of the Design Report or calculations or for the qualification of registered Professional Engineers certifying documents in compliance with the requirements of this Division.

(d) The Inspector shall verify that Design Calculations have been prepared for those components not requiring Design Reports. The Inspector shall not be responsible for the accuracy of the calculations.

Page 41

WA-5240 QUALITY ASSURANCE PROGRAMS

WA-5241 Stipulation of Inspections Prior to Issuance of Process Sheets or Controls

Prior to the issuance of process sheets or controls required by WA-4134.9, the Class TP Certificate Holder shall review them and the applicable drawings with the Inspector, who shall then stipulate the inspections he intends to make in order to fulfill the requirements of WA-5210.

WA-5242 Monitoring of Quality Assurance Programs

(a) The Inspector shall monitor the performance of the Design Owner, Packaging Owner, and Class TP Certificate Holder for conformity to the requirements of their Quality Assurance Program accepted by the Society. The Inspector shall verify that all changes to the Quality Assurance Manual have been accepted by the Authorized Inspection Agency

before they are put into effect.

(b) The Inspector shall monitor the Packaging Owner's compilation supporting data needed to complete the ASME Data Report Form N-3.

WA-5243 Process Control Checklist

The Inspector shall indicate on the Class TP Certificate Holder's process sheets or checklist his concurrence that compliance has been attained at each point stipulated by him (WA-5241).

WA-5250 QUALIFICATION RECORDS

WA-5251 Review of Qualification Records

The Inspector shall review the qualification records of the Class TP Certificate Holder.

WA-5253 Welding Procedures

The Inspector shall assure himself that the welding procedures employed in construction have been qualified under the provisions of this Division. The Class TP Certificate Holder shall submit evidence to the Inspector that these requirements have been met. When there is a specific reason to question the welding procedure, the Inspector may require requalification as a requirement for the procedure to be used on work subject to his inspection.

WA-5254 Welders and Welding Operators

The Inspector shall assure himself that all welding is performed by welders or welding operators qualified under the provisions of this Division. The Class TP Certificate Holder shall make available to the Inspector a certified copy of the record of performance qualification tests of each welder and welding operator as evidence that these requirements have been met. When there is a specific reason to question the ability of the welder or the welding operator to make welds that meet the requirements of the specification, the Inspector may require requalification before the welder or welding operator is permitted to continue welding on work subject to his inspection. The Inspector shall also assure himself that each welder and welding operator has been assigned an identifying symbol and that such symbols are regularly and consistently applied when required by this Division.

WA-5255 Examination Procedures

The Inspector shall assure himself that the examination and testing procedures required by this Division have been qualified. When there is a specific reason to question whether the examination or testing procedure requirements are being met, the Inspector may require requalification of the procedure.

WA-5256 Nondestructive Examination Personnel

The Inspector has the duty to verify the qualification and certification of nondestructive examination personnel employed by the Class TP Certificate Holder and has the duty to monitor the nondestructive examination activities and require requalification of any personnel when there is reason to question the performance of that person. In addition, the Inspector shall monitor the Class TP Certificate Holder's Quality Assurance Program as it relates to the nondestructive examination activities of Material Organizations, and NDE subcontractors that the Certificate Holder qualified.

WA-5260 MATERIALS, PARTS, AND HEAT TREATMENT

WA-5261 Inspection of Materials for Compliance

The Inspector shall assure himself that all materials used comply with all applicable requirements of this Division. The Class TP Certificate Holder shall make available to the Inspector certified reports of the results

of all tests performed in accordance with (a) and (b) below:

(a) the material specifications;

(b) the requirements in the applicable materials Articles of this Division, including certified reports of the results of all required tests and examinations performed.

WA-5262 Dimensional Check

The Inspector shall satisfy himself:

(a) that the item is being constructed within the tolerance required by the Design Specification, Design Drawings, and Construction Specifications, and this Division;

(b) that head and shell sections conform to the prescribed shape and meet the thickness requirements;

(c) that fittings and attachments to be welded to the vessel fit properly to the curvature of the vessel surface. If required by the Inspector, the Class TP Certificate Holder responsible for the vessel shall make available accurately formed templates for his use.

WA-5263 Check of Heat Treatment Practice

The Inspector shall satisfy himself that all heat treatment operations required by this Division are correctly performed and that the temperature readings and gradients conform to the requirements.

WA-5270 EXAMINATIONS AND TESTS

The Inspector shall witness in-process fabrication nondestructive examinations and destructive tests, when feasible; alternatively, he shall check the examination and test records to determine the acceptability of the items involved.

WA-5280 FINAL TESTS

The Inspector shall witness final hydrostatic, pneumatic, structural integrity, or leakage tests required by this Division and examinations performed during such tests by the Class TP Certificate Holder.

WA-5290 CERTIFICATION OF DATA REPORTS AND CONSTRUCTION REPORTS

(a) The appropriate Data Reports prepared by the Class TP Certificate Holder shall be certified by the Inspector only after they have been certified by a responsible representative of the Class TP Certificate Holder and after he has satisfied himself that all requirements of this Division have been met and that each Data Report certified is a correct record.

(b) The N-3 Data Report Form (WA-3220) shall be certified by the Inspector only after:

(1) it has been certified by the Packaging Owner;

(2) the Inspector has reviewed the N-3 Form and verified that the Data Reports referenced on the N-3 Form are on file and that such Data Reports verify Code compliance of all components or parts incorporated into the containment system of the transport packaging or that portion of the system covered by the N-3 Form.

WA-5300 RESPONSIBILITIES OF THE AUTHORIZED INSPECTION AGENCY

The responsibilities of the Authorized Inspection Agency shall include but not necessarily be limited to those given in (a) through (k) below.

(a) Maintain a staff of Authorized Nuclear Inspectors and Authorized Nuclear Inspector Supervisors (WA-5123).

(b) Make agreements with Design Owners, Packaging Owners, and Class TP Certificate Holders for inspection service (WA-5121 and WA-8130). Notify the Society whenever such agreements are terminated (WA-5121).

(c) Provide for participation in the Society's review of the applicant's Quality Assurance Program (WA-5125).

(d) Provide for the review and acceptance of any proposed modifications to Quality Assurance Manuals before they are put into effect (WA-5125).

(e) Review and accept the Class TP Certificate Holder's method of securing the nameplate to components to which, because of size or other considerations, the nameplate cannot be directly attached [WA-8220(b)].

(f) Review and accept the Class TP Certificate Holder's alternative method of identification, including the unique method of marking of components to which, because of size or other considerations, nameplates cannot be directly attached [WA-8220(b)].

(g) Review and accept the Class TP Certificate Holder's alternative method of marking of parts and piping subassemblies (WA-8230).

(h) Review and accept the Class TP Certificate Holder's provisions of positive identification and traceability of items from which nameplates are removed [WA-8240(b)].

Page 43

(i) Determine by agreement with the Class TP Certificate Holder the sequence for stamping and the completion of the Code Data Report [WA-8130(c)].

(j) Review and accept the Class TP Certificate Holder's procedure for providing traceability of parts or piping subassemblies which are furnished without stamping (WA-8332).

(k) And all other duties specifically required in ASME QAI-1-1995.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D3 WA-8000

ARTICLE WA-8000 CERTIFICATES OF AUTHORIZATION, NAMEPLATES, CODE SYMBOL STAMPING, AND DATA REPORTS

Page 45

Page 46

WA-8100 AUTHORIZATION TO PERFORM CODE ACTIVITIES

WA-8110 GENERAL

Certificates of Authorization to use the official Code Symbol Stamps shown in Table WA-8100-1 or Certificates of Accreditation to certify work by other means provided in this Division will be granted by the Society for a 3 year period pursuant to the provisions set forth in this Subarticle.

WA-8120 SCOPE OF AUTHORIZATION

(a) The N-type Certificate of Authorization (WA-3120) will identify the facility covered and state the scope of activities for which authorization is granted. The Society may, at its discretion, limit or extend the scope of an authorization to any types or classes of items or to a specific location.

(b) The Society may, at any time, make regulations concerning the issuance and use of Certificates and Code Symbol Stamps as it deems appropriate, and all regulations shall become binding upon the holders of a valid Certificate.

WA-8130 INSPECTION AGREEMENT REQUIRED

Design Owners, Packaging Owners, and Class TP Certificate Holders shall possess an agreement with an Authorized Inspection Agency to provide inspection and audit services. The agreement with the Authorized Inspection Agency shall be made prior to application for a survey or, in the case of the Design Owner or Packaging Owner, an interview. Design Owners, Packaging Owners, and Class TP Certificate Holders shall notify the Society whenever their agreements with an

Owners, Packaging Owners, and Class TP Certificate Holders shall notify the Society whenever their agreements with an Authorized Inspection Agency are cancelled or changed to another Authorized Inspection Agency.

WA-8140 QUALITY ASSURANCE PROGRAM REQUIREMENTS

It is a requirement that a Class TP Certificate Holder have a Quality Assurance Program (WA-4000) which has been evaluated and accepted by the Society.

WA-8150 APPLICATION FOR AUTHORIZATION

An Organization desiring a Class TP Certificate of Authorization shall apply to the Society upon forms issued by the Society describing the scope of Code activities to be performed.

WA-8152 Shop Assembly

Shop assembly of components to components, or components to piping subassemblies or other items, may be by N Certificate Holders if such activities are included within the scope of their N-type Certificate of Authorization.

WA-8153 Code Activities Prior to Certification

Code activities performed prior to issuance of a N-type Certificate of Authorization shall be subject to the acceptance of the Inspector.

**TABLE WA-8100-1
AUTHORIZATIONS AND CODE SYMBOL STAMPS ISSUED BY THE SOCIETY FOR CONSTRUCTION OF
CONTAINMENT SYSTEMS FOR TRANSPORT PACKAGING**

Type of Organization	Scope	Division 3 Class TP	Data Report Form	Notes
N	Containment system of transport packaging	 TP	...	...
NPT	Tubular products welded with filler metal	 TP	NM-1	(2)
	Part	 TP	N-2	(1), (3)
	Piping subassembly	 TP	NPP-1	...
Quality System Certificate Holder	Material	None	None	(2)
Design/Packaging Owner	Owner	None None	...	...

NOTES:

- (1) Data Report Form N-2 for parts shall be forwarded in duplicate to the Certificate Holder of the finished component.
- (2) Material (WA-1220) shall be documented by a Certified Material Test Report or a Certificate of Compliance in accordance with WB-2000.
- (3) A multiple number of parts may be included on the N-2 Data Report, provided the parts are of the same class, size, and design and that the parts are manufactured for the same N-type Certificate of Authorization Holder and authorized by the Inspector for stamping on the same day. Each part must be identified on the Data Report by an individual serial number.

**TABLE WA-8100-1 AUTHORIZATIONS AND CODE SYMBOL STAMPS ISSUED BY THE SOCIETY FOR
CONSTRUCTION OF CONTAINMENT SYSTEMS FOR TRANSPORT PACKAGING**

WA-8160 EVALUATION FOR AUTHORIZATION

WA-8161 Evaluation for a Class TP Certificate of Authorization

(a) Applicants for a new or renewed N-type Certificate of Authorization for Class TP construction require a survey of their shop facilities. The purpose of the survey is to evaluate the applicant's Quality Assurance Manual and the implementation of the Quality Assurance Program.

(b) The extent of the survey will be determined by the Society based on a review of the applicant's intended scope of Code activities described in the application. The acceptance by the Society of the Quality Assurance Program shall not be interpreted to mean endorsement of technical capability to perform design work such as system design or stress analysis. Such capability is implied for the specific component involved by the certification of Design Reports (WA-3555) by a Registered Professional Engineer.

(c) Authorization to apply a Code Symbol Stamp to an item will be granted only after a survey by the Society has satisfactorily demonstrated the adequacy and implementation of the Quality Assurance Program.

WA-8162 Evaluation for an Interim Letter

(a) It is not essential that the applicant's Quality Assurance Program be in actual use or ever have been used prior to or at the time of the Society's survey, provided the applicant has the capability to staff, equip, and otherwise implement the Program as described. An applicant whose Quality Assurance Program has been so accepted may be issued an Interim Letter for a period of 1 year indicating acceptance of the Quality Assurance Program as described in the Manual.

(b) An interim letter may be renewed annually, but not more than twice, subject to the following:

(1) an agreement with an Authorized Inspection Agency is in effect;

(2) the Quality Assurance Manual has been determined by the Authorized Nuclear Inspection Supervisor to be in compliance with the requirements of this Division.

Page 49

WA-8163 Evaluation for a Design Owner's or Packaging Owner's Certificate

(a) The Design Owner and the Packaging Owner, shall obtain a Design Owner's and a Packaging Owner's Certificate (WA-3230 and WA-3430) from the Society. In lieu of a survey, the Design Owner and Packaging Owner will be interviewed for the Society to verify the Design Owner and Packaging Owner's understanding of Code responsibilities (WA-3220 and WA-3420) and to obtain the Design Owner and Packaging Owner's agreement to meet the requirements.

WA-8170 ISSUANCE OF AUTHORIZATION

Each Certificate Holder shall have agreed that each Certificate and Code Symbol Stamp (if one is issued) is at all times the property of the Society, that it will be used according to the rules and regulations of this Division, and that the Certificate and Code Symbol Stamp will be promptly returned to the Society upon demand, or when the Certificate Holder discontinues the scope of Code activities covered by his Certificate. The holder of a Code Symbol Stamp shall not permit any other party to use its Certificate or Code Symbol Stamp. The Society reserves the absolute right to cancel or refuse to renew such authorization, returning fees paid for the prorated unexpired term.

WA-8180 RENEWAL OF AUTHORIZATION

Not later than 6 months prior to the date of expiration of any Certificate, the Certificate Holder shall apply for a renewal of such authorization and the issuance of a new Certificate.

WA-8200 NAMEPLATES AND STAMPING

WA-8210 GENERAL REQUIREMENTS

WA-8211 Nameplates

Each item to which a Code Symbol Stamp is applied shall have a nameplate, except as otherwise permitted by this Subarticle. Marking shall be as required by (a) through (e) below:

- (a) the applicable official Code Symbol Stamp, as shown in Table WA-8100-1;
- (b) Class of construction;
- (c) the statement "Certified by";
- (d) Class TP Certificate Holder's name;

N
TP

Certified by

(Name of Class TP Certificate Holder)

(Year Stamped) **(Containment System Serial number)**

FIG. WA-8212-1 FORM OF STAMPING

FIG. WA-8212-1 FORM OF STAMPING

- (e) Containment System serial number and, if applicable, national board number and/or Canadian registration number.

WA-8212 Stamping

The Code Symbol Stamp shall be stamped on a nameplate attached to an item, except as otherwise permitted by this Subarticle. The arrangement of markings shall be as shown in Fig. WA-8212-1. The data shall be in characters not less than $\frac{3}{32}$ in. (2.4 mm) high. The selected method shall not result in any harmful contamination or sharp discontinuities. Stamping directly on items, when used, shall be done with blunt-nosed continuous or blunt-nose interrupted dot die stamps.

WA-8213 Attachment of Nameplates

- (a) The nameplate shall be attached by a method that will not affect the structural integrity of the item.
- (b) If the nameplate is marked before it is attached, the Class TP Certificate Holder shall assure that the nameplate with the correct marking has been attached and the Inspector shall verify that this has been done.
- (c) When nameplates are attached with pressure sensitive acrylic adhesive systems, in addition to the requirements of this Article, those of Appendix XXI shall be met.

WA-8220 NAMEPLATES FOR CONTAINMENT SYSTEMS

(a) The markings required by WA-8210 shall be applied to a separate nameplate attached to the containment system. The name plate shall be of a visible, permanent type and not detrimental to the containment system. The type, method, and manner of marking

Page 50

shall be described in the Certificate Holder's Quality Assurance Program or Procedure.

(b) If because of size or other considerations the nameplates cannot be directly attached to the containment system, the Class TP Certificate Holder may secure the nameplate in a manner acceptable to the Authorized Inspection Agency. The use of this alternative method of identification, including the method of marking, shall be reviewed by and found acceptable to the Authorized Inspection Agency (WA-5121) prior to implementation by the Class TP Certificate Holder.

WA-8230 NAMEPLATES FOR NPT STAMPED ITEMS

(a) Parts and piping subassemblies shall have a separate nameplate equivalent to that required for completed components when the size and use of the item will accommodate such a nameplate. When the size or use of the item will not permit the installation of a nameplate, the marking shall consist of suitable identification of the item until it has been incorporated into the finished component or other NPT stamped item. This alternative method of marking shall be reviewed with and found acceptable to the Authorized Inspection Agency before being used by the Class TP Certificate Holder.

(b) In the case of tubular products welded with filler metal, nameplates are not required. The marking shall be applied directly to the material by etching or stamping.

WA-8300 CODE SYMBOL STAMPS

WA-8310 GENERAL REQUIREMENTS

(a) The Code Symbol Stamp shall be applied by the Class TP Certificate Holder only with authorization of the Inspector. In any case, the Code Symbol Stamp shall not be applied until completion of the required examination and testing.

(b) Table WA-8100-1 provides Code Symbol Stamp requirements as related to type of certificates, scope of work, and class of construction. The Class of construction shall be indicated by the letters TP stamped below and outside the official Code Symbol Stamp.

(c) The completed Code Data Report Form N-5 certifies that the Inspector has inspected the item and authorized the application of the Code Symbol Stamp. The sequence for stamping and the completion of the Code Data Report shall be determined by agreement between the Authorized Inspection Agency and the Class TP Certificate Holder.

WA-8330 REMOVABLE ITEMS

(a) Removable items which form part of a containment system shall have unique markings identifiable to the containment system.

WA-8400 DATA REPORTS

WA-8410 GENERAL REQUIREMENTS

The appropriate Data Report,¹ as specified in Table WA-8100-1, shall be filled out by the Class TP Certificate Holder or Packaging Owner and shall be signed by the Class TP Certificate Holder or Packaging Owner and the Inspector for each item (except as provided elsewhere in this Article) to be marked with a Code Symbol Stamp.

WA-8411 Compiling Data Report Records

Data Reports, which are the basis for approval of the N-3 and N-5 Data Reports, may be compiled in any one of the following methods:

(a) by attaching each Data Report for items which make up the containment system of the transport packaging to its respective N-3 or N-5; or

(b) by assigning each Data Report for items which make up the containment system of the transport packaging a unique identifying number and listing the numbers on the Data Report N-3 or N-5; or

(c) by attaching a drawing which uniquely identifies each item which make up the containment system of the transport packaging to its respective Data Report N-3 or N-5.

WA-8412 Availability of Data Reports

All Data Reports and referenced supporting material shall be available to the Inspector and enforcement authority having jurisdiction.

1 Samples of the forms referred to in this Subarticle may be found in Appendix V. Copies of these forms may be obtained from the Society.

WA-8420 PACKAGING OWNER'S DATA REPORT

The Packaging Owner who has obtained a Packaging Owner's Certificate of Accreditation shall be responsible for completing one or more of N-3. The Packaging Owner shall certify, by signing the form, that each

Page 51

Class TP Certificate Holder was the holder of the appropriate N-type Certificate of Authorization and that the containment system complies with the applicable requirements of this Division. Review of the completed Packaging Owner's Data Report N-3, including attached Data Reports for all components and installation as required to verify Code Compliance, shall be the Inspector's authority to sign the Packaging Owner's Data Report.

WA-8430 DATA REPORTS, TUBULAR PRODUCTS, AND FITTINGS WELDED WITH FILLER METAL

(a) Each piece of tubular products or fittings with filler metal shall be listed on a Data Report Form NM-1. This Data Report shall be completed by the Certificate Holder and signed by the Inspector.

(b) Multiple items may be listed on a single NM-1 Data Report Form, provided they are from the same heat and lot of material.

(c) When tubular products welded with filler metal are used to manufacture fittings, all the fittings made from the NPT stamped tubular product may be identified on one CMTR or NM-1, as applicable, prepared by the fitting manufacturer, which lists all the operations performed. The fitting manufacturer shall provide a copy of his CMTR or NM-1, as applicable, and a copy each of the CMTR and the NM-1 Data Report which were supplied with the tubular product.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D3 WA-9000

ARTICLE WA-9000 GLOSSARY

Page 53

WA-9100 INTRODUCTION

This Article defines selected terms used in this Section. The definitions in this Glossary shall prevail should a conflict exist with definitions found elsewhere in this Division or other documents referenced in this Division.

WA-9200 DEFINITIONS

Approved Supplier. A supplier that has been evaluated and approved by a Material Organization or Certificate Holder in accordance with the requirements of WA-3800.

Appurtenance. An item intended to be attached to a completed and stamped component which has work performed on it requiring verification by an Inspector.

Assembly. A grouping of Code items joined by mechanical means, welding, or brazing.

Audit. A documented evaluation performed to verify, by examination of objective evidence, that those selected elements of a previously approved quality program have been developed, documented, and implemented in accordance with specified requirements. An audit does not include surveillance or inspection for the purpose of process control, or acceptance of material or items.

Authorized Inspection Agency. An Authorized Inspection Agency is one designated as such by the appropriate legal authority of a state or municipality of the United States or by a province of Canada.

Authorized Nuclear Inspector. An Authorized Nuclear Inspector is an employee of an Authorized Inspection Agency who has qualifications for and has been properly qualified for Division 3.

Authorized Nuclear Inspector Supervisor. An Authorized Nuclear Inspector Supervisor is an employee of an Authorized Inspection Agency who has been assigned by that agency to oversee and direct the work of one or more Authorized Nuclear Inspectors and who has qualifications for and has been properly qualified for Division 3.

Certificate of Authorization. A document issued by ASME which authorizes the use of an ASME Code Symbol Stamp for a specified time and for a specified scope of activity.

Certificate of Compliance. A written statement attesting that the materials are in accordance with specified requirements.

Certificate Holder. An organization holding a valid N or NPT Certificate of Authorization issued by the Society.

Certification. The act of verifying and attesting in writing that documents, processes, procedures, items, or the qualifications of personnel are in accordance with specified requirements.

Certified Material Test Report. A document attesting that the material is in accordance with specified requirements, including the actual results of all required chemical analyses, tests, and examinations.

Code Addenda. Additions and revisions to individual sections of the Code published annually.

Code Cases. Documents issued by the Society to clarify the intent of existing Code requirements or to provide alternative rules for construction.

Code Class. The classification, specified by the Owner (or his designee) and included in the Design Specification, which establishes the rules for design and construction of items.

Code Editions. Documents issued at 3 year intervals by the Society which include all revisions and additions previously included in Addenda and corrections included in Errata published since the previous Edition.

Code Symbol Stamp. A metallic stamp issued by the Society for use in impressing one of the symbols shown in Table WA-8100-1.

Compliance. Conforming to the Code, a specification, or a procedure.

Page 56

Component. A vessel or valve, storage tank, piping system, that is designed, constructed, and stamped in accordance with the rules of this Division.

Construction (as used in Division 3). All operations required to build an item in accordance with Design Drawings and the Construction Specification.

Construction Documents. Shop drawings, field drawings, construction reports, construction procedures, and material documentation.

Construction Procedure. A written description of construction or fabrication methods the Constructor or Fabricator uses to ensure conformance with the requirements of the Construction Specification, Design Drawings, and this Division.

Construction Report. A report prepared by the Constructor that summarizes activities performed to construct the component

in accordance with the Construction Specification, Design Drawings, and the requirements of this Division.

Construction Specification. A document prepared by the Designer that establishes requirements for the construction of a component.

Corrective Action. Measures taken to rectify conditions adverse to quality, and, where necessary, to preclude repetition.

Data Report. A document which certifies that an item was constructed in accordance with the requirements of this Division.

Data Report Form. The form approved by the Society which is used to record the required Code Data.

Defective Material. Material that does not meet specified requirements.

Design Drawings. Drawings which are prepared to illustrate the structural and mechanical details necessary to comply with the Design Specification and this Division.

Design Report. The design document which shows that the allowable limits stated in this Division are not exceeded for the loadings specified in the Design Specification.

Design Specification (Division 3). A document prepared by the Design Owner which provides a complete basis for design in accordance with this Division.

Destructive Test. A test to determine the properties of a material or the behavior of an item which results in the destruction of the sample or item.

Discrepancy. A condition outside of an established tolerance or requirement.

Document Control. Those measures established to control the preparation, review, release, issuance, and disposition of documents, such as design calculations, purchase orders, specifications, instructions, procedures, and drawings, including changes thereto, which describe or document activities affecting quality.

Enforcement Authority. A regional or local governing body, such as a state or municipality of the United States or a Canadian province, empowered to enact and enforce boiler and pressure vessel legislation.

Environmental Conditions. Those conditions to which the item is subjected such as radiation, pressure, temperature, humidity, site elevation, wind, and wind direction.

Examination. Specific actions by qualified personnel using qualified procedures to verify that items and fabrication processes are in conformance with specified requirements. This term, when used in conjunction with qualification of personnel to perform quality-related activities, shall mean a written examination.

Fabrication. Those actions required to manufacture components, parts, and appurtenances. These actions may include forming, machining, assembling, welding, brazing, heat treating, examination, testing, inspection, and certification. Fabrication does not include design.

Hold Point. A designated stopping place during or following a specific activity at which inspection or examination is required before further work can be performed.

Hydrostatic Test. The pressurization of an item to a test pressure using water or other liquid as a testing medium with the required examination prescribed by the Code.

Identification and Verification Program. A documented system for the positive identification of material during storage and handling and verification of the identity of material on the accompanying Certified Material Test Report at the time of shipment.

Inspector. The Authorized Nuclear Inspector as defined in WA-5122. The term Inspector, as used in this Subsection, is the same as the term Authorized Inspector as used in Division 3.

Installation. Those actions required to place and attach components to their supports and join items of a nuclear power system by welding or mechanical means.

Instructions. Detailed written directions provided to persons or organizations to ensure proper completion of a task.

Item. A product constructed under a Certificate of Authorization (WA-3120) or material (WA-1220).

Joining. The act of connecting two or more items to one another, by welding, brazing, bolting, or other mechanical means.

Page 57

Jurisdictional Boundaries. The physical limits of a Code item which are identified to determine the applicability of Code rules for that item.

Material. For Section III, Division 3, metallic materials manufactured to an SA, SB, SFA, or any other material specification permitted by the Division.

Material Organization (Metallic). An organization accredited by holding Quality System Certificate issued by the Society, or qualified by an accredited Material Organization or Certificate Holder, in accordance with the requirements of Section III, WA-3800.

Material Specification. A document which establishes the requirements for a material.

Modification. A change to an item made necessary by, or resulting in, a change in design requirements.

Monitor. Observe or check compliance with this Division and the Owner's or Certificate Holder's Quality Assurance Program. This activity is not necessarily documented or required to be continuous.

Nonconformance. A deficiency in a characteristic, documentation, or procedure that renders an item or activity unacceptable or indeterminate.

Part. An item which is attached to or becomes a portion of a component or component support before completion and stamping of the component or component support. Parts have work performed on them requiring verification by an Inspector.

Performance Assessment. For Section III, a documented evaluation of material supplied by a previously audited and accepted Quality System Program to verify continued compliance with Code requirements.

Piping Subassembly. A section of piping system consisting of fittings and pipes or tubes which are fabricated as subassemblies in a shop or in the field before being installed in a nuclear power system.

Pneumatic Test. The pressurization of an item to a test pressure using a gas as the testing medium with the required examination prescribed by the Code.

Qualified Procedure. A procedure that has been demonstrated to meet the specified requirements for its intended purpose.

Quality Assurance. As used in this Division, quality assurance comprises all those planned and systematic actions necessary to provide adequate confidence that all items designed and constructed are in accordance with the rules of this Section.

Quality Assurance Manual. A written document which describes a Quality Assurance Program.

Quality Assurance Program. A controlled system of planned and systematic actions required to provide adequate confidence that items designed and constructed are in accordance with the rules of the Code.

Quality Control. Measurement of the characteristics of an item or process to determine conformance to specified requirements.

Quality System Certificate. A Certificate issued by the Society that permits an organization to perform specified Material Organization activities in accordance with Code requirements.

Quality System Program. A documented system of actions required to provide adequate confidence that materials conform to the requirements of the material specification and the rules of Section III.

Regulatory Authority. A Federal Government Agency, such as the United States Nuclear Regulatory Commission, empowered to issue and enforce regulations concerning the design, construction, and operation of nuclear power plants.

Repair. The process of physically restoring a nonconformance to a condition such that an item complies with Code requirements.

Rework. Refer to *Repair*.

Service. An activity performed by a subcontractor such as designing, rigging, temporary bolting, and nondestructive examination.

Service Limits. Stress and stress intensity limits applicable to Service Loadings given in the Design Specification.

Shop Drawings. Drawings provided by the Class TP Certificate Holder which describe construction, details, physical dimensions, arrangements, and any significant engineering features needed to establish conformance to the Construction Specification, and this Division.

Society. The American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990.

Source Material. For Section III, metallic products used for conversion to or qualification as material by a Certificate Holder or Material Organization.

Special Process. A process, the results of which are highly dependent on the control of the process or skill of the operator, or both.

Survey. A documented evaluation of an organization's ability to perform Code activities as verified by a determination of the adequacy of the organization's quality program and by a review of the implementation of that program at the location of the work.

Testing. An element of verification for the determination of the capability of an item to meet specified requirements by subjecting the item to a set of physical, chemical, environmental, or operating conditions.

Page 58

Traceability. The ability to verify the history, location, or application of an item by means of recorded identification.

Unqualified Source Material. Source material not produced by a Certificate Holder, Material Organization, or approved supplier in accordance with the requirements of Section III, WA-3800.

Use-as-is. Only applicable requirements of this Division have been met.

Verification. A review to ensure that activities have been performed and documented in accordance with applicable requirements.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D3 WB-1000

ARTICLE WB-1000 INTRODUCTION

Page 59

SUBSECTION WB

CLASS TP (TYPE B) CONTAINMENT

Page 61

WB-1100 SCOPE AND GENERAL REQUIREMENTS

WB-1110 ASPECTS OF CONSTRUCTION COVERED BY THESE RULES

(a) Subsection WB establishes rules for material, design, fabrication, examination inspection testing, and preparation of reports for containment systems of transport packagings.

(b) The rules of Subsection WB cover the requirements for strength and pressure integrity of items, the failure of which would violate the pressure-retaining boundary. The rules cover initial construction requirements, but do not cover

deterioration which may occur in service as a result of corrosion, radiation effects, or instability of material. WA-1130 gives further limitations to the rules of this Subsection.

[98]

WB-1120 RULES FOR TP CONTAINMENT SYSTEMS OF TRANSPORT PACKAGINGS

(a) Class TP containment systems of transport packagings shall be constructed in accordance with the rules of this Division. Only containment vessels and their appurtenances shall be classified as Class TP. Piping and valves which are part of the containment systems of transport packagings (WB-1130) or which penetrate or are attached to the containment vessel shall be classified as Class 1 by the Design Specification and shall meet the requirements of the applicable Subsection of Division 1.

(b) Subsection WB does not contain rules to cover all details of construction of TP containment systems of transport packagings. The Certificate Holder shall provide details of construction which will be consistent with those provided by the rules of this Division. These details of construction shall be subject to the approval of the Packaging Owner or his designee and acceptance by the Inspector.

[98]

WB-1130 BOUNDARIES OF JURISDICTION

WB-1131 Boundaries of the Containment System of a Transport Packaging

The containment system may include (a) and (b) as follows:

(a) the containment vessel;

(b) all penetration assemblies or appurtenances attached to the containment vessel; Boundaries of such items shall be given in the Design Specifications (WA-3250 and WB-1120).

WB-1132 Boundaries of the Containment Vessel

The Design Specification shall define the boundary of a containment vessel.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D3 WB-2000

ARTICLE WB-2000 MATERIAL

Page 65

WB-2100 GENERAL REQUIREMENTS FOR MATERIAL

WB-2110 SCOPE OF PRINCIPAL TERMS EMPLOYED

(a) The term *material* as used in this Subsection is defined in WA-1220. The term *Material Organization* is defined in WA-3800.

(b) The term *containment system material* as used in this Subsection applies to items such as vessel shells and heads; reinforcement around openings and penetrations and appurtenances such as leak testing and drainage ports, and structural reinforcements required by design to maintain structural integrity.

(c) The requirements of this Article make reference to the term *thickness*. For the purpose intended, the following definitions of nominal thickness apply.

(1) *plate* - the thickness is the dimension of the short transverse direction

(2) *forgings* - the thickness is the dimension defined as follows:

- (a) *hollow forgings* - the nominal thickness is measured between the inside and outside surfaces (radial thickness)
- (b) *disk forgings* (axial length less than the outside diameter) - the nominal thickness is the axial length
- (c) *flat ring forgings* (axial length less than the radial thickness) - for axial length ≤ 2 in. (51 mm), the axial length is the nominal thickness. For axial length > 2 in. (51 mm), the radial thickness is the nominal thickness.
- (d) *rectangular solid forgings* - the least rectangular dimension is the nominal thickness
- (3) *castings*
 - (a) Thickness t for fracture toughness testing is defined as the nominal pipe wall thickness of the connecting piping.
 - (b) Thickness t for heat treatment purposes is defined as the thickness of the pressure retaining wall of the casting, excluding flanges and sections designated by the designer as nonpressure retaining.

WB-2120 CONTAINMENT SYSTEM MATERIAL

WB-2121 Permitted Material Specifications

- (a) Containment system material and material welded thereto, except as permitted in WB-4435, and except for welding, brazing, and hard surfacing metals and cladding which is 10% or less of the thickness of the base material (WB-3122), shall conform to the requirements of one of the specifications for material given in Section II, Part D for Division 1, Class 1 or Division 3, Class TP construction and to all of the special requirements of this Article which apply to the product form in which the material is used.
- (b) The requirements of this Article do not apply to seals, packaging, gaskets, and valve seats.
- (c) Material made to specifications other than those specified in Section II, Part D, for Division 1, Class 1 or Division 3, Class TP may be used for pressure relief disks.
- (d) Material for instrument line fittings, NPS 1 (DN 25) and less, may be of material made to specifications other than those listed in Appendix 1 provided that the material is determined to be adequate for the service conditions by the containment system designer.
- (e) Welding and brazing material used in the manufacture of items shall comply with an SFA specification in Section II, Part C, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article. The requirements of this Article do not apply to material used as backing rings or backing strips in welded joints.

Page 72

WB-2122 Special Requirements Conflicting With Permitted Material Specifications

Special requirements stipulated in this Article shall apply in lieu of the requirements of the material specification wherever the special requirements conflict with the material specification requirements (WA-3856). Where the special requirements include an examination, test, or treatment which is also required by the material specification, the examination, test, or treatment need be performed only once. Required nondestructive examinations shall be performed as specified for each product form in WB-2500. Any examination, repair, test, or treatment required by the material specification or by this Article may be performed by the Material Organization or the Certificate Holder as provided in WB-4121. Any hydrostatic or pneumatic pressure test required by a material specification need not be performed, provided the material is identified as not having been pressure tested and it is subsequently pressure tested in the system in accordance with WB-6114, except where the location of the material in the component or the installation would prevent performing any nondestructive examination required by the material specification to be performed subsequent to the hydrostatic or pneumatic test.

WB-2123 Size Ranges

Material outside the limits of size or thickness given in any specification in Section II may be used if the material is in compliance with the other requirements of the specification and no size limitation is given in the rules for construction. In those specifications in which chemical composition or mechanical properties are indicated to vary with size or thickness,

any material outside the specification range shall be required to conform to the composition and mechanical properties shown for the nearest specified range (WA-3856).

WB-2124 Fabricated Hubbed Flanges

Fabricated hubbed flanges shall be in accordance with the following.

(a) Hubbed flanges may be machined from a hot rolled or forged billet. The axis of the finished flange shall be parallel to the long axis of the original billet. (This is not intended to imply that the axis of the finished flange and the original billet must be concentric.)

(b) Hubbed flanges, except as permitted in (a) above, shall not be machined from plate or bar stock material unless the material has been formed into a ring, and further provided that:

(1) in a ring formed from plate, the original plate surfaces are parallel to the axis of the finished flange (this is not intended to imply that the original plate surface must be present in the finished flange);

(2) the joints in the ring are welded butt joints that conform to the requirements of this Division. Thickness to be used to determine postweld heat treatment and radiography requirements shall be the lesser of t , or $(A - B)/2$, where these symbols are as defined in Appendix XI-3130.

(c) The back of the flange and the outer surface of the hub shall be examined by the magnetic particle method or the liquid penetrant method in accordance with WB-2540 to ensure that these surfaces are free from defects.

WB-2125 Bolting Material

(a) Material for bolts and studs shall conform to the requirements of one of the specifications listed in Section II, Part D, Subpart 1, Table 4. Material for nuts shall conform to SA-194 or to the requirements of one of the specifications for nuts or bolting listed in Section II, Part D, Subpart 1, Table 4.

(b) The use of washers is optional. When used, they shall be made of wrought material with mechanical properties compatible with the nuts with which they are to be employed.

WB-2130 CERTIFICATION OF MATERIAL

All material used in construction of components shall be certified as required in WA-3862. Certified Material Test Reports are required for containment system material except as provided by WA-3862. A Certificate of Compliance may be provided in lieu of a Certified Material Test Report for all other material. Copies of all Certified Material Test Reports and Certificates of Compliance applicable to material used in a component shall be furnished with the material.

WB-2140 WELDING MATERIAL

For the requirements governing the material to be used for welding, see WB-2400.

WB-2150 MATERIAL IDENTIFICATION

The identification of containment system material and materials welded thereto shall meet the requirements of WA-3856. Material for small items shall be controlled

Page 73

during manufacture and installation of a component so that they are identifiable as acceptable material at all times. Welding and brazing material shall be controlled during the repair of material and the manufacture and installation so that they are identifiable as acceptable until the material is actually consumed in the process (WB-4122).

WB-2160 DETERIORATION OF MATERIAL IN SERVICE

Consideration of deterioration of material caused by service is generally outside the scope of this Division. It is the responsibility of the N Certificate Holder to select material suitable for the conditions stated in the Design Specifications (WA-3250), with specific attention being given to the effects of service conditions upon the properties of the material. Any

special requirement shall be specified in the Design Specifications (WA-3252 and WB-3124). When so specified, the check analysis shall be made in accordance with the base metal specification and in accordance with WB-2420 for the welding material.

WB-2170 HEAT TREATMENT TO ENHANCE IMPACT PROPERTIES

Carbon steels, low alloy steels, and high alloy chromium (Series 4XX) steels may be heat treated by quenching and tempering to enhance their impact properties. Postweld heat treatment of the component at a temperature of not less than 1100°F (593°C) may be considered to be the tempering phase of the heat treatment.

WB-2180 PROCEDURES FOR HEAT TREATMENT OF MATERIAL

When heat treating temperature or time is required by the material specification and the rules of this Subsection, the heat treating shall be performed in temperature-surveyed and -calibrated furnaces or shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. Heat treating shall be performed under furnace loading conditions such that the heat treatment is in accordance with the material specification and the rules of this Division.

WB-2200 MATERIAL TEST COUPONS AND SPECIMENS FOR FERRITIC STEEL MATERIAL

WB-2210 HEAT TREATMENT REQUIREMENTS

WB-2211 Test Coupon Heat Treatment for Ferritic Material¹

Where ferritic steel material is subjected to heat treatment during fabrication or installation of a component, the material used for the tensile and impact test specimens shall be heat treated in the same manner as the component, except that test coupons and specimens for P-No. 1 material with a nominal thickness of 2 in. (51 mm) or less are not required to be so heat treated. The Certificate Holder shall provide the Material Organization with the temperature and heating and cooling rate to be used. In the case of postweld heat treatment, the total time at temperature or temperatures for the test material shall be at least 80% of the total time at temperature or temperatures during actual postweld heat treatment of the material, and the total time at temperature or temperatures for the test material, coupon, or specimen may be performed in a single cycle.

WB-2212 Test Coupon Heat Treatment for Quenched and Tempered Material

WB-2212.1 Cooling Rates.

Where ferritic steel material is subjected to quenching from the austenitizing temperature, the test coupons representing that material shall be cooled at a rate similar to and no faster than the main body of the material except in the case of certain forgings and castings (WB-2223.2 and WB-2226). This rule shall apply to coupons taken directly from the material as well as to separate test coupons representing the material, and one of the general procedures described in WB-2212.2 or one of the specific procedures described in WB-2220 shall be used for each product form.

1 Any postweld heat treatment time which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

WB-2212.2 General Procedures.

One of the general procedures stipulated in (a), (b), and (c) below may be applied to quenched and tempered material or test coupons representing the material, provided the specimens are taken relative to the surface of the product in accordance with WB-2220. Further specific details

Page 74

of the methods to be used shall be the obligation of the Material Organization and the Certificate Holder.

(a) Any procedure may be used which can be demonstrated to produce a cooling rate in the test material which matches the cooling rate of the main body of the product at the region midway between midthickness and the surface ($\frac{1}{4}t$) and no nearer any heat treated edge than a distance equal to the nominal thickness t being quenched within 25°F and 20

sec at all temperatures after cooling begins from the austenitizing temperature.

(b) If cooling rate data for the material and cooling rate control devices for the test specimens are available, the test specimens may be heat treated in the device to represent the material, provided that the provisions of (a) above are met.

(c) When any of the specific procedures described in WB-2220 are used, faster cooling rates at the edges may be compensated for by:

- (1) taking the test specimens at least t from a quenched edge, where t equals the material thickness;
- (2) attaching a steel pad at least t wide by a partial penetration weld (which completely seals the buffered surface) to the edge where specimens are to be removed; or
- (3) using thermal barriers or insulation at the edge where specimens are to be removed.

It shall be demonstrated (and this information shall be included in the Certified Material Test Report) that the cooling rates are equivalent to (a) or (b) above.

WB-2220 PROCEDURE FOR OBTAINING TEST COUPONS AND SPECIMENS FOR QUENCHED AND TEMPERED MATERIAL

WB-2221 General Requirements

The procedure for obtaining test coupons and specimens for quenched and tempered material is related to the product form. Coupon and specimen location and the number of tension test specimens shall be in accordance with the material specifications, except as required by the following paragraphs. References to dimensions signify nominal values.

WB-2222 Plates

WB-2222.1 Number of Tension Test Coupons.

The number of tension test coupons required shall be in accordance with the material specification and with SA-20, except that from carbon steel plates weighing 42,000 lb and over and alloy steel plates weighing 40,000 lb and over, two tension test coupons shall be taken, one representing the top end of the plate and one representing the bottom end of the plate.

WB-2222.2 Orientation and Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from a rolled surface and with the midlength of the specimen at least t from any heat treated edge, where t is the nominal thickness of the material.

WB-2222.3 Requirements for Separate Test Coupons.

Where a separate test coupon is used to represent the component material, it shall be of sufficient size to ensure that the cooling rate of the region from which the test coupons are removed represents the cooling rate of the material at least $\frac{1}{4}t$ deep and t from any edge of the product. Unless cooling rates applicable to the bulk pieces or product are simulated in accordance with WB-2212.2(b), the dimensions of the coupon shall be not less than $3t \times 3t \times t$, where t is the nominal material thickness.

WB-2223 Forgings

WB-2223.1 Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from any surface and with the midlength of the specimens at least t from any second surface, where t is the maximum heat treated thickness. A thermal buffer as described in WB-2212.2(c) may be used to achieve these conditions, unless cooling rates applicable to the bulk forgings are simulated as otherwise provided in WB-2212.2.

WB-2223.2

Test coupons for forgings that are very thick or complex and other forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment may be removed from prolongations or other stock provided on the product. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service. The coupons shall be taken so that specimens shall have their longitudinal axes at a distance below the nearest heat treated surface, equivalent at least to the greatest distance that the indicated high tensile stress surface will be from the nearest surface during heat treatment, and with the midlength of the specimens a minimum of twice this distance from a second heat treated surface. In any case, the longitudinal axes of the specimens shall not be nearer than $\frac{3}{4}$ in. (19 mm) to any heat treated surface and the midlength of the specimens shall be

Page 75

at least $1\frac{1}{2}$ in. (38 mm) from any second heat treated surface.

WB-2223.3 Coupons From Separately Produced Test Forgings.

Test coupons representing forgings from one heat and one heat treatment lot may be taken from a separately forged piece under the conditions given in (a) through (e) below.

(a) The separate test forging shall be of the same heat of material and shall be subjected to substantially the same reduction and working as the production forging it represents.

(b) The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forging.

(c) The separate test forging shall be of the same nominal thickness as the production forging.

(d) Test coupons for simple forgings shall be taken so that specimens shall have their longitudinal axes at the region midway between midthickness and the surface, and with the midlength of the specimens no nearer any heat treated edge than a distance equal to the forging thickness, except when the thickness-length ratio of the production forging does not permit, in which case a production forging shall be used as the test forging and the midlength of the specimens shall be at the midlength of the test forging.

(e) Test coupons for complex forgings shall be taken in accordance with WB-2223.2.

WB-2223.4 Test Specimens for Forgings.

When test specimens for forgings are to be taken under the applicable specification, the Inspector shall have the option of witnessing the selection, placing an identifying stamping on them, and witnessing the testing of these specimens.

WB-2224 Location of Coupons

(a) *Bars.* Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside or rolled surface and with the midlength of the specimens at least t from a heat treated end, where t is either the bar diameter or thickness.

(b) *Bolting.* For bolting materials, tests shall be made of either full-size bolts or test coupons as required by the base specification. The gage length of the tension specimens and the area under the notch of Charpy specimens shall be at least one diameter or thickness from the heat treated end.

WB-2225 Tubular Products and Fittings

WB-2225.1 Location of Coupons.

Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the inside or outside surface and with the midlength of the specimens at least t from a heat treated end, where t is the nominal wall thickness of the tubular product.

WB-2225.2 Separately Produced Coupons Representing Fittings.

Separately produced test coupons representing fittings may be used. When separately produced coupons are used, the requirements of WB-2223.3 shall be met.

WB-2226 Tensile Test Specimen Location (for Quenched and Tempered Ferritic Steel Castings)

NOTE: Users of this requirement should note that the hardenability of some grades may limit the usable section size.

(a) This section applies only to quenched and tempered ferritic steel castings with a thickness t exceeding 2 in. (51 mm) where t is the thickness of the pressure retaining wall of the casting, excluding flanges and sections designated by the designer as nonpressure-retaining. The order, inquiry, and drawing shall designate what the thickness t is for the casting.

(b) One of the following shall apply.

(1) The longitudinal centering of the thickness of the tension test specimen shall be taken at least $\frac{1}{4}t$ from the t dimension surface. For cylindrical castings, the longitudinal center line of the specimens shall be taken at least $\frac{1}{4}t$ from the outside or inside surface and the gage length at least t from the as-heat-treated end.

(2) Where separately cast test coupons are used, their dimensions shall be not less than $3t \times 3t \times t$ and each specimen cut from it shall meet the requirements of (b)(1) above. The test coupon shall be of the same heat of steel and shall receive substantially the same casting practices as the production casting it represents. (Centrifugal castings may be represented by statically cast coupons.) The test coupon shall be heat treated under the same conditions as the production casting(s). The t dimension of the test coupon shall be the same maximum thickness t as defined in (a) above. Where separate test blocks require reheat treatment, thermal buffers in accordance with (b)(1) above may be used.

(3) Where specimens are to be removed from the body of the casting, a steel, thermal buffer pad $1t \times 1t \times$ at least $3t$ shall be joined to the casting surface by a partial penetration weld completely sealing the buffered surface prior to the heat treatment process.

Page 76

The test specimens shall be removed from the casting in a location adjacent to the center third of the buffer pad. They shall be located at a minimum distance of $\frac{1}{2}$ in. (13 mm) from the buffered surface and $\frac{1}{4}t$ from the other heat treated surfaces.

(4) Where specimens are to be removed from the body of the casting, thermal insulation or other thermal barriers shall be used during the heat treatment process adjacent to the casting edge where specimens are to be removed. It shall be demonstrated that the cooling rate of the test specimen is no faster than that of specimens taken by the method described in (b)(1) above. This information shall be included in the test reports.

(5) Where castings are cast or machined to essentially the finished product configuration prior to heat treatment, the test specimens shall be removed from a casting prolongation or other stock on the product at a location below the nearest heat treated surface indicated on the order. The specimens shall be located with their longitudinal axes a distance below the nearest heat treated surface equivalent to at least the greatest distance that the indicated high tensile stress surface will be from the nearest heat treated surface and with their midlength a minimum of twice this distance from a second heat treated surface. In any case, the longitudinal axes of the test specimens shall be no nearer than $\frac{1}{4}$ in. (6 mm) to a heat treated surface and the midlength shall be at least $\frac{1}{2}$ in. (38 mm) from a second heat treated surface. The component manufacturer shall specify the surfaces of the finished product subjected to high tensile stress in service.

WB-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL

WB-2310 MATERIAL TO BE TOUGHNESS TESTED

WB-2311 Material for Which Toughness Testing Is Required

(a) Containment system material and material welded thereto shall be toughness tested in accordance with the requirements of this Subarticle, except that the material listed in (1) through (7) below is not to be toughness tested as a requirement of this Division:

(1) material with a nominal section thickness of $\frac{3}{16}$ in. (4.8 mm) and less where the thicknesses shall be taken as

defined in (a) through (c) below:

(a) for containment vessels, use the nominal thickness of the shell or head, as applicable;

(b) for items welded to vessels, use the lesser of the vessel shell thickness to which the item is welded or the maximum radial thickness of the item exclusive of integral shell butt welding projections;

(c) for flat heads or flanges, use the maximum shell thickness associated with the butt welding hub;

(2) bolting, including studs, nuts, and bolts, with a nominal size of 1 in. (25 mm) and less;

(3) bars with a nominal cross-sectional area of 1 sq in. (645 mm²) and less;

(4) all thicknesses of material for valves and fittings with a NPS 6 (DN 150) diameter and smaller;

(5) material for valves and fittings with all pipe connections of $\frac{5}{8}$ in. (16 mm) nominal wall thickness and less;

(6) austenitic stainless steels;

(7) nonferrous material.

(b) Drop weight tests are not required for the martensitic high alloy chromium (Series 4XX) steels and precipitation hardening steels listed in Appendix 1. The other requirements of WB-2332 apply for these steels. For nominal wall thicknesses greater than $2\frac{1}{2}$ in. (64 mm), the required Charpy V-notch values shall be 40 mils (1.00 mm) lateral expansion.

WB-2320 IMPACT TEST PROCEDURES

WB-2321 Types of Tests

WB-2321.1 Drop Weight Tests.

The drop weight test, when required, shall be performed in accordance with ASTM E 208-91. Specimen types P-No. 1, P-No. 2, or P-No. 3 may be used. The results, orientation, and location of all tests performed to meet the requirements of WB-2330 shall be reported in the Certified Material Test Report.

WB-2321.2 Charpy V-Notch Tests.

The Charpy V-notch test (C_v), when required, shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Fig. 11, Type A. A test shall consist of a set of three full-size 10 mm × 10 mm specimens. The lateral expansion and absorbed energy, as applicable, and the test temperature, as well as the orientation and location of all tests performed to meet the requirements of WB-2330 shall be reported in the Certified Material Test Report.

WB-2321.3 Fracture Toughness Tests.

Fracture toughness tests, when required, shall be performed in accordance with ASTM E 399-83. The tests shall be

Page 77

performed at the lowest service temperature.² A test shall consist of two test specimens.

WB-2321.4 Dynamic Tear Test.

The dynamic tear tests, when required, shall be performed in accordance with ASTM E 604-83. The tests shall be performed at the lowest service temperature.² A test shall consist of two test specimens.

WB-2322 Test Specimens

WB-2322.1 Location of Test Specimens.

Toughness test specimens for quenched and tempered material shall be removed from the locations in each product form specified in WB-2220 for tensile test specimens. For material in other heat treated conditions, toughness test

specimens shall be removed from the locations specified for tensile test specimens in the material specification. For all material, the number of tests shall be in accordance with WB-2340. For bolting, the C_v toughness test specimen shall be taken with the longitudinal axis of the specimen located at least one-half radius or 1 in. (25 mm) below the surface plus the machining allowance per side, whichever is less. The fracture plane of the specimens shall be at least one diameter or thickness from the heat treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

WB-2322.2 Orientation of Toughness Test Specimens

(a) Toughness test specimens shall be oriented as follows.

(1) Specimens for forgings, other than bolting and bars used for containment system components, shall be oriented in a direction normal to the principal direction in which the material was worked. Specimens are neither required nor prohibited from the thickness direction.

(2) Specimens from material for pipe, tube, and fittings, except for those made from plate and castings, shall be oriented in the axial direction.

(3) Specimens from bolting material and bars shall be oriented in the axial direction.

2 Lowest service temperature is the minimum metal temperature as detailed in the Design Specification.

(4) Specimens for all plate material, including that used for pipe, tube, and fittings, shall be oriented in a direction normal to the principal rolling direction, other than thickness direction.

(5) Specimens for cast material shall have their axes oriented the same as the axes of the tensile specimens (WB-2226).

(6) The plane of the toughness test specimen notch shall be normal to the surface of the material.

(b) Specimens for drop weight tests may have their axes oriented in any direction. The orientation used shall be reported in the Certified Material Test Report.

WB-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS³

WB-2331 Material for Containment Vessels

WB-2331.1 Test Requirements for Ferritic Steel Material for Containment Vessels

Ferritic steel material for containment vessels, other than bolting, shall be tested in accordance with (a) and (b), (c), or (d) below. Consideration shall be given to the test temperature requirements of leak testing and hydrostatic testing of the containment system (WB-6212).

(a) For material with a nominal section between $\frac{3}{16}$ in. (4.8 mm) and $\frac{5}{8}$ in. (16 mm) thick, the dynamic tear test shall exhibit at least 80% shear fracture at the lowest service temperature. For material of $\frac{5}{8}$ in. (16 mm) and more but not exceeding 12 in. (305 mm) thick, the reference temperature, RT_{NDT} , shall be established as follows:

(1) Determine a temperature T_{NDT} that is at or above the nil-ductility transition temperature by drop weight tests.

(2) At a temperature not greater than $T_{NDT} - 60^\circ\text{F}$ (16°C), each specimen of the C_v test (WB-2321.2) shall exhibit at least 35 mils (0.89 mm) lateral expansion and not less than 50 ft-lb (67.8 J) absorbed energy. Retesting in accordance with WB-2350 is permitted. When these requirements are met, T_{NDT} is the reference temperature RT_{NDT} .

(3) In the event that the requirements of (2) above are not met, conduct additional C_v tests in groups of three specimens (WB-2321.2) to determine the temperature T_c at which they are met. In this case the reference temperature $RT_{NDT} = T_c - 60^\circ\text{F}$. Thus, the reference temperature RT_{NDT} is the higher of T_{NDT} and $(T_c - 60^\circ\text{F})$.

3 In addition to providing a basis for acceptance standards for material, the test data are designated to be used as a basis for establishing inservice operation and for use in fracture prevention

(4) When a C_v test has not been performed at $T_{NDT} + 60^\circ\text{F}$, or when the C_v test at $T_{NDT} + 60^\circ\text{F}$, does not exhibit a minimum of 50 ft-lb and 35 mils lateral expansion, a temperature representing a minimum of 50 ft-lb and 35 mils lateral expansion may be obtained from a full C_v impact curve developed from the minimum data points of all the C_v tests performed.

(b) Apply the procedures of (a) above to (1), (2), and (3) below:

(1) the containment vessel and the closure system base materials;

(2) the base material, the heat affected zone, and weld metal from the weld procedure qualification tests in accordance with WB-4330;

(3) the weld metal of WB-2431.

(c) For materials where fracture toughness values are determined in accordance with WB-2321.3 the measured fracture toughness shall be reported in the Certified Material Test Report.

(d) Bars having a width or diameter of 2 in. (51 mm) and less which prohibit obtaining drop weight test specimens shall be tested in accordance with WB-2332.

WB-2331.2 Acceptance Standards for Ferritic Steel Material for Containment Vessels

Except as limited in WB-4330, the reference temperature RT_{NDT} shall be the highest value of the individual RT_{NDT} values determined in accordance with WB-2331.1(a) and (b). If applicable, the containment vessel and the closure system base materials shall be tested to determine the fracture toughness in accordance with WB-2321.3. The results shall meet the acceptance standards of either (a) or (b) below:

(a) For materials not exceeding 12 in. (305 mm), the reference temperature RT_{NDT} shall satisfy the value of A in accordance with Table WB-2331.2-1 where $A = LST - RT_{NDT}$ and LST is the Lowest Service Temperature.

(b) For materials not exceeding 4 in. (102 mm), the rapid-load fracture toughness of the base material shall satisfy the required value in Table WB-2331.2-2 and shall meet the additional requirements of (1) and (2) below:

(1) The RT_{NDT} of the heat affected zone and the weld metal shall be equal to or lower than the RT_{NDT} of the base material, and

(2) All full penetration fabrication weld joints are ultrasonically examined in accordance with WB-5110 and meet the ultrasonic acceptance standards of WB-5330.

(a) Rules for fracture toughness requirements based on fracture mechanics methodology are in preparation.

TABLE WB-2331.2-1
REQUIRED LST-RT_{NDT} VALUES FOR FERRITIC STEEL
MATERIAL FOR CONTAINMENT VESSEL MATERIAL

Nominal Wall Thickness, in.	A = LST-RT _{NDT} , F°
5/8	25
1	45
2	75
3	90
4	103
8	115
12	120

GENERAL NOTE: Linear interpolation is permissible.

TABLE WB-2331.2-1 REQUIRED LST-RT_{NDT} VALUES FOR FERRITIC STEEL MATERIAL FOR
CONTAINMENT VESSEL MATERIAL

**TABLE WB-2331.2-2
REQUIRED FRACTURE TOUGHNESS VALUES FOR
FERRITIC STEEL MATERIAL FOR CONTAINMENT
VESSELS HAVING A SPECIFIED YIELD STRENGTH
OF 50 ksi OR LESS AT 100°F**

Nominal Wall Thickness, in.	Rapid-load Fracture Toughness, ksi $\sqrt{\text{in.}}$ [Note (1)]
$\frac{5}{8}$	50
1	64
2	94
3	113
4	130

GENERAL NOTE: Linear interpolation is permissible.

NOTE:

(1) Measured for test time equal to or less than 10 ms.

TABLE WB-2331.2-2 REQUIRED FRACTURE TOUGHNESS VALUES FOR FERRITIC STEEL MATERIAL FOR CONTAINMENT VESSEL HAVING A SPECIFIED YIELD STRENGTH OF 50 ksi OR LESS AT 100°F

WB-2332 Material for Piping and Valves, Excluding Bolting Material

(a) Containment boundary material, other than bolting, with nominal wall thickness $2\frac{1}{2}$ in. (64 mm) and less for piping (pipe and tubes) and material for valves and fittings with all pipe connections of nominal wall thickness $2\frac{1}{2}$ in. (64 mm) and less shall be tested as required in (1) and (2) below.

(1) Test three C_v specimens at a temperature lower than or equal to the lowest service temperature. All three specimens shall meet the requirements of Table WB-2332(a)-1.

(2) Apply the procedures of (1) above to:

(a) the base material;

(b) the base material, the heat affected zone, and weld metal from the weld procedure qualification tests in accordance with WB-4330; and

(c) the weld metal of WB-2431.

TABLE WB-2332(a)-1 REQUIRED C_v VALUES FOR PIPING AND VALVES

**TABLE WB-2333-1
REQUIRED C_v VALUES FOR BOLTING MATERIAL**

Nominal Diameter, in.	Lateral Expansion, mils	Absorbed Energy, ft-lb
1 or less	No test required	No test required
Over 1 to 4, incl	25	No requirements
Over 4	25	45

TABLE WB-2333-1 REQUIRED C_v VALUES FOR BOLTING MATERIAL

(b) Pressure retaining material, other than bolting, with nominal wall thickness over $2\frac{1}{2}$ in. (64 mm) for piping (pipe and tubes) and material for valves, and fittings with any pipe connections of nominal wall thickness greater than $2\frac{1}{2}$ in. (64 mm) shall meet the requirements of WB-2331. The lowest service temperature shall not be lower than $RT_{NDT} + 100^\circ\text{F}$.

WB-2333 Bolting Material

For bolting material, including studs, nuts, and bolts, test three C_v specimens at a temperature no higher than the preload temperature or the lowest service temperature, whichever is less. All three specimens shall meet the requirements of Table WB-2333-1.

WB-2340 NUMBER OF TOUGHNESS TESTS REQUIRED

WB-2341 Plates

One test shall be made from each plate as heat treated. Where plates are furnished in the unheat-treated condition and qualified by heat treated test specimens, one test shall be made for each plate as-rolled. The term *as-rolled* refers to the plate rolled from a slab or directly from an ingot, not to its heat treated condition.

WB-2342 Forgings and Castings

(a) Where the weight of an individual forging or casting is less than 1,000 lb (454 kg), one test shall be made to represent each heat in each heat treatment lot.

(b) When heat treatment is performed in a continuous type furnace with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a heat treatment charge shall be considered as the lesser of a continuous run not exceeding 8 hr duration or a total weight, so treated, not exceeding 2,000 lb (907 kg).

(c) One test shall be made for each forging or casting of 1,000 lb to 10,000 lb (454 kg to 4,540 kg) in weight.

(d) As an alternative to (c), a separate test forging or casting may be used to represent forgings or castings of different sizes in one heat and heat treat lot, provided the test piece is a representation of the greatest thickness in the heat treat lot.

WB-2343 Bars

One test shall be made for each lot of bars with cross-sectional area greater than 1 sq in. (645 mm²), where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed 6,000 lb.

WB-2344 Tubular Products and Fittings

On products which are seamless or welded without filler metal, one test shall be made from each lot. On products which are welded with filler metal, one additional test with the specimens taken from the weld area shall also be made on each lot. A lot shall be defined as stated in the applicable material specification, but in no case shall a lot consist of products from more than one heat of material and of more than one diameter, with the nominal thickness of any product included not exceeding that to be tested by more than $\frac{1}{4}$ in. (6 mm); such a lot shall be in a single heat treatment load or in the same continuous run in a continuous furnace controlled within a 50°F (28°C) range and equipped with recording pyrometers.

WB-2345 Bolting Material

One test shall be made for each lot of material, where a lot is defined as one heat of material heat

Page 80

treated in one charge or as one continuous operation, not to exceed in weight the following:

$1\frac{3}{4}$ in. diameter and less	1,500 lb
Over $1\frac{3}{4}$ in. to $2\frac{1}{2}$ in. diameter	3,000 lb
Over $2\frac{1}{2}$ in. to 5 in. diameter	6,000 lb
Over 5 in. diameter	10,000 lb

WB-2346 Test Definitions

Unless otherwise stated in WB-2341 through WB-2345, the term *one test* is defined to include the combination of the drop weight test and the C_v test when RT_{NDT} is required [WB-2331.1(a) and WB-2331.1(b)] or only the C_v test or the fracture toughness test when RT_{NDT} is not required [WB-2331.1(c) and WB-2331.1(d)].

WB-2350 RETESTS

(a) For C_v tests required by WB-2330, one retest at the same temperature may be conducted provided the requirements of (1) through (3) below are met:

(1) the average value of the test results meets the minimum requirements;

(2) not more than one specimen per test is below the minimum requirements;

(3) the specimen not meeting the minimum requirements is not lower than 10 ft-lb or 5 mils below the specified requirements.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retest, both specimens shall meet the minimum requirements.

WB-2360 CALIBRATION OF INSTRUMENTS AND EQUIPMENT

Calibration of temperature instruments and test machines used in toughness testing shall be performed at the frequency given in (a) and (b) below.

(a) Temperature instruments used to control test temperature of specimens shall be calibrated and the results recorded to meet the requirements of WA-3858.2 at least once in each 3 month interval.

(b) Test machines shall be calibrated at least once per year and the results recorded using methods outlined in ASTM E 23

-72 and employing standard specimens obtained from the National Institute of Standards and Technology.

WB-2400 WELDING AND BRAZING MATERIAL

WB-2410 GENERAL REQUIREMENTS

(a) All welding material used in the construction and repair of components or material, except welding material used for cladding or hard surfacing, shall conform to the requirements of the welding material specification or to the requirements for other welding material as permitted in Section IX. In addition, welding material shall conform to the requirements stated in this Subarticle and to the rules covering identification in WB-2150.

(b) The Certificate Holder shall provide the organization performing the testing with the information listed below, as applicable.

- (1) welding process;
- (2) SFA Specification and classification;
- (3) other identification if no SFA Specification applies;
- (4) minimum tensile strength [WB-2431.1(e)] in the as-welded or heat treated condition or both [WB-2431.1(c)];
- (5) drop weight test for material as-welded or heat treated, or both (WB-2331);
- (6) Charpy V-notch test for material as-welded or heat treated, or both (WB-2331); the test temperature and the lateral expansion or the absorbed energy shall be provided;
- (7) Fracture toughness test for material as-welded or heat treated, or both (WB-2331);
- (8) the preheat and interpass temperatures to be used during welding of the test coupon [WB-2431.1(c)];
- (9) postweld heat treatment time, temperature range, and maximum cooling rate, if the production weld will be heat treated [WB-2431.1(c)];
- (10) elements for which chemical analysis is required per the SFA Specification or Welding Procedure Specification and WB-2432;
- (11) minimum delta ferrite (WB-2433).

WB-2420 REQUIRED TESTS

The required tests shall be conducted for each lot of covered, flux cored, or fabricated electrodes; for each heat of bare electrodes, rod, or wire for use with the OFW, GMAW, GTAW, PAW, and EGW (electrogas welding) processes (Section IX, QW-492); for each heat of consumable inserts; for each combination of heat of bare electrodes and lot of submerged arc flux (SAW); for each combination of lot of fabricated electrodes and lot of submerged arc flux; for each

Page 81

combination of heat of bare electrodes or lot of fabricated electrodes, and dry blend of supplementary powdered filler metal, and lot of submerged arc flux; or for each combination of heat of bare electrodes and lot of electrosag flux (ESW). Tests performed on welding material in the qualification of weld procedures will satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used, provided the tests required by WB-4000 and this Subarticle are made and the results conform to the requirements of this Article. The definitions in (a) through (h) below apply.

(a) A *dry batch of covering mixture* is defined as the quantity of dry covering ingredients mixed at one time in one mixing vessel; a dry batch may be used singly or may be subsequently subdivided into quantities to which the liquid binders may be added to produce a number of wet mixes [(c) below].

(b) A *dry blend* is defined as one or more dry batches mixed in a mixing vessel and combined proportionately to produce a uniformity of mixed ingredients equal to that obtained by mixing the same total amount of dry ingredients at one time in one mixing vessel.

(c) A *wet mix* is defined as the combination of a dry batch or dry blend [(a) and (b) above, respectively], and liquid binder

ingredients at one time in one mixing vessel.

(d) A *lot of covered, flux cored, or fabricated electrodes* is defined as the quantity of electrodes produced from the same combination of heat of metal and dry batch, dry blend, or chemically controlled mixes of flux or core materials. Alternatively, a lot of covered, flux cored, or fabricated electrodes may be considered one type and size of electrode, produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb, from chemically controlled tube, wire, or strip and a dry batch, a dry blend, or chemically controlled mixes of flux, provided each container of welding material is coded for identification and traceable to the production period, the shift, line, and the analysis range of both the mix and the rod, tube, or strip used to make the electrode.

(1) *Chemically controlled tube, wire, or strip* is defined as consumable tube, wire, or strip material supplied on coils with a maximum of one splice per coil that has been chemically analyzed to ensure that the material conforms to the electrode manufacturer's chemical control limits for the specific type of electrode. Both ends of each coil shall be chemically analyzed, except that those coils which are splice free need only be analyzed on one end of the coil.

(2) *Chemically controlled mixes of flux* are defined as flux material that has been chemically analyzed to ensure that it conforms to the percent allowable variation from the electrode manufacturer's standard for each chemical element for that type electrode. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending.

(e) A *heat of bare electrode, rod, wire, or consumable insert* is defined as the material produced from the same melt of metal.

(f) Alternatively, for carbon and low alloy steel bare electrode, rod, wire, or consumable inserts for use with SAW, OFW, GMAW, GTAW, PAW, and EGW processes, a *heat* may be defined as either the material produced from the same melt of metal or the material produced from one type and size of wire when produced in a continuous period [not to exceed 24 hr and not to exceed 100,000 lb (45,360 kg)] from chemically controlled wire, subject to requirements of (1), (2), and (3) below.

(1) For the chemical control of the product of the rod mill, coils shall be limited to a maximum of one splice prior to processing the wire. Chemical analysis shall be made from a sample taken from both ends of each coil of mill coiled rod furnished by mills permitting spliced coil practice of one splice maximum per coil. A chemical analysis need be taken from only one end of rod coils furnished by mills prohibiting spliced coil practice.

(2) Carbon, manganese, silicon, and other intentionally added elements shall be identified to ensure that the material conforms to the SFA or user's material specification.

(3) Each container of wire shall be coded for identification and traceability to the lot, production period, shift, line, and analysis of rod used to make the wire.

(g) A *lot of submerged arc or electroslag flux* is defined as the quantity of flux produced from the same combination of raw materials under one production schedule.

(h) A *dry blend of supplementary powdered filler metal* is defined as one or more mixes of material produced in a continuous period, not to exceed 24 hr and not to exceed 20,000 lb (9,070 kg) from chemically controlled mixes of powdered filler metal, provided each container of powdered metal is coded for identification and traceable to the production period, the shift, and the mixing vessel. A *chemically controlled mix of powdered filler metal* is defined as powdered filler metal material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the powdered filler metal manufacturer's standard, for each chemical element, for that type of powdered filler metal. A chemical analysis shall be made on each

Page 82

mix made in an individual mixing vessel after blending. The chemical analysis range of the supplemental powdered filler shall be the same as that of the welding electrode, and the ratio of powder to electrode used to make the test coupon shall be the maximum permitted for production welding.

WB-2430 WELD METAL TESTS

WB-2431 Mechanical Properties Test

Tensile and toughness tests shall be made, in accordance with this paragraph, of welding materials which are used to join P-Nos. 1, 3, 4, 5, 6, 7, 9, and 11 base materials in any combination, with the exceptions listed in (a) through (d) below:

- (a) austenitic stainless steel and nonferrous welding material used to join the listed P-Numbers;
- (b) consumable inserts (backing filler material);
- (c) welding material used for GTAW root deposits with a maximum of two layers;
- (d) welding material to be used for the welding of base material exempted from toughness testing by WB-2311 shall likewise be exempted from the impact testing required by WB-2330 and this paragraph.

WB-2431.1 General Test Requirements.

The welding test coupon shall be made in accordance with (a) through (f) below, using each process with which the weld material will be used in production welding.

- (a) Test coupons shall be of sufficient size and thickness such that the test specimens required herein can be removed.
- (b) The weld metal to be tested for all processes except electroslag welding shall be deposited in such a manner as to eliminate substantially the influence of the base material on the results of the tests. Weld metal to be used with the electroslag process shall be deposited in such a manner as to conform to one of the applicable Welding Procedure Specifications (WPS) for production welding, Section IX, QW-200.1. The base material shall conform to the requirements of Section IX, QW-403.1 or QW-403.4, as applicable.
- (c) The welding of the test coupon shall be performed within the range of preheat and interpass temperatures that will be used in production welding. Coupons shall be tested in the as-welded condition, or they shall be tested in the applicable postweld heat treated condition when the production welds are to be postweld heat treated. The postweld heat treatment holding time shall be at least 80% of the maximum time to the weld metal in production application. The total time for postweld heat treatment of the test coupon may be applied in one heating cycle. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the component. In addition, weld coupons for weld metal to be used with the electroslag process, which are tested in the as-welded condition or following a postweld heat treatment within the holding temperature ranges of Tables WB-4622.1-1 or WB-4622.4(c)-1, shall have a thickness within the range of 0.5 to 1.1 times the thickness of the welds to be made in production. Electroslag weld coupons to be tested following a postweld heat treatment, which will include heating the coupon to a temperature above the Holding Temperature Range of Table WB-4622.1-1 for the type of material being tested, shall have a thickness within the range of 0.9 to 1.1 times the thickness of the welds to be made in production.
- (d) Regardless of the welding process or welding material being tested, the tensile specimens, and the C_v test specimens where required, shall be located and prepared in accordance with the requirements of SFA-5.1, Specification for Mild Steel Covered Electrodes. Drop weight and fracture toughness test specimens, where required, shall be oriented so that the longitudinal axis is transverse to the weld with the notch in the weld face or in a plane parallel to the weld face. For specimen preparation and testing, the applicable parts of WB-2321.1 and WB-2321.2 shall apply. The longitudinal axis of the specimen shall be at a minimum depth of $1/4t$ from a surface, where t is the thickness of the test weld.
- (e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the base material specification. When base materials of different specifications are to be welded, the tensile strength requirements shall conform to the specified minimum tensile strength requirements of either of the base material specifications.
- (f) Toughness specimens of the weld metal shall be tested where toughness tests are required for either of the base materials of the production weld. The weld metal shall conform to the parts of WB-2331(a) or WB-2332 applicable to the base material. Where different requirements exist for the two base materials, the weld metal may conform to either of the two requirements.

WB-2431.2 Standard Test Requirements.

In lieu of the use of the General Test Requirements specified in WB-2431.1, tensile and toughness tests may be made in accordance with this subparagraph where they are required for mild and low alloy steel covered electrodes; the

Standard Test Requirements option. The limitations and testing under this Standard Test option shall be in accordance with (a) through (f) below.

(a) Testing to the requirements of this subparagraph shall be limited to electrode classifications included in Specifications SFA-5.1 or SFA-5.5.

(b) The test assembly required by SFA-5.1 or SFA-5.5, as applicable, shall be used for test coupon preparation, except that it shall be increased in size to obtain the number of C_v specimens, drop weight specimens, and fracture toughness test specimens required by WB-2330, where applicable.

(c) The welding of the test coupon shall conform to the requirements of the SFA Specification for the classification of electrode being tested. Coupons shall be tested in the as-welded condition and also in the postweld heat treated condition. The PWHT temperatures shall be in accordance with Table WB-4622.1-1 for the applicable P-Number equivalent. The time at PWHT temperature shall be 8 hr. (This qualifies PWHT of 10 hr or less.) When the PWHT of the production weld exceeds 10 hr, or the PWHT temperature is other than that required above, the general test of WB-2431.1 shall be used.

(d) The tensile and C_v specimens shall be located and prepared in accordance with the requirements of SFA-5.1 or SFA-5.5, as applicable. Drop weight and fracture toughness test specimens, where required, shall be located and oriented as specified in WB-2431.1(d).

(e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirement of the SFA Specification for the applicable electrode classification.

(f) The requirements of WB-2431.1(f) shall be applicable to the toughness testing of this option.

WB-2432 Chemical Analysis Test

Chemical analysis of filler metal or weld deposits shall be made in accordance with WB-2420 and as required by the following subparagraphs.

WB-2432.1 Test Method.

The chemical analysis test shall be performed in accordance with this subparagraph and Table WB-2432.1-1, and the results shall conform to WB-2432.2.

(a) A-No. 8 welding material to be used with GTAW and PAW processes and any other welding material to be used with any GTAW, PAW, or GMAW process shall have chemical analysis performed either on the filler metal or on a weld deposit made with the filler metal in accordance with (c) or (d) below.

**TABLE WB-2432.1-1
SAMPLING OF WELDING MATERIALS FOR
CHEMICAL ANALYSIS**

	GTAW/PAW	GMAW	All Other Processes
A-No. 8 filler metal	Filler metal or weld deposit	Weld deposit	Weld deposit
All other filler metal	Filler metal or weld deposit	Filler metal or weld deposit	Weld deposit

TABLE WB-2432.1-1 SAMPLING OF WELDING MATERIALS FOR CHEMICAL ANALYSIS

(b) A-No. 8 welding material to be used with other than the GTAW and PAW processes and other welding material to be used with other than the GTAW, PAW, or GMAW process shall have chemical analysis performed on a weld deposit of the material or combination of materials being certified in accordance with (c) or (d) below. The removal of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c) below. As an alternative, the deposit shall be made in accordance with (d) below for material that will be used for corrosion resistant overlay cladding. Where the Welding Procedure Specification or the welding material specification specifies percentage composition limits for analysis, it shall state that the specified limits apply for the filler metal analysis, the undiluted weld deposit analysis, or *in situ* cladding deposit analysis in conformance with the above required certification testing.

4 The methods given in the Appendix of SFA-5.9, Specification for Corrosion Resisting Chromium and Chromium-Nickel Steel Welding Rods and Bare Electrodes, shall be used to establish a welding and sampling method for the pad, groove, or other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution.

(c) The preparation of samples for chemical analysis of undiluted weld deposits shall comply with the method given in the applicable SFA Specification. Where a weld deposit method is not provided by the SFA specification, the sample shall be removed from a weld pad, groove, or other test weld⁴ made using the welding process that will be followed when the welding material or combination of welding materials being certified is consumed. The weld for A-No. 8 material to be used with the GMAW or EGW process shall be made using the shielding gas composition specified in the Welding Procedure Specifications that will be followed when the material is consumed. The test sample for ESW

Page 84

shall be removed from the weld metal of the mechanical properties test coupon. Where a chemical analysis is required for a welding material which does not have a mechanical properties test requirement, a chemical analysis test coupon shall be prepared as required by WB-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of WB-2431.1(c) do not apply.

**TABLE WB-2432.2(a)-1
CHEMICAL ANALYSIS FOR REACTOR VESSEL
WELDING MATERIAL**

Carbon and low alloy materials	C, Cr, Mo, Ni, Mn, Si, P, S, V, Cu
Chromium and Cr–Ni stainless material	C, Cr, Mo, Ni, Mn, Si, P, S, V, Cb + Ta, Ti, Cu

TABLE WB-2432.2(a)-1 CHEMICAL ANALYSIS FOR REACTOR VESSEL WELDING MATERIAL

**TABLE WB-2432.2(a)-2
CHEMICAL ANALYSIS FOR WELDING MATERIAL
FOR OTHER THAN REACTOR VESSEL WELDS**

Chromium–Nickel stainless steels	C, Cr, Mo, Ni, Mn, Si, Cb + Ta
---	---------------------------------------

TABLE WB-2432.2(a)-2 CHEMICAL ANALYSIS FOR WELDING MATERIAL FOR OTHER THAN REACTOR VESSEL WELDS

(d) The alternative method provided in (b) above for the preparation of samples for chemical analysis of welding material to be used for corrosion resistant overlay cladding shall require a test weld made in accordance with the essential variables of the Welding Procedure Specification that will be followed when the welding material is consumed. The test weld shall be made in conformance with the requirements of Section IX, QW-214.1. The removal of chemical analysis samples shall conform with QW-453 for the minimum thickness for which the welding procedure specification is qualified.

[98]

WB-2432.2 Requirements for Chemical Analysis.

The chemical elements to be determined, the composition requirements of the weld metal, and the recording of results of the chemical analysis shall be in accordance with (a) through (c) below.

(a)(1) All welding material to be used in the reactor vessel shall be analyzed for the elements listed in Table WB-2432.2(a)-1.

(2) All welding material of ferrous alloys A-No. 8 and A-No. 9 (Section IX, QW-442) to be used in other components shall be analyzed for the elements listed in Table WB-2432.2(a)-2 and for any other elements specified in the welding material specification referenced by the WPS or in the WPS.

(3) All other welding material shall be analyzed for the elements specified in either the welding material specification referenced by the WPS or in the WPS.

(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition limits. Where the Welding Procedure Specification contains a modification of the composition limits of SFA or other referenced welding material specifications, or provides limits for additional elements, these composition limits of the welding procedure specification shall apply for acceptability.

(c) The results of the chemical analysis shall be reported. Elements listed in Table WB-2432.2(a)-1 or Table WB-2432.2(a)-2 but not specified in the welding material specification or WPS shall be reported for information only.

[98]

WB-2433 Delta Ferrite Determination

A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, QW-442) backing filler metal (consumable inserts); bare electrode, rod, or wire filler metal; or weld metal, except that delta ferrite determinations are not required for SFA-5.9 and SFA-5.4, Type 16-8-2, or A-No. 8 weld filler metal to be used for weld metal cladding.

WB-2433.1 Method.

Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of chemical analysis of WB-2432 in conjunction with Fig. WB-2433.1-1.

(a) Calibration of magnetic instruments shall conform to AWS-A4.2-91.

(b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with WB-2432.1(c).

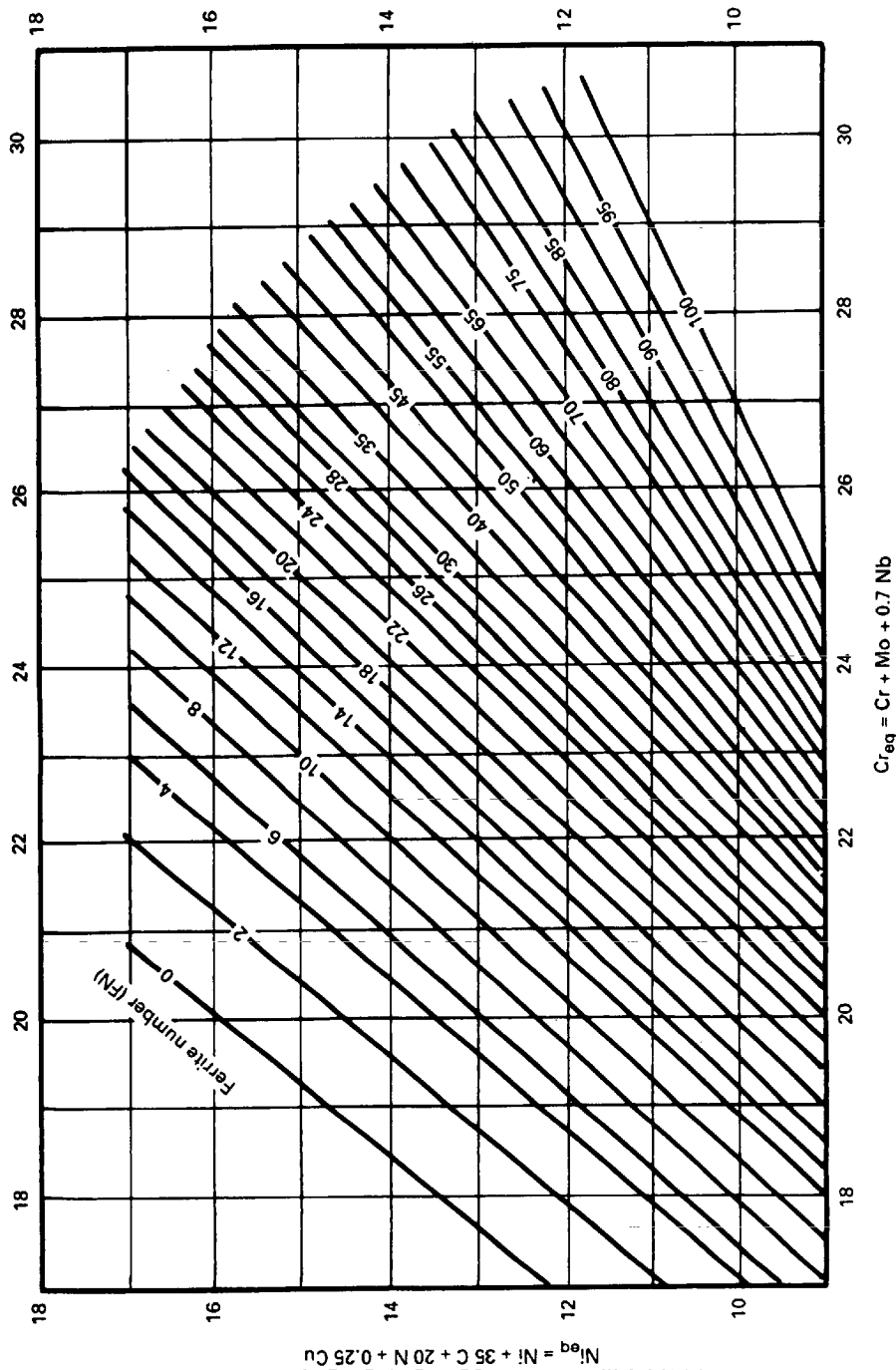
(c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number (FN).

WB-2433.2 Acceptance Standards.

The minimum acceptable delta ferrite shall be 5FN. The results of the delta ferrite determination shall be included in the Certified Material Test Report of WB-2130 or WB-4120.

Page 85

Page 86



GENERAL NOTES:

(a) The actual nitrogen content is preferred. If this is not available, the following applicable nitrogen value shall be used:

(1) GMAW welds - 0.08%, except that when self shielding flux cored electrodes are used - 0.12%.

(2) Welds made using other processes - 0.06%.

(b) This diagram is identical to the WRC-1992 Diagram, except that the solidification mode lines have been removed for ease of use.

FIG. WB-2433.1-1 WELD METAL DELTA FERRITE CONTENT

FIG. WB-2433.1-1 WELD METAL DELTA FERRITE CONTENT

WB-2440 STORAGE AND HANDLING OF WELDING MATERIAL

Suitable storage and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by fluxes and cored, fabricated, and coated electrodes.

WB-2450 BRAZING MATERIAL

Brazing filler material and fluxes shall conform to the rules covering identification in WB-2150 and to the requirement of (a), (b), and (c) below.

(a) The filler material used in brazing shall be a nonferrous metal or alloy with a solidus temperature about 800°F (427°C) and at least 500°F (278°C) above the highest temperature of the joint in service.

(b) The filler material shall melt and flow freely by capillary action within the desired temperature range, and, in conjunction with a suitable flux or controlled atmosphere, the filler material shall wet and adhere to the surfaces to be joined.

(c) Fluxes that are fluid and chemically active at the brazing temperature shall be used, when necessary, to prevent oxidation of the filler metal and the surfaces to be joined and to promote free flowing of the filler material.

WB-2500 EXAMINATION AND REPAIR OF CONTAINMENT SYSTEM MATERIAL

WB-2510 EXAMINATION OF CONTAINMENT SYSTEM MATERIAL

(a) Containment system material and material welded thereto shall be examined by nondestructive methods applicable to the material and product form as required by the rules of this Subarticle. Seamless pipe, tubes, and fittings, and less, need not be examined by the rules of this Subarticle.

(b) The requirements of this Subarticle for repair by welding, including examination of the repair welds, shall be met wherever repair welds are made to containment system material and material welded thereto. The exceptions in (a) above do not apply to repair welds.

WB-2520 EXAMINATION AFTER QUENCHING AND TEMPERING

Ferritic steel products that have their properties enhanced by quenching and tempering shall be examined by the methods specified in this Subarticle for each product form after the quenching and tempering phase of the heat treatment.

WB-2530 EXAMINATION AND REPAIR OF PLATE

WB-2531 Required Examination

All plates 2 in. (51 mm) nominal thickness and less shall be examined by the angle beam ultrasonic method in accordance with WB-2532.2. All plates greater than 2 in. (51 mm) thickness shall be examined by the straight beam ultrasonic method in accordance with WB-2532.1.

WB-2532 Examination Procedures

WB-2532.1 Straight Beam Examination.

The requirements for straight beam examination shall be in accordance with SA-578, Specification for Straight Beam Wave Ultrasonic Testing and Inspection of Plain and Clad Steel Plates for Special Applications, as shown in Section V, except that the extent of examination and the acceptance standards to be applied are given in (a) and (b) below.

(a) *Extent of Examination.* One hundred percent of one major plate surface shall be covered by moving the search unit in parallel paths with not less than a 10% overlap.

(b) *Acceptance Standards*

(1) Any area where one or more imperfections produce a continuous total loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed within a circle whose diameter is 3 in. (76 mm) or one-half of the plate thickness, whichever is greater, is unacceptable.

(2) In addition, two or more imperfections smaller than described in (1) above shall be unacceptable unless separated by a minimum distance equal to the greatest diameter of the larger imperfection, or unless they may be collectively encompassed by the circle described in (1) above.

WB-2532.2 Angle Beam Examination.

The requirements for angle beam examination shall be in accordance with SA-577, Specification for Ultrasonic Beam Wave Inspection of Steel Plates, as shown in Section V and supplemented by (a) and (b) below. The calibration

Page 87

notch, extent of examination, and acceptance standards to be applied are given in (a) through (c) below.

(a) *Calibration.* Angle beam examination shall be calibrated from a notch.

(b) *Extent of Examination.* One hundred percent of one major plate surface shall be covered by moving the search unit in parallel paths with not less than 10% overlap.

(c) *Acceptance Standards.* Material that shows one or more imperfections which produce indications exceeding in amplitude the indication from the calibration notch is unacceptable unless additional exploration by the straight beam method shows the imperfections are laminar in nature and are acceptable in accordance with WB-2532.1(b).

WB-2537 Time of Examination

Acceptance examinations shall be performed at the time of manufacture as required in (a) through (c) below.

(a) *Ultrasonic examination* shall be performed after rolling to size and after heat treatment, except for postweld heat treatment.

(b) *Radiographic examination* of repair welds, when required, may be performed prior to any required postweld heat treatment.

(c) *Magnetic particle or liquid penetrant examination* of repair welds shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment of P-No.1 material 2 in. (51 mm) and less nominal thickness.

WB-2538 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (d) below are met.

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) After defect elimination, the area is examined by the magnetic particle method in accordance with WB-2545 or the liquid penetrant method in accordance with WB-2546 to ensure that the defect has been removed or reduced to an imperfection of acceptable size.

(c) Areas ground to remove oxide scale or other mechanically caused impressions for appearance or to facilitate proper ultrasonic testing need not be examined by the magnetic particle or liquid penetrant test method.

(d) When the elimination of the defect reduces the thickness of the section below the minimum required to satisfy WB-3000, the product shall be repaired in accordance with WB-2539.

WB-2539 Repair by Welding

The Material Organization may repair by welding material from which defects have been removed, provided the depth of the repair cavity does not exceed one-third the nominal thickness and the requirements of the following subparagraphs are met. Prior approval of the Certificate Holder shall be obtained for the repair of plates to be used in the manufacture of containment systems.

WB-2539.1 Defect Removal.

The defect shall be removed by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for

repair (WB-4211.1).

WB-2539.2 Qualification of Welding Procedures and Welders.

The welding procedure and welders or welding operators shall be qualified in accordance with WB-4000 and Section IX.

WB-2539.3 Blending of Repaired Areas.

After repair, the surface shall be blended uniformly into the surrounding surface.

WB-2539.4 Examination of Repair Welds.

Each repair weld shall be examined by the magnetic particle method (WB-2545) or by the liquid penetrant method (WB-2546). In addition, when the depth of the repair cavity exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness, the repair weld shall be radiographed after repair in accordance with WB-5110 and to the acceptance standards of WB-5320. The penetrometer and the acceptance standards for radiographic examination of repair welds shall be based on the section thickness at the repair area.

WB-2539.5 Heat Treatment After Repairs.

The product shall be heat treated after repair in accordance with the heat treatment requirements of WB-4620.

WB-2539.6 Material Report Describing Defects and Repairs.

Each defect repair exceeding in depth the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart which shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographic film.

Page 88

WB-2539.7 Repair of Cladding by Welding.

The Material Organization may repair defects in cladding by welding, provided the requirements of (a) through (d) below are met.

(a) *Qualification of Welding Procedures and Welders.* The welding procedure and the welders or welding operators shall be qualified in accordance with WB-4000 and with Section IX.

(b) *Defect Removal and Examination of Cavity.* The defect shall be removed, and the cavity prepared for repair shall be examined by the liquid penetrant method (WB-2546).

(c) *Examination of Repaired Areas.* The repaired area shall be examined by a liquid penetrant method (WB-2546).

(d) *Report of Repairs.* Each defect repair shall be described in the Certified Material Test Report for each piece, including a chart which shows the location and size of the repair, the welding material identification, welding procedure, heat treatment, and examination results.

WB-2540 EXAMINATION AND REPAIR OF FORGINGS AND BARS

WB-2541 Required Examinations

(a) Forgings and bars shall be examined by the ultrasonic method in accordance with WB-2542, except forgings or sections of forgings which have coarse grains, or configurations which do not yield meaningful examination results by ultrasonic methods, shall be examined by radiographic methods in accordance with Section V, Article 2, using the acceptance standards of WB-5320. In addition, all external surfaces and accessible internal surfaces shall be examined by a magnetic particle method (WB-2545) or a liquid penetrant method (WB-2546).

(b) Forged flanges and fittings, such as elbows, tees, and couplings, shall be examined in accordance with the requirements of WB-2550.

(c) Bar material used for bolting shall be examined in accordance with WB-2580.

(d) Forgings and forged or rolled bars which are to be bored to form tubular products or fittings shall be examined in accordance with the requirements of WB-2550 after boring.

(e) Forgings and forged or rolled bars which will subsequently be bored to form valve parts shall be examined in accordance with WB-2541 after boring.

WB-2542 Ultrasonic Examination

WB-2542.1 Examination Procedure.

All forgings in the rough-forged or finished condition, and bars, shall be examined in accordance with Article 5 of Section V and the following supplemental requirements. The techniques of (a) through (d) below are required, as applicable.

(a) Forgings may be examined by the use of alternative ultrasonic methods which utilize distance amplitude corrections, provided the acceptance standards are shown to be equivalent to those listed in WB-2542.2.

(b) Cylindrical section bars shall be scanned from the entire external circumference.

(c) Noncylindrical section bars shall be scanned in two perpendicular directions to the maximum extent possible (through each pair of parallel sides).

(d) Bar products do not require recording and reporting of indications smaller than the acceptance standard, except when so specified for specialized applications.

WB-2542.2 Acceptance Standards

(a) *Straight Beam General Rule.* A forging shall be unacceptable if the results of straight beam examinations show one or more reflectors which produce indications accompanied by a complete loss of back reflection not associated with or attributable to geometric configurations. Complete loss of back reflection is assumed when the back reflection falls below 5% of full calibration screen height.

(b) *Straight Beam Special Rule for Vessel Shell Sections*

(1) A ring forging made to fine grain melting practice and used for vessel shell sections shall be unacceptable if the results of the straight beam radial examination show one or more reflectors producing a continuous complete loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed with a circle whose diameter is 3 in. (76 mm) or one-half of the wall thickness, whichever is greater.

(2) In addition, two or more reflectors smaller than described in (1) above shall be unacceptable unless separated by a minimum distance equal to the greatest diameter of the larger reflector or unless they may be collectively encompassed by the circle described in (1) above.

(c) *Angle Beam Rule.* A forging shall be unacceptable if the results of angle beam examinations show one or more reflectors which produce indications exceeding in amplitude the indication from the appropriate calibration notches.

Page 89

WB-2545 Magnetic Particle Examination

WB-2545.1 Examination Procedure.

The procedure for magnetic particle examination shall be in accordance with the methods of Article 7, Section V.

WB-2545.2 Evaluation of Indications

(a)

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication in excess of the WB-2545.3 acceptance standards, which is believed to be nonrelevant, shall be recommended by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

WB-2545.3 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for material less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for material 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more indications in any 6 sq in. (3,871 mm²) of area whose major dimension is no more than 6 in. (152 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

WB-2546 Liquid Penetrant Examination

WB-2546.1 Examination Procedure.

The procedure for liquid penetrant examination shall be in accordance with the methods of Section V, Article 6.

WB-2546.2 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities, such as may occur from machining marks, surface conditions, or an incomplete bond between base metal and cladding, may produce similar indications which are not relevant.

(b) Any indication in excess of the WB-2546.3 acceptance standards, which is believed to be nonrelevant, shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation, which would mask defects, are unacceptable.

(c) *Relevant indications* are indications which result from imperfections. *Linear indications* are indications in which the length is more than three times the width. *Rounded indications* are indications which are circular or elliptical with the length equal to or less than three times the width.

WB-2546.3 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for material less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for material from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for

material 2 in. (51 mm) thick and greater;⁸

16

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more indications in any 6 sq in. (3,871 mm²) of area whose major dimension is no more than 6 in. (152 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

Page 90

WB-2547 Time of Examination

Acceptance examinations, including those for repair welds, shall be performed at the time of manufacture as required in (a) through (e) below.

(a) Ultrasonic examination may be performed at any time after forging [WB-2541(d)], and the maximum practical volume, including weld repairs, if required, shall be examined after final heat treatment, excluding postweld heat treatment.

(b) Radiographic examination of repair welds, if required, may be performed prior to any required postweld heat treatment.

(c) Magnetic particle or liquid penetrant examination shall be performed in the finished condition, except repair welds of P-No. 1 material, 2 in. (51 mm) nominal thickness and less, may be examined prior to postweld heat treatment.

(d) Forgings and rolled bars which are to be bored or turned to form tubular parts or fittings shall be examined after boring or turning, except for threading.

(e) Forgings and forged or rolled bars which will subsequently be bored or turned to form valve parts shall be examined after boring or turning, except for threading.

WB-2548 Elimination of Surface Defects

Elimination of surface defects shall be made in accordance with WB-2538.

WB-2549 Repair by Welding

Repair by welding shall be in accordance with WB-2539, except that:

(a) the depth of repair that is permitted is not limited; and

(b) for ferritic steel forgings, the completed repair may be examined by the ultrasonic method in accordance with the requirements of WB-2542 in lieu of radiography.

WB-2550 EXAMINATION AND REPAIR OF SEAMLESS AND WELDED TUBULAR PRODUCTS AND FITTINGS

WB-2551 Required Examination

In addition to the requirements of the material specification and of this Article, seamless and welded tubular products (including pipe flanges and fittings machined from forgings and bars) shall comply with the following.

(a) Wrought seamless and welded pipe and tubing shall be examined over the entire volume⁵ of the material in accordance with (1), (2), (3), or (4), as follows. Tubular products may require both outside and inside surface conditioning prior to examination.

(1) Pipe and Tubing

(a) Pipe and tubing smaller than $2\frac{1}{2}$ in. (64 mm) O.D. shall be examined by the ultrasonic method in accordance with WB-2552.1(a) in two opposite circumferential directions⁶ and by the eddy current method in accordance with WB-2554

, provided the product is limited to sizes, materials, and thicknesses for which meaningful results can be obtained by eddy current examination as evidenced by detection of required standards. Each method shall be calibrated to the appropriate standard: that is, the ultrasonic method shall be calibrated to the axial notches or grooves of WB-2552.1(b), and the eddy current method shall be calibrated to the circumferential notches and grooves as well as the radial hole of WB-2554.2.

(b) As an alternative to the eddy current examination or when the eddy current examination does not yield meaningful results, an axial scan ultrasonic examination in two opposite axial directions,⁶ in accordance with WB-2552.1(b), shall be made.

(2) Pipe and tubing $2\frac{1}{2}$ in. (64 mm) O.D. and larger shall be examined by the ultrasonic method in accordance with WB-2552.1(a) in two opposite circumferential directions, and in accordance with WB-2552.1(b) in two opposite axial directions. Alternatively, for welded without filler metal pipe larger than $6\frac{3}{4}$ in. (70 mm) O.D., the plate shall be examined by the ultrasonic method in accordance with WB-2530 prior to forming and the weld shall be examined by the radiographic method in accordance with WB-2553. Radiographic examination of welds, including repair welds, shall be performed after final rolling and forming and may be performed prior to any required postweld heat treatment.

(3) Copper-nickel alloy and nickel alloy seamless pipe and tubing shall be examined as follows.

(a) Each pipe and tube, all sizes shall be ultrasonically examined in accordance with WB-2552.2(a) in two opposite circumferential directions.

⁵ The volumetric examinations required by this paragraph need only be conducted from one surface.

⁶ The direction of ultrasonic examinations referenced is the direction of sound propagation.

(b) Pipe and tubing smaller than $2\frac{1}{2}$ in. (64 mm) O.D. shall be examined by the eddy current method in accordance with WB-2554 if meaningful indications can be obtained from the reference specimen

Page 91

notches. If meaningful indications cannot be obtained from the reference specimen, an axial scan ultrasonic examination in two opposite axial directions, in accordance with WB-2552.1(b), shall be made.

(c) Pipe and tubing $2\frac{1}{2}$ in. (64 mm) O.D. and larger shall be examined by an axial scan ultrasonic examination in two opposite axial directions in accordance with WB-2552.1(b).

(d) Wrought seamless and welded without filler metal fittings (including pipe flanges and fittings machined from forgings and bars) shall be examined in accordance with the material specification, and in addition by the magnetic particle method in accordance with WB-2555, or the liquid penetrant method in accordance with WB-2556 on all external surfaces and all accessible internal surfaces (excluding bolt holes and threads). Additionally, for fittings over NPS 6 (DN 150), the entire volume shall be examined by the ultrasonic method, if feasible, in accordance with WB-2552, or the radiographic method in accordance with WB-2553. Alternatively, the plate shall be examined by the ultrasonic method in accordance with WB-2530 prior to forming and the weld shall be examined by the radiographic method in accordance with WB-2553. Radiographic examination of welds, including repair welds, shall be performed after final rolling and forming, and may be performed prior to any required postweld heat treatment.

WB-2552 Ultrasonic Examination⁶

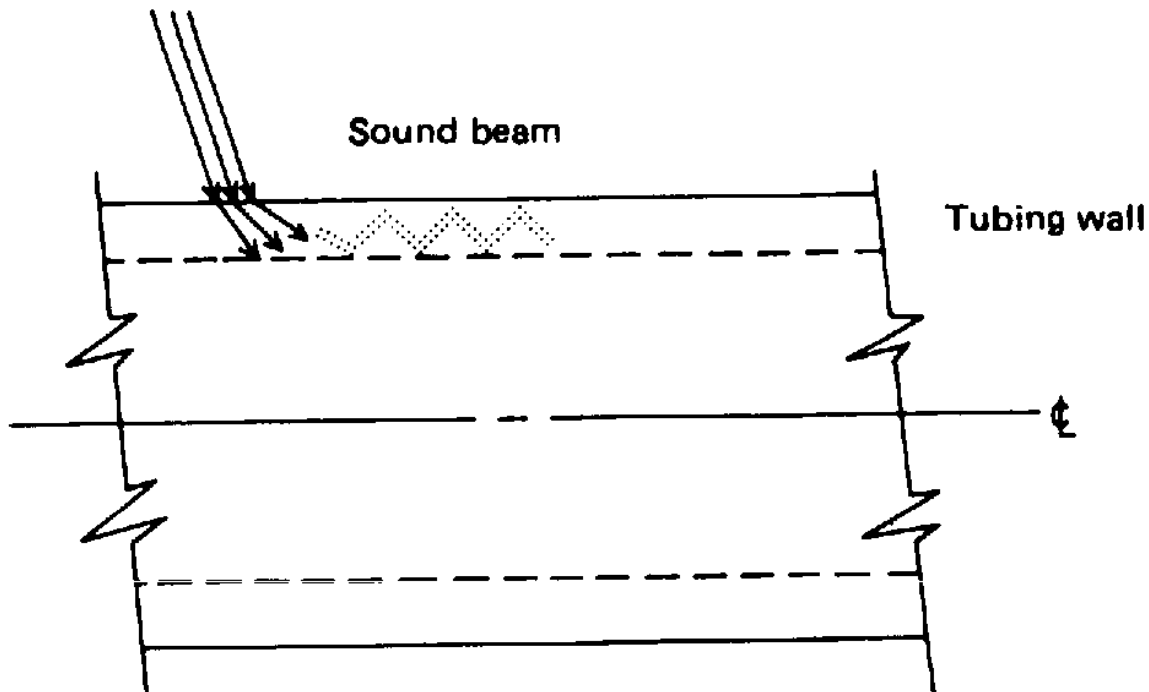
WB-2552.1 Examination Procedure for Pipe and Tubing.

Independent channels or instruments shall be employed for circumferential and axial scans.

(a) *Circumferential Direction.* The procedure for ultrasonic examination of pipe and tubing in the circumferential direction shall be in accordance with SE-213 except as required in WB-2551(a)(1), (a)(2), and (a)(3)(a), and the requirements of this paragraph. The procedure shall provide a sensitivity which will consistently detect defects that produce indications equal to, or greater than, the indications produced by the standard defects included in the reference specimens specified in WB-2552.3.

(b) *Axial Direction.* When required by WB-2551, the ultrasonic examination of pipe and tubing shall include angle beam scanning in the axial direction. The procedure for the axial scans shall be in accordance with SE-213, except that

beam scanning in the axial direction. The procedure for the axial scans shall be in accordance with SE-213, except that the propagation of sound in the tube or pipe wall shall be in the axial direction instead of the circumferential direction and as required in WB-2551(a)(1)(b), (a)(2), and (a)(3)(b) and (c). Fig. WB-2552-1 illustrates the characteristic oblique entry of sound into the pipe or tube wall and the axial direction of ultrasonic energy propagation to detect transverse notches or similar surface discontinuities.



**FIG. WB-2552-1 AXIAL PROPAGATION
OF SOUND IN TUBE WALL**

FIG. WB-2552-1 AXIAL PROPAGATION OF SOUND IN TUBE WALL

(c) *Acceptance Standards.* Products with defects that produce indications in excess of the indications produced by the standard defects in the reference specimen are unacceptable unless the defects are eliminated or repaired in accordance with WB-2558 or WB-2559.

WB-2552.2 Examination Procedure for Fittings

(a) *Procedure.* The procedure for ultrasonic examination of fittings shall be in accordance with the requirements of SA-388 for straight beam examination and, where feasible, angle-beam examination in two circumferential directions.

(b) *Acceptance Standards.* Fittings shall be unacceptable if straight beam examination shows one or more reflectors which produce indications accompanied by complete loss of back reflection not associated with or attributable to the geometric configuration, or if angle beam examination results show one or more reflectors which produce indications exceeding in amplitude the indications from the calibrated notch. Complete loss of back reflection is assumed when the

back reflection falls below 5% of full calibration screen height.

WB-2552.3 Reference Specimens

(a) The reference specimen shall be of the same nominal diameter and thickness, and of the same nominal composition and heat treated condition as the product which is being examined. For circumferential scanning, the standard defects shall be axial notches or grooves on the outside and inside surfaces of the reference specimen, and shall have a length of approximately 1 in. (25 mm) or less, a width not to exceed $\frac{1}{16}$ in. (1.6 mm) for a square notch or U-notch, a width proportional

Page 92

to the depth for a V-notch, and a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the nominal wall thickness. For axial scanning in accordance with SE-213, a transverse (circumferential) notch shall be introduced on the inner and outer surfaces of the standard. Dimensions of the transverse notch shall not exceed those of the longitudinal notch. The reference specimen may be the product being examined.

(b) The reference specimen shall be long enough to simulate the handling of the product being examined through the examination equipment. When more than one standard defect is placed in a reference specimen, the defects shall be located so that indications from each defect are separate and distinct without mutual interference or amplification. All upset metal and burrs adjacent to the reference notches shall be removed.

WB-2552.4 Checking and Calibration of Equipment.

The proper functioning of the examination equipment shall be checked and the equipment shall be calibrated by the use of the reference specimens, as a minimum:

(a) at the beginning of each production run of a given size and thickness of a given material;

(b) after each 4 hr or less during the production run;

(c) at the end of the production run;

(d) at any time that malfunctioning is suspected. If, during any check, it is determined that the test equipment is not functioning properly, all of the product that has been tested since the last valid equipment calibration shall be reexamined.

WB-2553 Radiographic Examination

(a) *General.* When radiographic examination is performed as an alternative for ultrasonic examination of the entire volume of the material, it shall apply to the entire volume of the pipe, tube, or fitting material. Acceptance standards specified for welds shall apply to the entire volume of material examined.

(b) *Examination Procedure.* The radiographic examination shall be performed in accordance with Article 2 of Section V, as modified by WB-5111.

(c) *Acceptance Standard.* Welds that are shown by radiography to have any of the following types of discontinuities are unacceptable:

(1) any type of crack or zone of incomplete fusion or penetration;

(2) any other elongated indication which has a length greater than:

(a) $\frac{1}{4}$ in. for t up to $\frac{3}{4}$ in., inclusive

(b) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. to $2\frac{1}{4}$ in., inclusive

(c) $\frac{3}{4}$ in. for t over $2\frac{1}{4}$ in.

where t is the thickness of the thinner portion of the weld;

(3) any group of aligned indications having an aggregate length greater than t in a length of $12t$, unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length

of the largest indication;

(4) rounded indications in excess of that shown as acceptable in Appendix VI.

WB-2554 Eddy Current Examination

This examination method is restricted to materials with uniform magnetic properties and of sizes for which meaningful results can be obtained.

WB-2554.1 Examination Procedure.

The procedure for eddy current examination shall provide a sensitivity that will consistently detect defects by comparison with the standard defects included in the reference specimen specified in WB-2554.2. Products with defects that produce indications in excess of the reference standards are unacceptable unless the defects are eliminated or repaired in accordance with WB-2558 or WB-2559 as applicable.

WB-2554.2 Reference Specimens.

The reference specimen shall be of the same nominal diameter and thickness, and of the same nominal composition and heat treated condition as the product that is being examined. The standard shall contain tangential or circumferential notches on the outside surface plus a $\frac{1}{16}$ in. (1.6 mm) diameter hole drilled through the wall. For copper-nickel alloy and nickel alloy materials, the standard shall have one notch extending circumferentially on the outside surface and one notch extending circumferentially on the inside surface plus a $\frac{1}{16}$ in. (1.6 mm) diameter hole drilled through the wall. These shall be used to establish the rejection level for the product to be tested. The reference notches shall have a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the wall thickness. The width of the notch shall not exceed $\frac{1}{16}$ in. (1.6 mm). The length shall be approximately 1 in. (25 mm) or less. The size of reference specimens shall be as specified in WB-2552.3.

WB-2554.3 Checking and Calibration of Equipment.

The checking and calibration of examination equipment shall be the same as in WB-2552.4.

Page 93

WB-2555 Magnetic Particle Examination

Magnetic particle examination shall be performed in accordance with the requirements of WB-2545.

WB-2556 Liquid Penetrant Examination

Liquid penetrant examination shall be performed in accordance with the requirements of WB-2546.

WB-2557 Time of Examination

(a) Products that are quenched and tempered shall be examined, as required, after the quenching and tempering heat treatment.

(b) Products that are not quenched and tempered shall receive the required examinations as follows.

(1) Ultrasonic or eddy current examination, when required, shall be performed after final heat treatment, except postweld heat treatment.

(2) Radiographic examination, when required, may be performed prior to any required postweld heat treatment.

(3) Magnetic particle or liquid penetrant examination, including repair welds, shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment for P-No. 1 (Section IX of the Code) materials of 2 in. (51 mm) and less nominal thickness.

(4) Forgings and rolled bars which are to be bored and/or turned to form tubular parts or fittings shall be examined after boring and/or turning, except for threading. Fittings shall be examined after final forming.

WB-2558 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (c) below are met.

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) After defect elimination, the area is examined by the method which originally disclosed the defect to assure that the defect has been removed or reduced to an imperfection of acceptable size.

(c) If the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of WB-3000, the product shall be repaired in accordance with WB-2559.

WB-2559 Repair by Welding

Repair of defects shall be in accordance with WB-2539, except repair by welding is not permitted on copper-nickel alloy and nickel alloy materials.

WB-2570 EXAMINATION AND REPAIR OF STATICALLY AND CENTRIFUGALLY CAST PRODUCTS

In addition to the requirements of the material specification and of this Article, statically and centrifugally cast products shall comply with the following subparagraphs.

WB-2571 Required Examination

Cast products shall be examined by the radiographic method, except cast ferritic steels which shall be examined by either the radiographic or ultrasonic method, or a combination of both methods, as required for the product form by Table WB-2571-1.

In addition, all cast products shall be examined on all external surfaces and all accessible internal surfaces by either the magnetic particle or liquid penetrant method. Machined surfaces, except threaded surfaces, of a cast product shall be examined by either the liquid penetrant or magnetic particle method after machining.

WB-2572 Time of Nondestructive Examination

(a) *Ultrasonic Examination.* Ultrasonic examination, if required, shall be performed at the same stage of manufacture as required for radiography.

(b) *Radiographic Examination.* Radiography may be performed prior to or after finish machining at the following limiting thicknesses.

(1) For finished thicknesses under $2\frac{1}{2}$ in. (64 mm), castings shall be radiographed within 20% of the finished thickness when Type 2 radiographic film is used or within $\frac{1}{2}$ in. (13 mm) of the finished thickness when Type 1 radiographic film is used. The penetrameter and the acceptance reference radiographs shall be based on the finished thickness.

(2) For finished thickness from $2\frac{1}{2}$ in. (64 mm) up to 6 in. (152 mm), castings shall be radiographed within 20% of the finished thickness. The penetrameter and the acceptance reference radiographs shall be based on the finished thickness.

(3) For finished thicknesses over 6 in. (152 mm), castings shall be radiographed with $\frac{1}{2}$ in. (13 mm) or 15% of the finished thickness, whichever is greater.

The penetrameter and the acceptance reference radiographs shall be based on the finished thickness.

TABLE WB-2571-1 REQUIRED EXAMINATIONS

Nominal Pipe Size	Item	Applicable Special Requirements for Class 1 Castings
Inlet piping connections of 2 in. and less	Cast products other than valves	Cast products shall be examined by the radiographic method, except cast ferritic steels, which shall be examined by either the radiographic or ultrasonic method, or a combination of both methods. Castings or sections of castings which have coarse grains or configurations which do not yield meaningful examination results by the ultrasonic method shall be examined by the radiographic method. In addition, all cast products shall be examined on all external surfaces and all accessible internal surfaces by either the magnetic particle or the liquid penetrant method. Machined surfaces, except threaded surfaces, of a cast product shall be examined by either the liquid penetrant or the magnetic particle method after machining.
	Cast valves	None
	Repair welds in valves of P-No. 1 or P-No. 8 material	None
	Repair welds in cast products, excluding repair welds in valves of P-No. 1 or P-No. 8 material	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, repair welds in cavities the depth of which exceed the lesser of $\frac{3}{8}$ in. or 10% of the section thickness shall be radiographed in accordance with WB-2575.
Inlet piping connections over 2 in. up to and including 4 in.	Cast products — See <i>Cast valves</i> below for exceptions	Cast products shall be examined by the radiographic method, except cast ferritic steels, which shall be examined by either the radiographic or the ultrasonic method, or a combination of both methods. Castings or sections of castings which have coarse grains or configurations which do not yield meaningful examination results by the ultrasonic method shall be examined by the radiographic method. In addition, all cast products shall be examined on all external surfaces and all accessible internal surfaces by either the magnetic particle or the liquid penetrant method. Machined surfaces, except threaded surfaces, of a cast product shall be examined by either the liquid penetrant or the magnetic particle method after machining.
	Cast valves	Magnetic particle or liquid penetrant examination may be performed, in lieu of volumetric examination, except the welding ends of cast valves shall be radiographed for a minimum distance of t (when t is the design section thickness of the weld) from the final weld end.
	Repair welds	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, repair welds in cavities the depth of which exceed the lesser of $\frac{3}{8}$ in. or 10% of the section thickness shall be radiographed in accordance with WB-2575.
Inlet piping connections over 4 in.	Cast products	Cast products shall be examined by the radiographic method, except cast ferritic steels, which shall be examined by either the radiographic or the ultrasonic method, or a combination of both methods. Castings or sections of castings which have coarse grains or configurations which do not yield meaningful examination results by the ultrasonic method shall be examined by the radiographic method. In addition, all cast products shall be examined on all external surfaces and all accessible internal surfaces by either the magnetic particle or the liquid penetrant method. Machined surfaces, except threaded surfaces, of a cast product shall be examined by either the liquid penetrant or the magnetic particle method after machining.
	Repair welds	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, repair welds in cavities the depth of which exceed the lesser of $\frac{3}{8}$ in. or 10% of the section thickness shall be radiographed in accordance with WB-2575.

TABLE WB-2571-1 REQUIRED EXAMINATIONS

(c) Radiography of castings for valves may be performed in as-cast or rough machined thickness exceeding the limits of (b)(1), (b)(2), or (b)(3) above, subject to the following conditions.

(1) When the thickness of the as-cast or rough machined section exceeds 2 in. (51 mm), acceptance shall be based on reference radiographs for the next lesser thickness; e.g., if the section being radiographed exceeds $4\frac{1}{2}$ in. (114 mm), use reference radiographs of ASTM E 186-75 (reapproved 1979). The penetrameter shall be based on the thickness of the section being radiographed.

(2) When the thickness of the as-cast or rough machined section is 2 in. (51 mm) or less, the reference radiographs of ASTM E 446-78 shall be used and the penetrameter shall be based on the final section thickness.

(3) Weld ends for a minimum distance of t or $\frac{1}{2}$ in. (13 mm), whichever is less (where t is the design section thickness of the weld), from the final welding end shall be radiographed at a thickness within the limits given in (b)(1), (b)(2), or (b)(3) above as applicable. As an alternative, the weld ends may be radiographed in the as-cast or rough machined thickness in accordance with (c)(1) and (c)(2) above, and the penetrameter shall be based on the final section thickness.

(d) *Magnetic Particle or Liquid Penetrant Examination.* Magnetic particle or liquid penetrant examination shall be performed after the final heat treatment required by the material specification. Repair weld areas shall be examined after postweld heat treatment when a postweld heat treatment is performed, except that repair welds in P-No. 1 (see Section IX of the Code) material 2 in. (51 mm) nominal thickness and less may be examined prior to postweld heat treatment. For cast products with machined surfaces, all finished machined surfaces, except threaded surfaces and small deep holes, shall also be examined by the magnetic particle or the liquid penetrant method.

WB-2573 Provisions for Repair of Base Material by Welding

The Material Organization may repair, by welding, products from which defects have been removed, provided the requirements of this Article are met.

WB-2573.1 Defect Removal.

The defects shall be removed or reduced to an acceptable size by suitable mechanical or thermal cutting or gouging methods, and the cavity prepared for repair. When thermal cutting is performed, consideration shall be given to preheating the material.

WB-2573.2 Repair by Welding.

The Material Organization may repair castings by welding after removing the material containing unacceptable defects. The depth of the repair is not limited. A cored hole or access hole may be closed by the Material Organization by welding in accordance with the requirements of this paragraph, provided the hole is closed by filler metal only. If the hole is closed by welding in a metal insert, the welding shall be performed by a holder of a Certificate of Authorization in accordance with the requirements of the Code.

WB-2573.3 Qualification of Welding Procedures and Welders.

Each manufacturer is responsible for the welding done by his organization and shall establish the procedures and conduct the tests required by WB-4000 and by Section IX of the Code in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures. He is also responsible for the welding performed by his subcontractors and shall assure himself that the subcontractors conduct the tests required by WB-4000 and by Section IX of the Code in order to qualify their welding procedures and the performance of their welders and welding operations.

WB-2573.4 Blending of Repaired Areas.

After repair, the surface shall be blended uniformly into the surrounding surface.

WB-2573.5 Examination of Repair Welds

(a) Each repair weld shall be examined by the magnetic particle method in accordance with the requirements of

WB-2577 or by the liquid penetrant method in accordance with the requirements of WB-2576. In addition, when radiography is specified in the order for the original casting, repair cavities, the depth of which exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the nominal wall thickness, shall be radiographed after repair except that weld slag, including elongated slag, shall be considered as inclusions under Category B of the applicable reference radiographs. The total area of all inclusions, including slag inclusions, shall not exceed the limits of the applicable severity level of Category B of the reference radiographs. The penetrameter and the acceptance standards for radiographic examination of repair welds shall be based on the actual section thickness at the repair area.

(b) Examination of repair welds in P-No. 1 and P-No. 8 material is not required for valves with inlet piping connections NPS 2 (DN 50) and less.

Page 96

WB-2573.6 Heat Treatment After Repairs.

The material shall be heat treated after repair in accordance with the heat treatment requirements of WB-4620, except that the heating and cooling rate limitations of WB-4623 do not apply.

WB-2573.7 Elimination of Surface Defects.

Surface defects shall be removed by grinding or machining provided the requirements of (a) through (c) below are met.

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) After defect elimination, the area is reexamined by the magnetic particle method in accordance with WB-2577 or the liquid penetrant method in accordance with WB-2576 to assure that the defect has been removed or reduced to an imperfection of acceptable size.

(c) If the elimination of the defect reduces the section thickness below the minimum required by the specification or drawing, the casting shall be repaired in accordance with WB-2539.

WB-2573.8 Material Report Describing Defects and Repairs.

Each defect repair exceeding in depth the lesser of $\frac{3}{4}$ in. (19 mm) or 10% of the nominal wall thickness shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart that shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographic film, when radiography is specified in the order for the original casting.

WB-2574 Ultrasonic Examination of Ferritic Steel Castings

Ultrasonic examination shall be performed in accordance with T-541.4 of Article 5 of Section V. Each manufacturer shall certify that the procedure is in accordance with the requirements of WB-2574 and shall make the procedure available for approval upon request.

WB-2574.1 Acceptance Standards

(a) The Quality Levels of SA-609 as shown in Section V shall apply for the casting thicknesses indicated:

(1) Quality Level 1 for thicknesses up to 2 in. (51 mm);

(2) Quality Level 3 for thicknesses 2 in. (51 mm) to 4 in. (102 mm);

(3) Quality Level 4 for thicknesses greater than 4 in. (102 mm).

(b) In addition to the Quality Level requirements stated in (a) above, the requirements in (1) through (5) below shall apply for both straight beam and angle beam examination.

(1) Areas giving indications exceeding the Amplitude Reference Line with any dimension longer than those specified in the following tabulation are unacceptable:

UT Quality Level	Longest Dimension of Area ⁷⁸⁹
1	1.5 in.
2	2.0 in.
3	2.5 in.
4	3.0 in.

(2) Quality Level 1 shall apply for the volume of castings within 1 in. (25 mm) of the surface regardless of the overall thickness.

(3) Discontinuities indicated to have a change in depth equal to or greater than one-half the wall thickness or 1 in. (25 mm) (whichever is less) are unacceptable.

(4) Two or more indications in the same plane with amplitudes exceeding the Amplitude Reference Line and separated by a distance less than the longest dimension of the larger of the adjacent indications are unacceptable if they cannot be encompassed within an area less than that of the Quality Level specified in (b)(1) above.

(5) Two or more indications greater than permitted for Quality Level 1 for castings less than 2 in. (51 mm) in thickness, greater than permitted for Quality Level 2 for thicknesses 2 in. (51 mm) through 4 in. (102 mm), and greater than permitted for Level 3 for thicknesses greater than 4 in. (102 mm), separated by a distance less than the longest dimension of the larger of the adjacent indications are unacceptable, if they cannot be encompassed in an area less than that of the Quality Level requirements stated in (a) above.

7 The areas for the Ultrasonic Quality Levels in SA-609 refer to the surface area on the casting over which continuous indication, exceeding the transfer corrected distance amplitude curve, is maintained.

8 Areas are to be measured from dimensions of the movement of the search unit, using the center of the search unit as the reference point.

9 In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases, other criteria which incorporate a consideration of beam angles or beam spread must be used for realistic evaluation of the discontinuity.

WB-2575 Radiographic Examination

WB-2575.1 Examination.

Cast containment system materials shall be examined by the radiographic method when specified in the order for the original castings, except that cast ferritic steels may be examined by either the radiographic or ultrasonic method, or a combination of both methods. Castings or sections of castings that have coarse grains or configurations that do not yield meaningful examination results by ultrasonic methods shall be examined by the radiographic method.

WB-2575.2 Extent.

Radiographic examination shall be performed on containment system castings such as vessel heads and flanges, valve bodies, bonnets and disks, pump casings and covers, and piping and fittings. The extent of radiographic coverage shall be of the maximum feasible volume and, when the shape of the casting precludes complete coverage, the coverage shall be at least as exemplified in the typical sketches as shown in Fig. WB-2575.2-1.

WB-2575.3 Examination Procedure.

The radiographic examination shall be performed in accordance with Article 3 of Section V, with the following modifications.

(a) *Film Selection.* Only Types 1, 2, and 3 are permitted.

(b) *Radiographic Density.* The transmitted film density through the radiographic image of the body of the appropriate penetrometer and the area of interest shall be 1.3 minimum for single film viewing. For composite viewing of multiple film exposures, each film of the composite set shall have a minimum density of 1.0. The maximum density shall be 4.0

for either single or composite viewing. A tolerance of 0.05 in density is allowed for variations between densitometer readings.

(c) The requirements of T-274 and T-285 of Article 3 of Section V need not be met.

(d) *Image Quality Indicator (IQI) Design.* Penetrators shall be manufactured and identified in accordance with the requirements or alternates allowed in SE-142 and Appendices.

(e) *Image Quality Indicator (IQI) Selection.* The radiographic quality level shall be 2-4 *T* for section thicknesses up to and including $\frac{3}{4}$ in. (19 mm) and 2-2 *T* for section thicknesses greater than $\frac{3}{4}$ in. (19 mm) Radiographic quality is defined in Note 2 of SE-94.

(f) When radiographing weld ends of cast valves, NPS 4 (DN 100) and less, double-wall radiography may be used subject to the conditions of (1) and (2) below.

(1) The penetrometer thickness shall be based on the design section thickness of the double wall, excluding the weld preparation lip.

(2) Acceptance standards shall be based on nominal single-wall thickness.

WB-2575.4 Procedure Requirements.

Radiographic examination shall be performed in accordance with a written procedure. Each manufacturer shall certify that the procedure is in accordance with the requirements of WB-2575. The procedure shall be available for the interpretation of the films and shall be submitted together with the radiographs. Each procedure shall include at least the following information:

(a) the type of material to be radiographed;

(b) the material thickness ranges to be radiographed;

(c) the type of radiation source, actual or maximum source size or focal spot, X-ray equipment voltage rating and manufacturer. The equipment manufacturer's or supplier's publications, such as technical manuals, decay curves, or written statements documenting the actual or maximum source size or focal spot, shall be acceptable as source size verification. For X-ray machines 320 kV and less, the focal spot size may be determined by the pinhole method;¹⁰

(d) type and thickness of intensifying screens and filters;

(e) minimum source-to-film distance.

WB-2575.5 Radiographic Setup Information.

To aid in proper interpretation of radiographs, details of the radiographic examination setup used shall accompany each group of radiographs. As a minimum, the information shall include:

(a) film brand and the type and number of films in the cassette;

(b) for multiple film technique, state whether viewing is to be single or superimposed;

(c) blocking or masking technique, if used;

(d) isotope or X-ray voltage used;

(e) source-to-film distance used;

(f) distance between film and object when film/cassette is not in contact with object;

(g) geometric arrangement for the radiograph(s) (sketch);

(h) orientation of location markers;

(i) description of how internal markers, when used, locate area of interest;

10 Nondestructive Testing Handbook, Volume I, First Edition, pp. 14.32, 14.33, "Measuring Focal-Spot Size." Also, pp. 20, 21 of Radiography in Modern Industry, Fourth Edition.

shall be permanently stamped on the surface of the casting being radiographed in a manner permitting the area of interest on a radiograph to be accurately located on the casting and providing evidence on the radiograph that the extent of coverage required by WB-2575.2 has been obtained. On castings or sections of castings where stamping is not feasible, the radiographic procedure shall so state, in which case a radiographic film location map shall be provided.

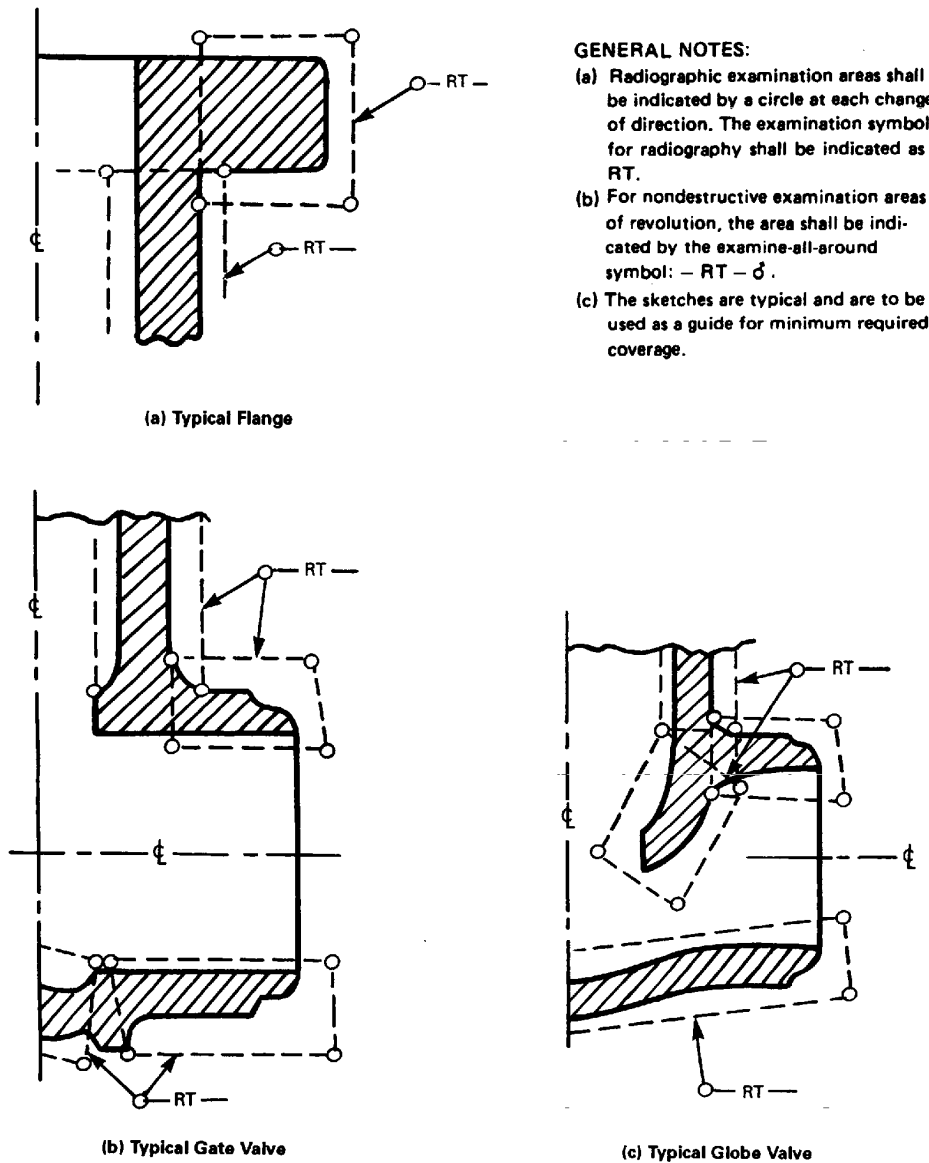


FIG. WB-2575.2-1 TYPICAL PARTS OF VALVES FOR RADIOGRAPHIC EXAMINATION

FIG. WB-2575.2-1 TYPICAL PARTS OF VALVES FOR RADIOGRAPHIC EXAMINATION

WB-2575.6 Acceptance Criteria.

Castings shall meet the acceptance requirements of Severity Level 2 of ASTM E 446-72, E 446-75, or E 446-78, Reference Radiographs for Steel Castings up to 2 in. in Thickness, ASTM E 186-67, E 186-73, or E 186-75, Reference Radiographs for Heavy-Walled (2 to 4 $\frac{1}{2}$ in.) Steel Castings, as graphed, except that Category D, E, F, or G defects are not acceptable. The requirements of ASTM E 280-68, E 280-72, or E 280-75 shall apply for castings 4 $\frac{1}{4}$ to 12 in. (108 mm to 305 mm) in thickness.

WB-2576 Liquid Penetrant Examination

(a) Castings shall be examined, if required, on all accessible surfaces by the liquid penetrant method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by bleeding out of the penetrant; however, localized surface discontinuities as may occur from machining marks, scale, or dents, may produce indications which are not relevant. Any indication in excess of the acceptance standards believed to be nonrelevant shall be regarded as a defect until it is reexamined to verify whether actual defects are present. Nonrelevant indications and broad areas of pigmentation that would mask indications of defects are unacceptable. Surface conditioning may precede the reexamination. Relevant indications are those which result from mechanical discontinuities. Linear indications are those whose length is more than three times the width. Rounded indications are those which are circular or elliptical with the length less than three times the width. Indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) are considered relevant.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) any linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for materials less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for materials from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for materials 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ (3.2 mm) in. for thicknesses less than $\frac{5}{8}$ in. (16 mm) and greater than $\frac{3}{16}$ in. (4.8 mm) for thicknesses $\frac{5}{8}$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 sq in. (3,871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

WB-2577 Magnetic Particle Examination (for Ferritic Steel Products Only)

(a) Castings of magnetic material shall be examined, if required, on all accessible surfaces by a magnetic particle method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by retention of the examination medium. All indications are not necessarily defects since certain metallurgical discontinuities and magnetic permeability variations may produce indications that are not relevant. Any indication in excess of the acceptance standards which is believed to be nonrelevant shall be regarded as a defect until it is reexamined to verify whether actual defects are present. Nonrelevant indications which would mask indications of defects are unacceptable. Surface conditioning may precede the reexamination. Relevant indications are those which result from unacceptable mechanical discontinuities and have a major dimension greater than $\frac{1}{16}$ in. (1.6 mm). Linear indications are those whose length is more than three times the width. Rounded indications are those which are circular or elliptical with the length less than three times the width.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) linear indications greater than $\frac{1}{16}$ in. (1.6 mm) long for materials less than $\frac{5}{8}$ in. (16 mm) thick, greater than $\frac{1}{8}$ in. (3.2 mm) long for materials from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$ in. (4.8 mm) long for materials 2 in. (51 mm) thick and greater;

(2) rounded indications with dimensions greater than $\frac{1}{8}$ in. (3.2 mm) long for materials from $\frac{5}{8}$ in. (16 mm) thick to under 2 in. (51 mm) thick, and $\frac{3}{16}$

Page 100

in. (4.8 mm) long for materials 2 in. (51 mm) thick and greater.

(3) four or more relevant indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 sq in. (3,871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

WB-2580 EXAMINATION OF BOLTS, STUDS, AND NUTS

WB-2581 Required Examination

All bolting material shall be visually examined in accordance with WB-2582. Nominal sizes greater than 1 in. (25 mm) shall be examined by either the magnetic particle or the liquid penetrant method. In addition, nominal sizes greater than 2 in. (51 mm) but not over 4 in. (102 mm) shall be examined by the ultrasonic method as required by WB-2585 and nominal sizes greater than 4 in. (102 mm) shall be examined by the ultrasonic method as required by WB-2586.

WB-2582 Visual Examination

The areas of threads, shanks, and heads of final machined parts shall be visually examined. Harmful discontinuities such as laps, seams, or cracks that would be detrimental to the intended service are unacceptable.

WB-2583 Magnetic Particle Examination (for Ferritic Steel Bolting Material Only)

WB-2583.1 Examination Procedure.

All bolts, studs, and nuts greater than 1 in. (25 mm) nominal bolt size shall be examined by the magnetic particle method in accordance with ASTM A 275-78. If desired, the supplier may perform liquid penetrant examination in accordance with WB-2584 instead of magnetic particle examination. Such examination shall be performed on the finished component after threading or on the materials stock at approximately the finished diameter before threading and after heading (if involved). This examination shall be performed on all accessible surfaces.

WB-2583.2 Evaluation of Indications

(a) All indications shall be evaluated in terms of the acceptance standards. Linear indications are those indications in which the length is more than three times the width. Rounded indications are those which are circular or elliptical with the length equal to or less than three times the width.

(b) All indications are not necessarily relevant: leakage of magnetic fields and permeability variations may produce indications that are not relevant to the detection of unacceptable discontinuities. Indications with major dimensions of $\frac{1}{16}$ in. (1.6 mm) or less are not relevant.

(c) Any indication that is believed to be nonrelevant, and that is larger than acceptable, shall be considered to be a defect and shall be reexamined after light surface conditioning.

(d) Any indication observed during such reexamination shall be considered relevant and shall be evaluated in terms of the acceptance standards.

(e) As an alternative to magnetic particle reexamination, other nondestructive examination means (such as liquid penetrant examination for surface discontinuities) may be used to determine relevancy.

WB-2583.3 Acceptance Standard.

Linear nonaxial indications are unacceptable. Linear axial indications greater than 1 in. (25 mm) in length are unacceptable.

WB-2584 Liquid Penetrant Examination

WB-2584.1 Examination Procedure.

All bolts, studs, and nuts greater than 1 in. (25 mm) nominal bolt size shall be examined by a liquid penetrant method in accordance with the methods of Article 6, Section V. Such examination shall be performed on the finished component after threading or on the materials stock at approximately the finished diameter before threading and after heading (if involved).

WB-2584.2 Evaluation of Indications.

All indications shall be evaluated in terms of the acceptance standards. Linear indications are those indications in which the length is more than three times the width. Rounded indications are those which are circular to elliptical with the length equal to or less than three times the width. All penetrant indications are not necessarily relevant. Surface imperfections such as machining marks and scratches may produce indications that are nonrelevant to the detection of unacceptable discontinuities. Broad areas of pigmentation, which could mask indications of defects, are unacceptable. Indications with major dimensions of $\frac{1}{16}$ in. (1.6 mm) or less are not relevant. Any indication that is believed to be nonrelevant, and that is larger than acceptable, shall be considered to be a defect and shall be reexamined after light surface conditioning. Any area of pigmentation also shall be reexamined after recleaning or light surface conditioning, as appropriate. Any indication observed during such reexamination shall be considered relevant

Page 101

and shall be evaluated in terms of the acceptance standards.

WB-2584.3 Acceptance Standard.

Linear nonaxial indications are unacceptable. Linear axial indications greater than 1 in. (25 mm) long are unacceptable.

WB-2585 Ultrasonic Examination for Sizes Greater Than 2 in. (51 mm)

All bolts, studs, and nuts greater than 2 in. (51 mm) nominal bolt size shall be ultrasonically examined over the entire surface prior to threading in accordance with the following requirements.

WB-2585.1 Ultrasonic Method.

Examination shall be carried out by the straight beam, radial-scan method in accordance with SA-388 of Article 23 of Section V.

WB-2585.2 Examination Procedure.

Examination shall be performed at a nominal frequency of 2.25 MHz with a search unit not to exceed 1 sq in. (645 mm²).

WB-2585.3 Calibration of Equipment.

Calibration sensitivity shall be established by adjustment of the instrument so that the first back reflection is 75% to 90% of full-screen height.

WB-2585.4 Acceptance Standard.

Any discontinuity that causes an indication in excess of 20% of the height of the first back reflection or any discontinuity that prevents the production of a first back reflection of 50% of the calibration amplitude is not acceptable.

WB-2586 Ultrasonic Examination for Sizes Over 4 in. (102 mm)

In addition to the requirements of WB-2585, all bolts, studs, and nuts over 4 in. (102 mm) nominal bolt size shall be ultrasonically examined over the entire end surface before or after threading in accordance with the following

requirements.

WB-2586.1 Ultrasonic Method.

Examination shall be carried out by the straight beam, longitudinal-scan method.

WB-2586.2 Examination Procedure.

Examination shall be performed at a nominal frequency of 2.25 MHz with a search unit having a circular cross section with a diameter not less than $\frac{1}{2}$ in. (13 mm) nor more than $1\frac{1}{8}$ in. (29 mm).

WB-2586.3 Calibration of Equipment.

Calibration shall be established on a test bar of the same nominal composition and diameter as the production part and a minimum of one-half of the length. A $\frac{3}{8}$ in. (10 mm) diameter by 3 in. (76 mm) deep flat-bottom hole shall be drilled in one end of the bar and plugged to full depth. A distance-amplitude curve shall be established by scanning from both ends of the test bar.

WB-2586.4 Acceptance Standard.

Any discontinuity that causes an indication in excess of that produced by the calibration hole in the reference specimen as corrected by the distance-amplitude curve is not acceptable.

WB-2587 Time of Examination

Acceptance examinations shall be performed after the final heat treatment required by the basic material specification.

WB-2588 Elimination of Surface Defects

Unacceptable surface defects on finished bolts, studs, and nuts are not permitted, and are cause for rejection.

WB-2589 Repair by Welding

Weld repairs of bolts, studs, and nuts are not permitted.

WB-2600 MATERIAL ORGANIZATION'S QUALITY SYSTEM PROGRAMS

WB-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS

(a) Except as provided in (b) below, Material Organizations shall have a Quality System Program or an Identification and Verification Program, as applicable, which meets the requirements of WA-3800.

(b) The requirements of WA-3862 and WA-3856 shall be met as required by WB-2130 and WB-2150, respectively. The other requirements of WA-3800 need not be used by Material Organizations for small products, as defined in (c) below, and for material which is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Assurance Program (WA-4000) shall include measures to provide assurance that the material is furnished in accordance with the material specification and with the applicable requirements of this Subsection.

(c) For the purpose of this paragraph, small products are defined as given in (1) through (4) below:

- (1) pipe, tube, pipe fittings, and flanges NPS 2 (DN 50) and less;
- (2) bolting material, including studs, nuts, and bolts of 1 in. (25 mm) nominal diameter and less;
- (3) bars with a nominal cross-sectional area of 1 sq in. (645 mm²) and less; and
- (4) material for valves with inlet pipe connections of NPS 2 (DN 50) and less.

WB-2700 DIMENSIONAL STANDARDS

Dimensions of standard items shall comply with the standards and specifications listed in Table WB-3132-1.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D3 WB-3000

ARTICLE WB-3000 DESIGN

Page 103

WB-3100 GENERAL DESIGN

WB-3110 LOADING CRITERIA

WB-3111 Loading Conditions

The loadings that shall be taken into account in designing a containment component include, but are not limited to, those in (a) through (g) below:

- (a) internal and external pressure;
- (b) impact loads;
- (c) weight of the component and normal contents under operating or test conditions, including additional pressure due to static and dynamic head of liquids;
- (d) superimposed loads such as other components, operating equipment, impact limiting devices, shielding, insulation, and corrosion resistant or erosion resistant linings;
- (e) transportation and handling shock and vibration loads;
- (f) reactions of attachment and supports;
- (g) temperature effects due to the contents, the external environment, and other components.

WB-3111.1 Maximum Normal Operating Pressure (MNOP).

Maximum Normal Operating Pressure is the maximum pressure that would develop in the containment system in a period of one year under normal conditions of transportation without venting.

WB-3111.2 Maximum Normal In-Plant Handling Pressure (MNIP).

Maximum Normal In-Plant Handling Pressure is the maximum pressure that would develop in the containment system under the most severe conditions of normal in-plant handling operations.

WB-3112 Operating Conditions

- (a) Containment systems of transport packaging (WA-1110) are subject to operating conditions, which are required to be considered in the design of the transport packaging in order to satisfy applicable safety criteria.
- (b) Operating conditions for transport packaging are classified as either normal operating conditions or hypothetical accident conditions. Normal operating conditions include normal conditions of transport and in-plant handling conditions.
- (c) As a consequence of specific operating conditions, containment systems are subject to pressure, temperature, and mechanical loadings.
- (d) The selection of operating conditions, and the determination of their significance to the design and operability of the

containment system, are beyond the scope of this Division. Appropriate guidance for the selection of operating conditions may be derived from safety criteria documents for transport packaging and the requirements of regulatory and enforcement authorities having jurisdiction.

WB-3113 Test Conditions

(a) Each containment system shall be subject to pressure test (WB-6000). The minimum test pressure shall not be less than either 1.5 times MNOP or 1.25 times MNIP.

(b) Other additional proof test may be specified by the Design Owner in the Design Specification.

WB-3114 Stress Limits

Stress limits associated with operating and test conditions are specified in WB-3220 and WB-3230.

WB-3120 SPECIAL CONSIDERATIONS

WB-3121 Corrosion

Design shall preclude significant corrosion, erosion, mechanical abrasion, or other material degradation.

Page 108

WB-3122 Cladding

Material metallurgically bonded to the base metal for the specific purpose of acting as a barrier to environmental attack, without a structural function, shall be referred to as cladding. No structural strength shall be attributed to the cladding. Significant loads induced by the cladding shall be considered in design of the containment component.

WB-3123 Welding

WB-3123.1 Dissimilar Welds.

In satisfying the requirements of this Subarticle, caution should be exercised in design and construction involving dissimilar metals having different coefficients of thermal expansion in order to avoid difficulties in service.

WB-3123.2 Fillet Welded Attachments.

Fillet welds conforming to Fig. WB-4427-1 may be used for attachments to components except as limited by WB-4433. Limits for primary and secondary stress intensities in the weld shall be one-half of the allowable primary and secondary stress intensities for the weaker of the materials being joined. Evaluation for cyclic loading shall be made in accordance with WB-3221.9, using a fatigue strength reduction factor of four, and shall include consideration of temperature differences between the component and the attachment, and of expansion or contraction of the component produced by internal or external pressure.

WB-3130 GENERAL DESIGN RULES

WB-3131 Scope

Design rules generally applicable to all components are provided in the following paragraphs. Specific design rules for containment components are contained in WB-3300. In case of conflict between WB-3130 and the specific design rules, the specific design rules govern.

WB-3133 Buckling and Instability

The rules applicable to evaluate the buckling and instability of containment component structural members are under development.

WB-3135 Attachments

Lugs, brackets, stiffeners, and other attachments (WB-4430) may be welded, bolted, or studded to the outside or inside of a component. The effect of attachments in producing thermal stresses, stress concentrations, and restraints on load resisting members shall be taken into account in checking for compliance with design criteria.

WB-3200 DESIGN BY ANALYSIS

WB-3210 DESIGN CRITERIA

WB-3211 Requirements for Acceptability

The requirements for the acceptability of a design by analysis are given in (a) through (d) below.

(a) The design shall be such that stress intensities will not exceed the limits described in this Subarticle and tabulated in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4.

(b) The design details shall conform to the rules given in WB-3300.

(c) For configurations where compressive stresses occur, in addition to the requirements in (a) and (b) above, the critical buckling stress shall be taken into account as specified in WB-3133.

(d) Protection against nonductile fracture shall be provided. An acceptable procedure for nonductile failure prevention is given in WB-2300.

WB-3212 Basis for Determining Stresses

The theory of failure, used in the rules of this Division for combining stresses, is the maximum shear stress theory. The maximum shear stress at a point is equal to one-half the difference between the algebraically largest and the algebraically smallest of the three principal stresses at the point.

WB-3213 Terms Relating to Stress Analysis

Terms used in this Division relating to stress analysis are defined in the following subparagraphs.

WB-3213.1 Stress Intensity.¹

Stress intensity is the equivalent intensity of combined stress. The stress intensity is defined as twice the maximum shear stress. The stress intensity is the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tensile stresses are considered positive and compressive stresses are considered negative.

¹ This definition of stress intensity is not related to the definition of stress intensity applied in the field of Fracture Mechanics.

WB-3213.2 Gross Structural Discontinuity.

Gross structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution

Page 109

through the entire wall thickness of the pressure retaining member. Gross discontinuity type stresses are those portions of the actual stress distributions that produce net bending and membrane force resultants when integrated through the wall thickness. Examples of gross structural discontinuities are head-to-shell and flange-to-shell junctions, reinforcement of openings in containment shells and heads, and junctions between shells of different diameters or thicknesses.

WB-3213.3 Local Structural Discontinuity.

Local structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through a fractional part of the wall thickness. The stress distribution associated with a local discontinuity causes only very localized types of deformation or strain and has no significant effect on the shell type discontinuity deformations.¹ Examples are small fillet radii, small attachments, and partial penetration welds.

WB-3213.4 Normal Stress.

Normal stress is the component of stress normal to the plane of reference. This is also referred to as direct stress. Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to be made up in turn of two components, one of which is uniformly distributed and equal to the average value of stress across the thickness under consideration, and the other of which varies from this average value with the location across the thickness.

WB-3213.5 Shear Stress.

Shear stress is the component of stress tangent to the plane of reference.

WB-3213.6 Membrane Stress.

Membrane stress is the component of normal stress that is uniformly distributed and equal to the average value of stress across the thickness of the section under consideration.

WB-3213.7 Bending Stress.

Bending stress is the variable component of normal stress described in WB-3213.4. The variation may or may not be linear across the thickness.

WB-3213.8 Primary Stress.

Primary stress is any normal stress or a shear stress developed by an imposed loading, which is necessary to satisfy the laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses that considerably exceed the yield strength will result in failure or, at least, in gross distortion. Primary membrane stress is divided into general and local categories. A general primary membrane stress is one that is so distributed in the structure that no redistribution of load occurs as a result of yielding. Examples of primary stresses are:

- (a) general membrane stress in a circular cylindrical or a spherical shell due to internal pressure or to distributed live loads;
- (b) bending stress in the central portion of a flat head due to pressure;
- (c) longitudinal stress due to cylinder bending in the central portion of a horizontal cylindrical shell being decelerated by forces applied at its extreme ends.

WB-3213.9 Secondary Stress.

The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions that cause the stress to occur and failure from one application of the stress is not to be expected. Examples of secondary stresses are:

- (a) general thermal stress [WB-3213.13(a)];
- (b) bending stress at a gross structural discontinuity.

WB-3213.10 Local Primary Membrane Stress.

Cases arise in which a membrane stress produced by pressure or other mechanical loading and associated with a primary or a discontinuity effect produces excessive distortion in the transfer of load to other portions of the structure. Conservatism requires that such a stress be classified as a local primary membrane stress even though it has some characteristics of a secondary stress. A stressed region may be considered local if the distance over which the membrane stress intensity exceeds $1.1S_m$ does not extend in the meridional direction more than $1.0\sqrt{Rt}$, where R is the minimum midsurface radius of curvature and t is the minimum thickness in the region considered. Regions of local primary stress intensity involving axisymmetric membrane stress distributions that exceed $1.1S$ shall not be closer in the meridional

direction than $2.5 \sqrt{Rt}$, where R is defined as $(R_1 + R_2)/2$ and t is defined as $(t_1 + t_2)^m/2$ (where t_1 and t_2 are the minimum thicknesses at each of the regions considered, and R_1 and R_2 are the minimum midsurface radii of curvature at these regions where the membrane stress intensity exceeds $1.1S_m$). Discrete regions of local primary membrane stress intensity, such as those resulting from concentrated loads acting on brackets, where the membrane stress intensity exceeds $1.1S_m$, shall be spaced so that there is no overlapping of the areas in which the membrane stress intensity exceeds $1.1S_m$.

WB-3213.11 Peak Stress.

Peak stress is that increment of stress that is additive to the primary plus secondary stresses by reason of local discontinuities or local thermal stress [WB-3213.13(b)], or localized application of dynamic load including the effects, if any, of stress concentrations. The basic characteristic of a peak stress is that it does not cause any noticeable

Page 110

distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture. A stress that is not highly localized falls into this category if it is of a type that cannot cause noticeable distortion. Examples of peak stresses are:

- (a) the thermal stress in the austenitic steel cladding of a carbon steel component;
- (b) certain thermal stresses, which may cause fatigue but not distortion;
- (c) the stress at a local structural discontinuity;
- (d) surface stresses produced by thermal shock.

WB-3213.12 Load and Displacement Controlled Stresses

(a) Load controlled stresses are the stresses resulting from application of a loading, such as internal pressure, inertial loads, or the effects of gravity, whose magnitude is not reduced as a result of displacement.

(b) Displacement control stresses are those stresses resulting from the application of a loading, such as a thermal stress, whose magnitude is reduced as a result of deformation.

WB-3213.13 Thermal Stress.

Thermal stress is a self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally should under a change in temperature. For the purpose of establishing allowable stresses, two types of thermal stress are recognized, depending on the volume or area in which distortion takes place, as described in (a) and (b) below.

(a) General thermal stress is associated with distortion of the structure in which it occurs. If a stress of this type, neglecting stress concentrations, exceeds twice the yield strength of the material, the elastic analysis may be invalid and successive thermal cycles may produce incremental distortion. Therefore this type is classified as secondary stress in Table WB-3217-1. Examples of general thermal stresses are:

- (1) stress produced by an axial temperature distribution in a cylindrical shell;
- (2) stress produced by the temperature difference between a nozzle and the shell to which it is attached;
- (3) the equivalent linear stress² produced by the radial temperature distribution in a cylindrical shell.

2 Equivalent linear stress is defined as the linear stress distribution that has the same net bending moment as the actual stress distribution.

(b) Local thermal stress is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses shall be considered only from the fatigue standpoint and are therefore classified as local stresses in Table WB-3217-1. Examples of local thermal stresses are:

- (1) the stress in a small hot spot in a vessel wall;

(2) the difference between the actual stress and the equivalent linear stress resulting from a radial temperature distribution in a cylindrical shell;

(3) the thermal stress in a cladding material that has a coefficient of expansion different from that of the base metal.

WB-3213.14 Total Stress.

Total stress is the sum of the primary, secondary, and peak stress contributions. Recognition of each of the individual contributions is essential to establishment of appropriate stress limitations.

WB-3213.15 Operational Cycle.

Operational cycle is defined as the initiation and establishment of new conditions followed by a return to the conditions that prevailed at the beginning of the cycle. The types of operating conditions that may occur are further defined in WB-3112.

WB-3213.16 Stress Cycle.

Stress cycle is a condition in which the alternating stress difference [WB-3221.9(e)] goes from an initial value through an algebraic maximum value to an algebraic minimum value and then returns to the initial value. A single operational cycle may result in one or more stress cycles. Dynamic effects shall also be considered as stress cycles.

WB-3213.17 Fatigue Strength Reduction Factor.

Fatigue strength reduction factor is a stress intensification factor that accounts for the effect of a local structural discontinuity (stress concentration) on the fatigue strength. In the absence of experimental data, the theoretical stress concentration factor may be used.

WB-3213.18 Free End Displacement.

Free end displacement consists of the relative motions that would occur between a fixed attachment and connected piping if the two members were separated and permitted to move.

WB-3213.19 Expansion Stresses.

Expansion stresses are those stresses resulting from restraint of free end displacement of the piping system.

WB-3213.20 Deformation.

Deformation of a component part is an alteration of its shape or size.

WB-3213.23 Elastic Follow-Up.

Stresses and strains induced in a subject component caused by movements, such as thermal expansions or contractions, of much larger adjacent components, such that the subject component would yield first and thereby undergo potentially

Page 111

large plastic deformations in absorbing the deformations from the adjacent larger elastic component. These stresses are not self-limiting and have the nature of primary stresses in the subject component.

WB-3213.24 Ratcheting.

Ratcheting is a progressive incremental inelastic deformation or strain that can occur in a component that is subjected to variations of mechanical stress, thermal stress, or both.

WB-3213.25 Shakedown.

Shakedown of a structure occurs if, after a few cycles of load application, ratcheting ceases. The subsequent structural response is elastic, or elastic-plastic, and progressive incremental inelastic deformation is absent. Elastic shakedown is

the case in which the subsequent response is elastic.

WB-3214 Stress Analysis

A detailed stress analysis of all major structural components shall be prepared in sufficient detail to show that each of the stress limitations of WB-3220 and WB-3230 is satisfied when the component is subjected to the loadings of WB-3110.

WB-3215 Derivation of Stress Intensities

One requirement for the acceptability of a design (WB-3210) is that the calculated stress intensities shall not exceed specified allowable limits. These limits differ depending on the stress category (primary, secondary, etc.) from which the stress intensity is derived. This paragraph describes the procedure for the calculation of the stress intensities that are subject to the specified limits. The steps in the procedure are stipulated in (a) through (e) below.

(a) At the point on the component that is being investigated, choose an orthogonal set of coordinates, such as tangential, longitudinal, and radial, and designate them by the subscripts t , l , and r . The stress components in these directions are then designated σ_t , σ_l , and σ_r for direct stresses and τ_{lt} , τ_{lr} , and τ_{rt} for shear stresses.

(b) Calculate the stress components for each type of loading to which the part will be subjected, and assign each set of stress values to one or a group of the following categories:³

(1) general primary membrane stress P_m (WB-3213.8);

(2) local primary membrane stress P_L (WB-3213.10);

3 Membrane stress intensity is derived from the stress components averaged across the thickness of the section. The averaging shall be performed at the component level in (b) or (c).

(3) primary bending stress P_b (WB-3213.7 and WB-3213.8);

(4) expansion stress P_e (WB-3213.19);

(5) secondary stress Q (WB-3213.9);

(6) peak stress F (WB-3213.11). WB-3217 provides guidance for this step.

(c) For each category, calculate the algebraic sum of the σ_t values that result from the different types of loadings and similarly for the other five stress components. Certain combinations of the categories must also be considered.

(d) Translate the stress components for the t , l , and r directions into principal stresses σ_1 , σ_2 , and σ_3 . In many pressure component calculations, the t , l , and r directions may be so chosen that the shear stress components are zero and σ_t , σ_l , and σ_r are identical to σ_1 , σ_2 , and σ_3 .

(e) Calculate the stress differences S_{12} , S_{23} , and S_{31} from the relations:

$$S_{12} = \sigma_1 - \sigma_2$$

$$S_{23} = \sigma_2 - \sigma_3$$

$$S_{31} = \sigma_3 - \sigma_1$$

The stress intensity³ S is the largest absolute value of S_{12} , S_{23} , and S_{31} .

WB-3216 Derivation of Stress Differences⁴

If the specified operation of the component does not meet the conditions of WB-3221.9(d), the ability of the component to withstand the specified cyclic service without fatigue failure shall be determined as provided in WB-3221.9(e). The determination shall be made on the basis of the stresses at a point of the component, and the allowable stress cycles shall be adequate for the specified service at every point. Only the stress differences due to cyclic service loadings, as specified in the Design Specification, need to be considered.

WB-3216.1 Constant Principal Stress Direction.

For any case in which the directions of the principal stresses at the point being considered do not change during the cycle, the steps stipulated in (a) through (c) below shall be taken to determine the alternating stress intensity.

4 The concept of stress differences discussed in WB-3216 is essential to determination of the maximum range, since algebraic signs must be retained in the computation. Note that this limitation on range is applicable to the entire history of Normal Operating Conditions, not just to the stresses resulting from each individual transient.

(a) *Principal Stresses.* Consider the values of the three principal stresses at the point versus time for the

Page 112

complete stress cycle, taking into account both the gross and local structural discontinuities and the thermal effects, which vary during the cycle. These are designated as σ_1 , σ_2 , and σ_3 for later identification.

(b) *Stress Differences.* Determine the stress differences $S_{12} = \sigma_1 - \sigma_2$, $S_{23} = \sigma_2 - \sigma_3$, and $S_{31} = \sigma_3 - \sigma_1$ versus time for the complete cycle. In what follows, the symbol S_{ij} is used to represent any one of these three stress differences.

(c) *Alternating Stress Intensity.* Determine the extremes of the range through which each stress difference S_{ij} fluctuates and find the absolute magnitude of this range for each S_{ij} . Call this magnitude S_{rij} and let $S_{alt\ ij} = 0.5S_{rij}$. The alternating stress intensity S_{alt} is the largest $S_{alt\ ij}$ value.

WB-3216.2 Varying Principal Stress Direction.

For any case in which the directions of the principal stresses at the point being considered do change during the stress cycle, it is necessary to use the more general procedure of (a) through (e) below.

(a) Consider the values of the six stress components σ_p , σ_p , σ_p , τ_{lp} , τ_{lp} , and τ_{rt} versus time for the complete stress cycle, taking into account both the gross and local structural discontinuities and the thermal effects that vary during the cycle.

(b) Choose a point in time when the conditions are one of the extremes for the cycle (either maximum or minimum, algebraically) and identify the stress components at this time by the subscript i . In most cases, it will be possible to choose at least one time during the cycle when the conditions are known to be extreme. In some cases, it may be necessary to try different points in time to find the one that results in the largest value of alternating stress intensity.

(c) Subtract each of the six stress components σ_{ip} , σ_{ip} , etc., from the corresponding stress components σ_p , σ_p , etc., at each point in time during the cycle and call the resulting components σ'_p , σ'_p , etc.

(d) At each point in time during the cycle, calculate the principal stresses σ'_1 , σ'_2 , and σ'_3 derived from the six stress components σ'_p , σ'_p , etc. Note that the directions of the principal stresses may change during the cycle but each principal stress retains its identity as it rotates.

(e) Determine the stress differences $S'_{12} = \sigma'_1 - \sigma'_2$, $S'_{23} = \sigma'_2 - \sigma'_3$, and $S'_{31} = \sigma'_3 - \sigma'_1$ versus time for the complete cycle and find the largest absolute magnitude of any stress difference at any time. The alternating stress intensity S_{alt} is one-half of this magnitude.

WB-3217 Classification of Stresses

Table WB-3217-1 provides assistance in the determination of the category to which a stress should be assigned.

WB-3220 STRESS LIMITS FOR OTHER THAN BOLTS

WB-3221 Normal Operating Condition Limits

Normal Operating Condition Limits are those sets of limits that must be satisfied for all normal operating conditions identified in the Design Specification. The design stress intensity values S_m are given by WB-3229. The limits are summarized by Fig. WB-3221-1.

WB-3221.1 General Primary Membrane Stress Intensity.

(Derived from P_m in Fig. WB-3221-1.) This stress intensity is derived from the average value across the thickness of a section of the general primary stresses (WB-3213.8) produced by normal operating condition loads, which include internal pressure and other specified mechanical loads, but excluding all bending, local secondary, and peak stresses.

Elastic follow-up stresses shall be treated as primary stresses. Averaging is to be applied to the stress components prior to determination of the stress intensity values. The allowable value of this stress intensity is S_m at the coincident Primary Service Temperature.

WB-3221.2 Local Membrane Stress Intensity.

(Derived from P_L in Fig. WB-3221-1.) This stress intensity is derived from the average value across the thickness of a section of the local primary stresses (WB-3213.10) produced by pressure and coincident mechanical loads, but excluding all thermal and peak stresses. Elastic follow-up stresses shall be treated as primary stresses. Averaging is to be applied to the stress components prior to the determination of the stress intensity values. The limits are specified in Fig. WB-3221-1.

WB-3221.3 Primary Bending Stress Intensity.

(Derived from P_b in Fig. WB-3221-1.) Component of primary stress proportional to distance from centroid of solid section. Excludes discontinuities and concentrations. Elastic follow-up stresses shall be treated as primary stresses.

WB-3221.4 Primary Membrane and Bending Stress Intensities.

The combined stresses due to primary membrane and bending stresses developed during normal operation, with limits as shown in Fig. WB-3221-1.

WB-3221.5 Secondary Stress Intensities.

(Derived from Q in Fig. WB-3221-1.) Self-equilibrating stress

Page 113

necessary to satisfy continuity of structure, occurs at structural discontinuities. It can be caused by pressure, mechanical loads, or differential thermal expansion. Excludes local stress concentrations.

WB-3221.6 Primary Plus Secondary Stress Intensity.

This stress intensity is derived from the highest value at any point across the thickness of a section of the general or local primary membrane stresses, plus primary bending stresses plus secondary stresses, produced by the specified normal operating conditions with limits as shown in Fig. WB-3221-1.

WB-3221.7 Expansion Stress Intensity.

(Not applicable to containment shells and heads; P_e in Fig. WB-3221-1.) This stress intensity is the highest value of stress, neglecting local structural discontinuities, produced at any point across the thickness of a section by the loadings that result from restraint of free end displacement with limits as shown in Fig. WB-3221-1.

WB-3221.8 Peak Stress Intensity.

(Derived from F in Fig. WB-3221-1.) These stresses include increments added to primary or secondary stress by a concentration (notch) and certain thermal stresses, which may cause fatigue but not distortion.

WB-3221.9 Analysis for Cyclic Operation

(a) *Suitability for Cyclic Condition.* The suitability of a component for specified operation loadings involving

Page 115

cyclic application of loads and thermal conditions shall be determined by the methods described herein, except that the suitability of high strength bolts shall be determined by the methods of WB-3231.1(d), and the possibility of thermal stress ratchet shall be investigated. If the specified operating loadings of the component meet all of the conditions of (d) below, no analysis for cyclic service is required, and it may be assumed that the limits on peak stress intensities, as governed by fatigue, have been satisfied by compliance with the applicable requirements for material, design, fabrication, examination, and testing of this Division. If the operating loadings do not meet all the conditions of (d) below, a fatigue analysis shall be made in accordance with (e) below or a fatigue test shall be made in accordance with

TABLE WB-3217-1 CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES
[Note (1)]TABLE WB-3217-1 (CONT'D)
CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES [Note (1)]

Vessel Part	Location	Origin of Stress	Type of Stress	Classification
Square or rectangular vessel of flat plates	Center region	Uniform pressure	Membrane Bending	P_m P_b
	Junction between flat plates	Uniform pressure	Membrane Bending	P_L P_b
	Any section across entire vessel	Lateral internal loading	Bending across full cross section	P_m
Integral attachments and nozzles	Within the limits of reinforcement defined by WB-3334	Pressure and external loads and moments (including inertial multipliers)	General membrane	P_m
			Bending (other than gross structural discontinuity stresses) averaged through nozzle thickness	P_m
	Outside the limits of reinforcement defined by WB-3334	Pressure and external axial, shear, and torsional loads other than those attributable to restrained free end displacements of attached piping	General membrane	P_m
			Local membrane	P_L
			Bending	Q
	Nozzle wall	Gross structural discontinuities	Peak	F
			Local membrane Bending Peak	P_L Q F
Cladding	Any	Differential expansion	Membrane	F
			Bending	F
Any	Any	Radial temperature distribution [Note (4)]	Equivalent linear stress [Note (5)]	Q
			Nonlinear portion or stress distribution	F
Any	Any	Any	Stress concentration (notch effect)	F

NOTES:

- (1) Q and F classification of stresses refers to other than primary service condition (Fig. WB-3221-1).
- (2) If the bending moment at the edge is required to maintain the bending stress in the middle to acceptable limits, the edge bending is classified as P_b . Otherwise, it is classified as Q .
- (3) Consideration shall also be given to the possibility of wrinkling and excessive deformation in vessels with a large diameter-thickness ratio.
- (4) Consider possibility of thermal stress ratchet.
- (5) Equivalent linear stress is defined as the linear stress distribution that has the same net bending moment as the actual stress distribution.
- (6) The special stress limits of WB-3226 shall also be met.
- (7) Components such as concentric shells attached to each other at the ends or in close radial contact may develop stresses due to temperature differences or differential expansion between dissimilar materials. Members subjected to compressive load shall be evaluated against buckling, treating the membrane stresses as P_m .
- (8) If an end connection of two concentric shells is relatively weak, the differential thermal expansion of the shells may lead to the formation of a plastic hinge in the connection and elastic follow-up could cause excessive deformation or failure (see WB-3213.23). The end connection shall be evaluated for such a condition treating the bending stresses as P_b .

TABLE WB-3217-1 (CONT'D) CLASSIFICATION OF STRESS INTENSITY IN VESSELS FOR SOME TYPICAL CASES [Note (1)]

(b) *Peak Stress Intensity.* This stress intensity is derived from the highest value at any point across the thickness of a section of the combination of all primary, secondary, and peak stresses produced by specified operating pressures and other mechanical loads, and by general and local thermal effects associated with normal operating conditions, and including the effects of gross and local structural discontinuities.

(c) *Conditions and Procedures.* The conditions and procedures of WB-3221.9 are based on a comparison of peak stresses with strain cycling fatigue data. The strain cycling fatigue data are represented by design fatigue strength curves of Figs. I-9.0. These curves show the allowable amplitude S of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles. This stress intensity amplitude is calculated on the assumption of elastic behavior and, hence, has the dimensions of stress, but does not represent a real stress when the elastic range is exceeded. The fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable stress intensity amplitude directly comparable. Where necessary, the curves have been adjusted to include the maximum effects of mean stress, which is the condition where the stress fluctuates about a mean value that is different from zero. As a consequence of this procedure, it is essential that the requirements of WB-3221.6 be satisfied at all times with transient stresses included, and that the calculated value of the alternating stress intensity be proportional to the actual strain amplitude. To evaluate the effect of alternating stresses of varying amplitudes, a linear damage relation is assumed in (e)(4) below.

(d) *Components Not Requiring Analysis for Cyclic Service.* An analysis for cyclic service is not required, and it may be assumed that the limits on peak stress intensities, as governed by fatigue, have been satisfied for a component by compliance with the applicable requirements for material, design, fabrication, examination, and testing of this Division, provided the specified operating loading of the component, or portion thereof, meets all the conditions stipulated in (1) through (6) below.

(1) *Atmospheric to Operating Pressure Cycle.* The specified number of times (including startup and shutdown) that the pressure will be cycled from atmospheric pressure to service pressure and back to atmospheric pressure during normal operating does not exceed the number of cycles on the applicable fatigue curve of Figs. I-9.0 corresponding to an S_a value of three times the S_m value for the material at service temperature.

(2) *Normal Operating Pressure Fluctuation.* The specified full range of pressure fluctuations during normal operating does not exceed the quantity $\frac{1}{3} \times \text{maximum normal operating pressure} \times (S_a/S_m)$, where S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant pressure fluctuations and S_m is the allowable stress intensity for the material at service temperature. If the total specified number of significant pressure fluctuations exceeds the maximum number of cycles defined on the applicable design fatigue curve, the S_a value corresponding to the curve may be used. Significant pressure fluctuations are those for which the total excursion exceeds one-third of the Maximum Normal Operating or In-Plant Handling Pressure multiplied by (S/S_m) where S is defined as follows:

(a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

⁵ As an exception to the use of strain controlled test data, Fig. I-9.2.2 of Section III, Curves B and C are based on load controlled fatigue data.

(3) *Temperature Difference - Startup and Shutdown.* The temperature difference, °F, between any two adjacent points ⁵ of the component during normal operation does not exceed $S_a/2E\alpha$, where S_a is the value obtained from the applicable design fatigue curves for the specified number of startup-shutdown cycles, α is the value of the instantaneous coefficient of thermal expansion at the mean value of the temperatures at

the two points as given by Section II, Part D, Subpart 2, Table TE, and Table E is taken from Section II, Part D, Subpart 2, Table TM at the mean value of the temperature at the two points.

(4) *Temperature Difference - Normal Operating Condition.* The temperature difference, °F, between any two adjacent points does not change during normal operation by more than the quantity $S_d/2E\alpha$, where S_d is the value obtained from the applicable design fatigue curve of Figs. I-9.0 for the total specified number of significant temperature difference fluctuations. A temperature difference fluctuation shall be considered to be significant if its total algebraic range exceeds the quantity $S/2E\alpha$, where S is defined as follows:

(a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_d obtained from the applicable design fatigue curve for 10^6 cycles.

(b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_d obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(5) *Temperature Difference - Dissimilar Materials.* For components fabricated from materials of differing moduli of elasticity or coefficients of thermal expansion, the total algebraic range of temperature fluctuation, °F, experienced by the component during normal operation does not exceed the magnitude $S_d/2(E_1\alpha_1 - E_2\alpha_2)$, where S_d is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature fluctuations, E_1 and E_2 are the moduli of elasticity (Section II, Part D, Subpart 2, Table TM), and α_1 and α_2 are the values of the instantaneous coefficients of thermal expansion (Section II, Part D, Subpart 2, Table TE) at the mean temperature value involved for the two materials of construction. A temperature fluctuation shall be considered to be significant if its total excursion exceeds the quantity $S/2(E_1\alpha_1 - E_2\alpha_2)$, where S is defined as follows:

(a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_d obtained from the applicable design fatigue curve for 10^6 cycles.

(b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_d obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve. If the two materials used have different applicable design fatigue curves, the lower value of S_d shall be used in applying the rules of this paragraph.

(6) *Mechanical Loads.* The specified full range of mechanical loads, excluding pressure but including support reactions and assembly/disassembly loads, does not result in load stresses whose range exceeds the S_d value obtained from the applicable design fatigue curve of Section III, Figs. I-9.0 for the total specified number of significant load fluctuations. If the total specified number of significant load fluctuations exceeds the maximum number of cycles defined on the applicable design fatigue curve, the S_d value corresponding to the maximum number of cycles defined on the curve may be used. A load fluctuation shall be considered to be significant if the total excursion of load stress exceeds the quantity S , where S is defined as follows:

(a) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_d obtained from the applicable design fatigue curve for 10^6 cycles.

(b) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_d obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(e) *Procedure for Analysis for Cyclic Loading.* If the specified Normal Operating Loadings for the component do not meet the conditions of WB-3221.9(d), the ability of the component to withstand the specified cyclic service without fatigue failure shall be determined as provided in this subsubparagraph. The determination shall be made on the basis of the stresses at a point, and the allowable stress cycles shall be adequate for the specified Normal Operating Loadings at every point. Only the stress differences due to service cycles as specified in the Design Specifications need be considered. Compliance with these requirements means only that the component is suitable from the standpoint of possible fatigue failure; complete suitability for the specified Normal Operating Loadings is also dependent on meeting the general stress limits of WB-3222 and any applicable special stress limits of WB-3226.

(1) *Stress Differences.* For each condition of normal operation, determine the stress differences and the alternating stress intensity S_a in accordance with WB-3216.

(2) *Local Structural Discontinuities.* These effects shall be evaluated for all conditions using stress concentration factors determined from theoretical, experimental, or photoelastic studies, or numerical stress analysis techniques. Experimentally determined fatigue strength reduction factors may be used when determined in accordance with the

procedures of Section III, II-1600, except for high strength alloy steel bolting for which the requirements of WB-3231.1(d) shall apply when using the design fatigue curve of Fig. I-9.4. Except for the case of crack-like defects, no fatigue strength reduction factor greater than five need be used.

(3) *Design Fatigue Curves.* Figs. I-9.0 contain the applicable fatigue design curves for the materials permitted by this Division. When more than one curve is presented for a given material, the applicability of

Page 117

each is identified. Where curves for various strength levels of a material are given, linear interpolation may be used for intermediate strength levels of these materials. The strength level is the specified minimum room temperature value. The design fatigue curves of Section III, Figs. I-9.0 are defined over a cyclic range of 10 to 10^6 cycles, except that for austenitic steels, nickel-chromium-iron alloys, and nickel-iron-chromium alloys, nickel-chromium-molybdenum-iron alloys, and nickel-copper alloys, the design fatigue curve is extended to 10^{11} cycles in Section III, Figs. I-9.2.2 and I-9.5. Criteria for the use of the latter curve are given in Section III, Fig. I-9.2.2 and are also presented graphically by the flow chart given in Section III, Fig. I-9.2.3.

(4) *Effect of Elastic Modulus.* Multiply S_{alt} (as determined in WB-3216.1 or WB-3216.2) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve of Figs. I-9.0 at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the service cycle being considered is the only one which produces significant fluctuating stresses, this is the allowable number of cycles.

(5) *Cumulative Damage.* If there are two or more types of stress cycle that produce significant stresses, their cumulative effect shall be evaluated as stipulated in Steps 1 through 6 below.

Step 1: Designate the specified number of times each type of stress cycle of types 1, 2, 3, . . . , n , will be repeated during the life of the component as $n_1, n_2, n_3, \dots, n_n$ respectively.

NOTE: In determining $n_1, n_2, n_3, \dots, n_n$, consideration shall be given to the superposition of cycles of various origins that produce a total stress difference range greater than the stress difference ranges of the individual cycles. For example, if one type of stress cycle produces 1000 cycles of a stress difference variation from zero to 1000 cycles of a stress difference variation from zero to +60,000 psi and another type of stress cycle produces 10,000 cycles of a stress difference variation from zero to -50,000 psi, the two types of cycle to be considered are defined by the following parameters:

(a) for type 1 cycle, $n_1 = 1000$ and $S_{alt 1} = (60,000 + 50,000)/2 = 55,000$ psi;

(b) for type 2 cycle, $n_2 = 9000$ and $S_{alt 2} = (50,000 + 0)/2 = 25,000$ psi.

Step 2: For each type of stress cycle, determine the alternating stress intensity S_{alt} by the procedures of WB-3216.1 or WB-3216.2 above. Call these quantities $S_{alt 1}, S_{alt 2}, S_{alt 3}, \dots, S_{alt n}$.

Step 3: For each value $S_{alt 1}, S_{alt 2}, S_{alt 3}, \dots, S_{alt n}$, use the applicable design fatigue curve to determine the maximum number of repetitions that would be allowable if this type of cycle were the only one acting. Call these values $N_1, N_2, N_3, \dots, N_n$.

Step 4: For each type of stress cycle, calculate the usage factors $U_1, U_2, U_3, \dots, U_n$ from $U_1 = n_1/N_1, U_2 = n_2/N_2, U_3 = n_3/N_3, \dots, U_n = n_n/N_n$.

Step 5: Calculate the cumulative usage factor U from $U = U_1 + U_2 + U_3 + \dots + U_n$.

Step 6: The cumulative usage factor U shall not exceed 1.0.

WB-3221.10 Deformation Limits.

Any deformation limits prescribed by the Design Specifications, such as those intended to limit leakage, shall be satisfied.

WB-3224 Hypothetical Accident Condition Limits

Hypothetical accident condition limits are those sets of limits that must be satisfied for all hypothetical accident

conditions identified in the Design Specification. The stress limits that must be satisfied for accident loads are summarized by Fig. WB-3224-1.

WB-3225 Testing Limits

The evaluation of pressure test loadings [WB-3113(a)] shall be in accordance with (a) through (c) below, except that these rules do not apply to the relief valves.

(a) The containment system shall be subjected to an internal pressure test. The primary stress produced in the containment system during the test shall not exceed 90% of the tabulated yield strength S_y at test temperature.

(b) Additional tests may be specified in the Design Specification. Stresses produced in the containment systems by such a test shall not exceed the limits specified for normal operating conditions (Fig. WB-3221-1).

(c) Tests, with the exception of either the first 10 hydrostatic tests in accordance with WB-6220, the first 10 pneumatic tests in accordance with WB-6320, or any combination of 10 such tests, shall be considered in the fatigue evaluation of the component. In this fatigue evaluation, the limits on the primary plus secondary stress intensity range (WB-3221.6) may be taken as the larger of $3S'_m$ or $2S'_y$ when at least one extreme of the stress intensity range is determined by the Test Loadings.

WB-3226 Special Stress Limits

The following deviations from the basic stress limits are provided to cover special Normal Operating Loadings

Page 118

or configurations. Some of these deviations are more restrictive, and some are less restrictive, than the basic stress limits. In cases of conflict between these requirements and the basic stress limits, the rules of WB-3226 take precedence for the particular situations to which they apply.

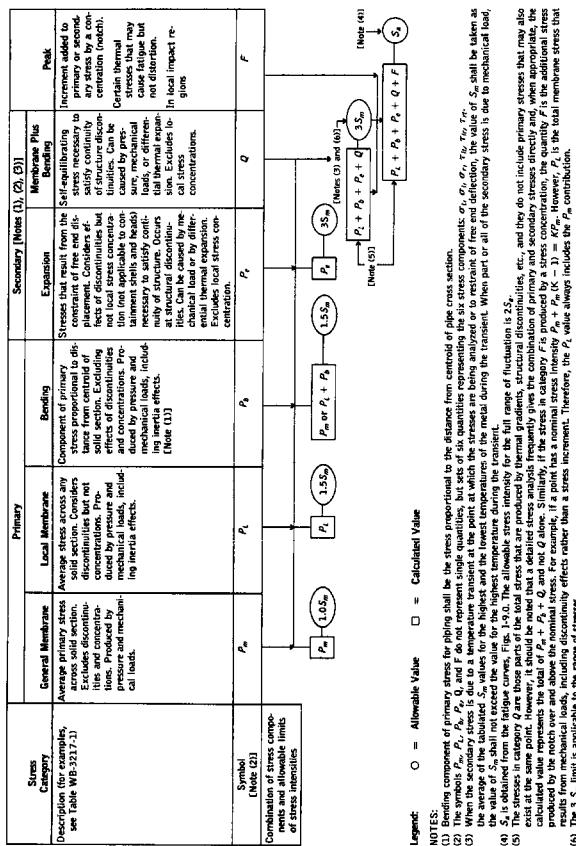
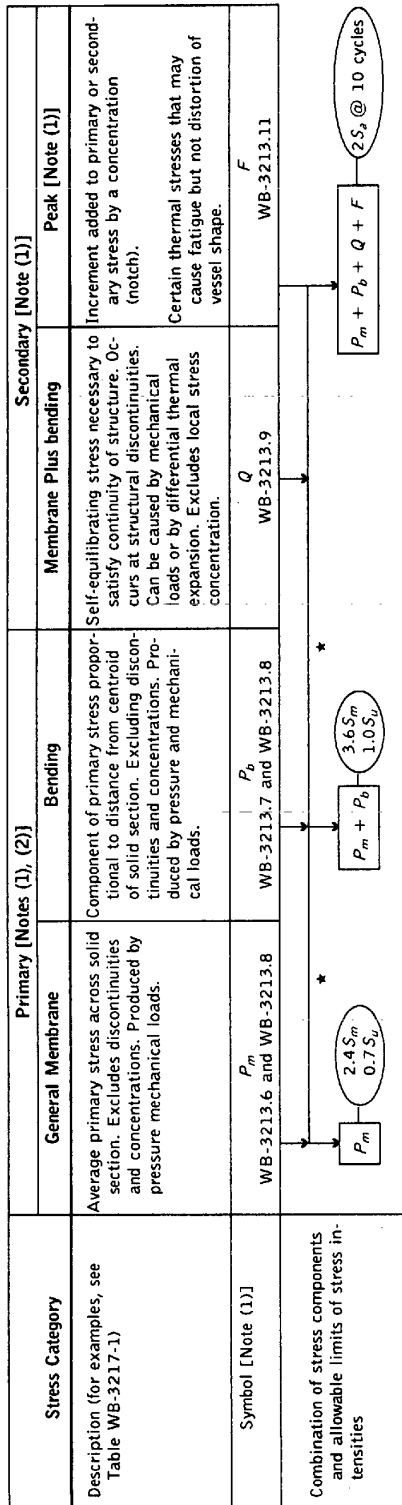


FIG. WB-3221-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR NORMAL OPERATING CONDITIONS

FIG. WB-3221-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR NORMAL OPERATING CONDITIONS



Legend: ○ = Allowable Value □ = Calculated Value

NOTES:

- (1) The symbols P_m , P_b , Q , and F do not represent single quantities, but sets of six quantities representing the six stress components: σ_1 , σ_2 , σ_3 , τ_{12} , τ_{13} , τ_{23} .
(2) For configurations where compressive stresses occur, the stress limits shall be revised to take into account critical buckling stresses [WB-3211(c)].

* Use the lesser of the values specified.

FIG. WB-3224-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR HYPOTHETICAL ACCIDENT CONDITION

FIG. WB-3224-1 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY FOR HYPOTHETICAL ACCIDENT CONDITION

WB-3226.1 Bearing Loads

(a) The average bearing stress for resistance to crushing under the maximum load, experienced as a result of Test Loadings, or any Normal Operating Loadings, except those for which Hypothetical Accident Condition limits are designated, shall be limited to S_y at temperature, except that when the distance to a free edge is larger than the distance over which the bearing load is applied, a stress of $1.5S_y$ at temperature is permitted. For clad surfaces, the yield strength of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.

(b) When bearing loads are applied near free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. In the case of load stress only (WB-3213.12), the average shear stress shall be limited to $0.6S_m$. In the case of load stress plus secondary stress (WB-3213.10), the average shear stress shall not exceed (1) or (2) below:

(1) for materials to which Note (2) of Section II, Part D, Subpart 1, Tables 2A and 2B applies, the lower of $0.5S_y$ at 100°F (38°C) and $0.675S_y$ at temperature;

(2) for all other materials, $0.5S_y$ at temperature.

For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

(c) When considering bearing stresses in pins and similar members, the S_y at temperature value is applicable, except that a value of $1.5S_y$ may be used if no credit is given to bearing area within one pin diameter from a plate edge.

WB-3226.2 Pure Shear

(a) The average primary shear stress across a section loaded in pure shear, experienced as a result of Test Loadings, or any Normal Operating Condition, except those for which Hypothetical Accident Condition limits are designated (for example, keys, shear rings, screw threads), shall be limited to $0.6S_m$.

(b) The maximum primary shear that is experienced as a result of Test Loadings, or any Normal Operating Condition (except those for which Hypothetical Accident Condition limits are designated), exclusive of stress concentration, at the periphery of a solid circular section in torsion shall be limited to $0.8S_m$. Primary plus secondary and peak shear stresses shall be converted to stress intensities (equal to two times the pure shear stress) and as such shall not exceed the basic stress limits of WB-3221.6 and WB-3221.9.

WB-3226.3 Progressive Distortion of Nonintegral Connections.

Screwed on caps, screwed in plugs, shear ring closures, and breech lock closures are examples of nonintegral connections that are subject to failure by bell mouthing or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore, primary plus secondary stress intensities (WB-3221.6), which result in slippage between the parts of a nonintegral connection in which disengagement could occur as a result of progressive distortion, shall be limited to the value S_y (Section II, Part D, Subpart 2, Table Y-1).

WB-3226.4 Triaxial Stresses.

The algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) shall not exceed four times the tabulated value of S_m except for Hypothetical Accident Condition.

WB-3226.5 Applications of Elastic Analysis for Stresses Beyond the Yield Strength.

Certain of the allowable stresses permitted in the design criteria are such that the maximum stress calculated on an elastic basis may exceed the yield strength of the material. The limit on primary plus secondary stress intensity of $3S_m$ (WB-3221.6) has been placed at a level that ensures shakedown to elastic action after a few repetitions of the stress cycle, except in regions containing significant local structural discontinuities or local thermal stresses. These last two factors are considered only in the performance of a fatigue evaluation. Therefore:

(a) In evaluating stresses for comparison with the stress limits on other than fatigue allowables, stresses shall be calculated on an elastic basis.

(b) In evaluating stresses for comparison with fatigue allowables, all stresses except those that result from local

Page 121

thermal stresses [WB-3213.13(b)] shall be evaluated on an elastic basis. In evaluating local thermal stresses, the elastic equations shall be used, except that the numerical value substituted for Poisson's ratio shall be determined from the expression:

$$\nu = 0.5 - 0.2 (S_y/S_a), \text{ but not less than } 0.3$$

where

S_a

= value obtained from the applicable design fatigue curve (Figs. I-9.0) for the specified number of cycles of the condition being considered

S_y

= yield strength of the material at the mean value of the temperature of the cycle

[98]

WB-3227 Applications of Inelastic Analysis Procedures

Inelastic design rules are in preparation.

[98]

WB-3229 Design Stress Values

The design stress intensity values S_m are given in Section II, Part D, Subpart 1, Tables 2A and 2B for component materials. Values for intermediate temperatures may be found by interpolation. These form the basis for the various stress limits. Values of yield strength are given in Section II, Part D, Subpart 2, Table Y-1. Values of the coefficient of thermal expansion are in Section II, Part D, Subpart 2, Table TE, and values of the modulus of elasticity are in Section II, Part D, Subpart 2, Table TM. The basis for establishing stress values is given in Section III, Appendix III. The design fatigue curves used in conjunction with WB-3221.9 are those of Section III, Figs. I-9.0.

WB-3230 STRESS LIMITS FOR BOLTS

WB-3231 Design Conditions

(a) The number and cross-sectional area of bolts required to resist the Operating Condition loads shall be determined by analysis.

(b) When gaskets are used for pressure testing only, the design is satisfactory when the gasket factor m and the minimum design seating stress y are taken as zero.

(c) The membrane and bending stresses in the bolt produced by thermal expansion due to differences in the temperature or thermal expansion coefficients, shall be treated as primary stresses in bolting analysis.

(d) The bolting analysis shall consider "prying effects," which cause the bolts to be loaded due to rotation of the closure plate.

[98]

WB-3231.1 Normal Operating Condition Limits

(a) *Average Stress.* The membrane stress intensity averaged across the bolt cross section and neglecting stress concentrations, shall not exceed two times the stress values of Section II, Part D, Subpart 1, Table 4. In addition, the stress due to internal pressure and gasket seating shall not exceed one times the tabulated values.

(b) *Shear Stress.* The average bolt shear stress expressed in terms of available shear stress area shall not exceed $0.4S_y$.

(c) *Maximum Stress.* The maximum value of stress intensity, except as restricted by WB-3231.1(d), at the periphery of the bolt cross section resulting from direct tension plus bending and neglecting stress concentrations, shall not exceed three times the stress values of Section II, Part D, Subpart 1, Table 4.

(d) *Fatigue Analysis of Bolts.* The suitability of bolts for cyclic service shall be determined in accordance with the procedures of (1) and (2) below.

(1) *Bolting Having Less Than 100.0 ksi (689 MPa) Tensile Strength.* Bolts made of material that has specified minimum tensile strength of less than 100.0 ksi (689 MPa) shall be evaluated for cyclic service by the methods of WB-3221.9, using the applicable design fatigue curve of Section III, Figs. I-9.0 and appropriate fatigue strength reduction factor WB-3213.17.

(2) *High Strength Alloy Steel Bolting.* High strength alloy steel bolts and studs may be evaluated for cyclic service by the methods of WB-3221.9(e) using design fatigue curve of Section III, Fig. I-9.4 provided:

(a) the maximum value of the stress intensity [WB-3231.1(c)] at the periphery of the bolt cross section, neglecting stress concentration, shall not exceed $2.7S_m$ if the higher of the two fatigue design curves given in Section III, Fig. I-9.4 is used. The $2S_m$ limit for direct tension is unchanged.

(b) threads shall be of a Vee-type having a minimum thread root radius no smaller than 0.003 in. (0.08 mm);

(c) fillet radii at the end of the shank shall be such that the ratio of fillet radius to shank diameter is not less than 0.060.

(d) *Fatigue Strength Reduction Factor* (WB-3213.17). Unless it can be shown by analysis or tests that allowed value is appropriate, the fatigue strength reduction factor used in the fatigue evaluation of threaded members shall not be less than 4.0. However,

Page 122

when applying the rules of (b) above for high strength alloy steel bolts, the value used shall not be less than 4.0.

(e) *Effect of Elastic Modulus.* Multiply S_{alt} (as determined in WB-3216.2) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the service cycle being considered is the only one that produces significant fluctuating stresses, this is the allowable number of cycles.

(f) *Cumulative Damage.* The bolts shall be acceptable for the specified cyclic application of loads and thermal stresses provided the cumulative usage factor U , as determined in WB-3221.9(e)(5), does not exceed 1.0.

[98]

WB-3231.2 Hypothetical Accident Condition Limits

(a) *Average Stress.* The membrane stress intensity averaged across the bolt cross section and neglecting stress concentrations, shall not exceed the lesser of three times the stress values of Section II, Part D, Subpart 1, Table 4 or $0.7S_m$.

(b) *Shear Stress.* The average bolt shear stress expressed in terms of available shear stress area shall not exceed the smaller of $0.42S_m$ and $0.6S_y$.

(c) *Maximum Stress.* The maximum value of stress intensity at the periphery of the bolt cross section resulting from

direct tension plus bending and neglecting stress concentrations shall not exceed three times the stress values of Section II, Part D, Subpart 1, Table 4.

(d) *Design Stress Intensity Values.* The design stress intensity values S_m are given in Section II, Part D, Subpart 1, Table 4 for bolting. Values for intermediate temperature may be found by interpolation. The basis for establishing stress intensity values is given in Section III, Appendix III.

WB-3300 CONTAINMENT VESSEL

WB-3310 GENERAL REQUIREMENTS

WB-3311 Acceptability

The requirements for acceptability of a containment vessel design are as follows.

(a) The design shall be such that the requirements of WB-3100 and WB-3200 shall be satisfied.

(b) The rules of this Subarticle shall be met. In cases of conflict between WB-3200 and WB-3300 the requirements of WB-3300 shall govern.

WB-3320 DESIGN CONSIDERATIONS

WB-3321 Normal and Hypothetical Accident Conditions

The provisions of WB-3110 apply.

WB-3322 Special Considerations

The provisions of WB-3120 apply.

WB-3323 General Design Rules

The provisions of WB-3130 apply, except when they conflict with rules of this Subarticle. In case of conflict, this Subarticle governs in the design of containment vessels.

WB-3324 Design for Local Puncture Associated With a Hypothetical Accident Condition

Regions of the containment vessel that are subject to direct impingement by the puncture bar shall be suitably designed to prevent puncture of the vessel. The allowable stress limits specified in WB-3200 do not apply in the local vicinity of direct impingement on the containment vessel shell [i.e., within the smaller distance of one and a half (1.5) diameter of the puncture bar or two times the thickness of the containment vessel shell measured from the edge of the puncture bar].

In lieu of analysis, for a 6-inch-diameter puncture bar and a 40-inch-drop, lead-shielded, multiple-layered steel containment vessel, the outer shell thickness shall not be less than:

$$(t_{req}) = (a W/S_u)^{0.71}$$

where:

W	= total weight of loaded vessel, lbs
S_u	= ultimate tensile strength of the outer shell at temperature, psi
t_{req}	= minimum outer shell thickness, in.
a	= 1.3 for vessels less than 30 in. (762 mm) in diameter; 1.0 for vessels equal to or larger than 30 in. (762 mm) in diameter

Requirements for wall thickness for other than a lead-shielded, multiple-layered steel containment vessel, in lieu of

WB-3330 OPENINGS AND REINFORCEMENT

WB-3331 General Requirements for Openings

(a) For containment vessels or parts thereof that meet the requirements of WB-3221.9(d), analysis showing satisfaction of the requirements of WB-3221.1, WB-3221.3, WB-3221.6, and WB-3221.6 in the immediate vicinity of the openings is not required for pressure loading if the rules of WB-3330 are met.

(b) For containment vessels or parts thereof that do not meet the requirements of WB-3221.9(d) so that a fatigue analysis is required, the rules contained in WB-3330 ensure satisfaction of the requirements of WB-3221.1, WB-3221.3, and WB-3221.6 in the vicinity of openings, and no specific analysis showing satisfaction of those stress limits is required for pressure loading. The requirements of WB-3221.6 may also be considered to be satisfied if, in the vicinity of an integral attachment to or a protrusion from the containment vessel, the stress intensity resulting from external nozzle loads and thermal effects, including gross but not local structural discontinuities, is shown by analysis to be less than $1.5S_m$.

(c) The provisions of (a) and (b) above are not intended to restrict the design to any specified section thicknesses or other design details, provided the basic stress limits are satisfied. If it is shown by analysis that all the stress requirements have been met, the rules of WB-3330 are waived.

(d) Openings shall be circular, elliptical, or of any other shape that results from the intersection of a circular or elliptical cylinder with a containment vessel of the shapes permitted by this Division. If fatigue analysis is not required, the restrictions on hole spacing are applicable unless there will be essentially no reaction loads at those locations.

(e) All references to dimensions apply to the finished dimensions excluding material added as corrosion allowance. Rules regarding metal available for reinforcement are given in WB-3335.

(f) Any type of opening permitted in these rules may be located in a welded joint.

WB-3332 Reinforcement Requirements for Openings in Shells and Formed Heads

WB-3332.1 Openings Not Requiring Reinforcement.

The rules for openings not requiring reinforcement are given in (a) through (c) below, where R is the mean radius and t is the nominal thickness of the vessel shell or head at the location of the opening; and *locally stressed area* means any area in the containment boundary where the primary local membrane stress exceeds $1.1S_m$ but excluding those areas where such primary local membrane stress is due to an unreinforced opening.

(a) A single opening has a diameter not exceeding $0.2\sqrt{Rt}$, or if there are two or more openings within any circle of diameter $2.5\sqrt{Rt}$, but the sum of the diameters of such unreinforced openings shall not exceed $0.25\sqrt{Rt}$.

(b) No two unreinforced openings shall have their centers closer to each other, measured on the inside of the containment vessel wall, than 1.5 times the sum of their diameters.

(c) No unreinforced opening shall have its center closer than $2.5\sqrt{Rt}$ to the edge of a locally stressed area in the containment boundary.

WB-3332.2 Required Area of Reinforcement.

The total cross-sectional area of reinforcement A , required in any given plane for a containment vessel under internal pressure, shall not be less than:

$$A = dt_r F$$

where

d

= finished diameter of a circular opening or finished dimension (chord length) of an opening on the plane being

considered for elliptical and oblong openings in corroded condition, in.

F

= a correction factor that compensates for the variation in pressure stresses on different planes with respect to the axis of a containment vessel (a value of 1.00 shall be used for all configurations, except that Fig. WB-3332.2-1 may be used for integrally reinforced openings in cylindrical shells and cones)

t_r

= the thickness that meets the requirements of WB-3221.1 in the absence of the opening, in.

Not less than half the required material shall be on each side of the center line.

WB-3333 Reinforcement Required for Openings in Flat Heads

Flat heads that have an opening with a diameter that does not exceed one-half the head diameter shall have a total cross-sectional area of reinforcement not less than that given by the formula:

$$A = 0.5dt_r$$

where d is as defined in WB-3332 and t_r is the thickness,

Page 124

in., which meets the requirements of WB-3221.1 and WB-3221.3 in the absence of the opening.

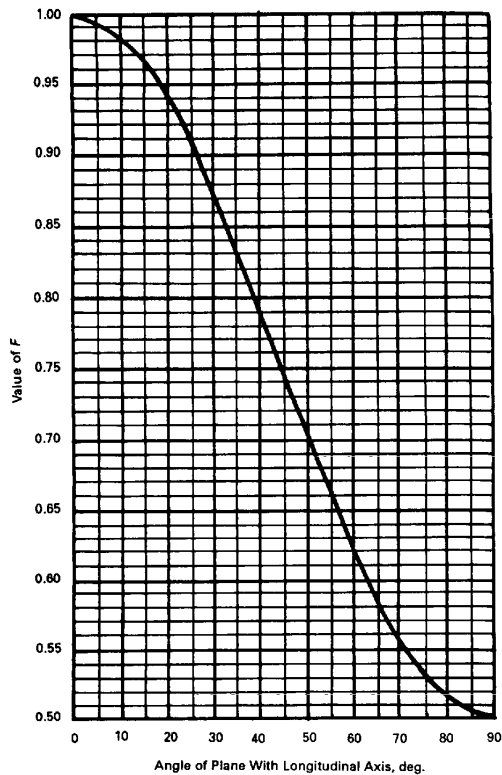


FIG. WB-3332.2-1 CHART FOR DETERMINING
VALUE OF F

FIG. WB-3332.2-1 CHART FOR DETERMINING VALUE OF F

WB-3334 Limits of Reinforcement

The boundaries of the cross-sectional area in any plane normal to the containment vessel wall and passing through the center of the opening and within which metal shall be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane and are given in the following subparagraphs.

WB-3334.1 Limit of Reinforcement Along the Containment Vessel Wall.

The limits of reinforcement, measured along the midsurface of the nominal wall thickness, shall meet the following.

(a) One hundred percent of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) the diameter of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus the sum of the thicknesses of the containment vessel wall and the nozzle wall of any integral attachment or protrusion.

(b) Two-thirds of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) $r + 0.5\sqrt{Rt}$, where R is the mean radius of shell or head, t is the nominal containment vessel wall thickness, and r is the radius of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus two-thirds the sum of the thicknesses of the containment vessel wall and the wall of any integral attachment or protrusion.

WB-3335 Metal Available for Reinforcement

Metal may be counted as contributing to the area of reinforcing called for in WB-3332, provided it lies within the limits of reinforcement specified in WB-3334, and shall be limited to material that meets the following requirements:

(a) metal forming a part of the containment vessel wall, which is in excess of that required on the basis of membrane stress intensity (WB-3221.1) and is exclusive of corrosion allowance;

(b) similar excess metal in the wall of any integral attachment or protrusion, provided the item is integral with the containment vessel wall or is joined to it by a full penetration weld;

(c) weld metal that is fully continuous with the containment vessel weld;

(d) the mean coefficient of thermal expansion of metal to be included as reinforcement under (b) and (c) above shall be within 15% of the value of the containment vessel wall material;

(e) metal not fully continuous with the shell, such as that in items attached by partial penetration welds, shall not be counted as reinforcement;

(f) metal available for reinforcement shall not be considered as applying to more than one opening.

WB-3336 Strength of Reinforcing Material

Material used for reinforcement shall preferably be the same as that of the containment vessel wall. If the

Page 125

material of the wall of any integral attachment, protrusion, or reinforcement has a lower design stress intensity value S_m than that for the containment vessel material, the amount of area provided by the attachment wall protrusion or reinforcement in satisfying the requirements of WB-3332 shall be taken as the actual area provided multiplied by the ratio of the attachment wall protrusion or reinforcement design stress intensity value to the containment vessel material design stress intensity value. No reduction in the reinforcing required may be taken for the increased strength of reinforcing material or for weld metal having higher design stress intensity values than that of the material of the vessel wall. The

strength of the material at the point under consideration shall be used in fatigue analyses.

WB-3337 Attachment of Nozzles and Other Connections

WB-3337.1 General Requirements.

Category D connections (WB-3351) shall be attached to the shell or head of the containment boundary by one of the methods provided in WB-3342.

WB-3337.2 Full Penetration Welds.

Full penetration welds, as shown in Figs. WB-4244(a)-1, WB-4244(b)-1, WB-4244(c)-1, and WB-4244(e)-1, may be used (except as otherwise provided in WB-3337.3) for the purpose of achieving continuity of metal and facilitating the required radiographic examination. When all or part of the required reinforcement is attributable to the connecting item, the connecting items shall be attached by full penetration welds through either the containment shell or head, the thickness of the connecting item, or both.

WB-3337.3 Partial Penetration Welds

(a) Partial penetration welds, as shown in Figs. WB-4244(d)-1 and WB-4244(d)-2, are allowed only for connecting items on which there are substantially no reaction loads, such as openings for instrumentation. For such connecting items, all reinforcement shall be integral with the portion of the containment boundary penetrated. Partial penetration welds shall be of sufficient size to develop the full strength of the connecting items. Connecting items attached by partial penetration welds shall have an interference fit or a maximum diametral clearance between the item and the containment boundary penetration of:

(1) 0.010 in. for $d \leq 1$ in.

(2) 0.020 in. for $1 \text{ in.} < d \leq 4$ in.

(3) 0.030 in. for $d > 4$ in.

where d is the outside diameter of the item, except that the above limits on maximum clearance need not be met for the full length of the opening, provided there is a region at the weld preparation and a region near the end of the opening opposite the weld that does meet the above limits on maximum clearance, and the latter region is extensive enough (not necessarily continuous) to provide a positive stop for deflection of the connecting item.

(b) In satisfying the limit of WB-3221.6, the stress intensities resulting from pressure induced strains (dilation of hole) may be treated as secondary in the penetrating part of partial penetration welded construction, provided the requirements of WB-3342.4(d) and Fig. WB-4244(d)-1 are fulfilled.

WB-3340 DESIGN OF WELDED CONSTRUCTION

WB-3341 Welded Joint Category

The term *Category* defines the location of a joint in a containment vessel, but not the type of joint. The categories established are for use in specifying special requirements regarding joint type and degree of examination for certain welded joints. Since these special requirements, which are based on service, material, and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in the categories. The special requirements apply to joints of a given category only when specifically stated. The joints included in each category are designated as joints of Categories A, B, C, and D. Fig. WB-3341-1 illustrates typical joint locations included in each category.

WB-3341.1 Category A.

Category A comprises longitudinal welded joints within the main containment shell, transitions in diameter, any welded joint within a sphere, within a formed or flat head, or within the side plates⁶ of a flat sided containment vessel; and circumferential welded joints connecting hemispherical heads to main containment shells, or transitions in

diameters.

6 Side plates of a flat sided vessel are defined as any of the flat plates forming an integral part of the pressure retaining enclosure.

WB-3341.2 Category B.

Category B comprises circumferential welded joints within the main containment shell or transitions in diameter, including joints between the transition and a cylinder at either the large or small end; and circumferential welded joints connecting

Page 126

formed heads other than hemispherical to main shells, or to transitions in diameter.

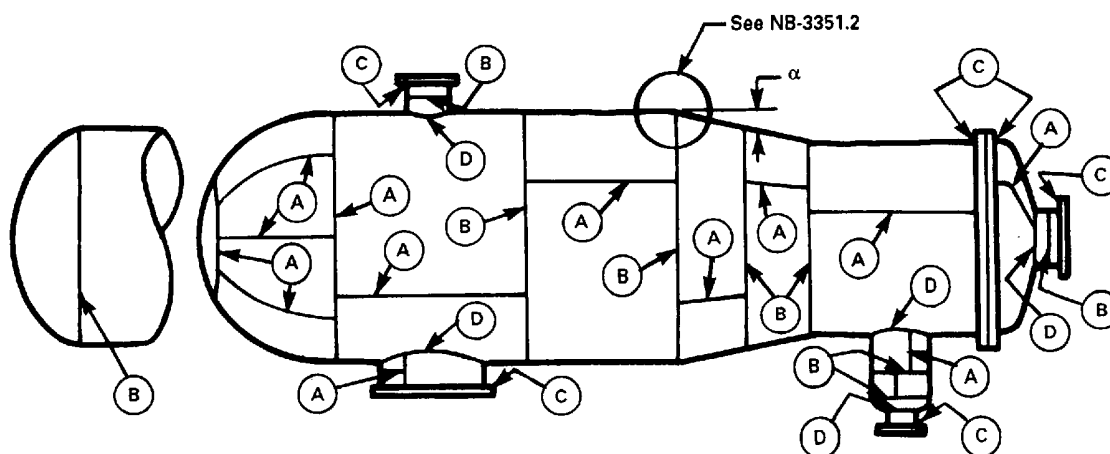


FIG. WB-3341-1 WELDED JOINT LOCATIONS TYPICAL OF CATEGORIES A, B, C, AND D

FIG. WB-3341-1 WELDED JOINT LOCATIONS TYPICAL OF CATEGORIES A, B, C, AND D

WB-3341.3 Category C.

Category C comprises welded joints connecting flanges or flat heads to main containment shell, to formed heads, or to transitions in diameter, any welded joint connecting one side plate to another side plate of a flat sided containment vessel.

WB-3341.4 Category D.

Category D comprises welded joints connecting integral attachments or protrusions to main containment shells, to spheres, to transitions in diameter, to heads, or to flat sided containment vessels.

WB-3342 Permissible Types of Welded Joints

The design of the containment vessel shall meet the requirements for each category of joint. Butt joints are full penetration joints between plates or other elements that lie approximately in the same plane. Category B angle joints between plates or other elements that have an offset angle α not exceeding 30 deg. are considered as meeting the requirements for butt joints. Fig. WB-3341-1 shows typical butt welds for each category joint.

WB-3342.1 Joints of Category A.

All welded joints of Category A as defined in WB-3341 shall meet the fabrication requirements of WB-4241 and shall

be capable of being examined in accordance with WB-5210.

WB-3342.2 Joints of Category B.

All welded joints of Category B as defined in WB-3341 shall meet the fabrication requirements of WB-4242 and shall be capable of being examined in accordance with WB-5220. When joints with opposing lips to form an integral backing strip or joints with backing strips not later removed are used, the suitability for cyclic service shall be analyzed by the method of WB-3222.4 using a fatigue strength reduction factor of not less than 2.

WB-3342.3 Joints of Category C.

All welded joints of Category C, as defined in WB-3341, shall meet the fabrication requirements of WB-4243 and shall be capable of being examined in accordance with WB-5230. Minimum dimensions of the welds and throat thickness shall be as shown in Fig. WB-4243-1 where:

(a) for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle not greater than 45 deg. measured from the face:

t, t_n	= nominal thicknesses of welded parts, in.
t_c	= $0.7t_n$ or $1/4$ in. (6 mm), whichever is less
t_w	= $t_n/2$ or $t/4$, whichever is less

(b) for all other material forms and for forged flat heads, and forged flanges with the weld preparation bevel angle greater than 45 deg. measured from the face:

t, t_n	= nominal thicknesses of welded parts, in.
t_c	= $0.7t_n$ or $1/4$ in. (6 mm), whichever is less
t_w	= t_n or $t/2$, whichever is less

WB-3342.4 Joints of Category D.

All welded joints of Category D, as defined in WB-3341, shall be in accordance with the requirements of one of (a) through (e) below.

(a) *Butt Welded Connections*. Connections shall meet the fabrication requirements of WB-4244(a) and shall be capable of being examined in accordance with WB-5242. The minimum dimensions and geometrical

Page 127

requirements of Fig. WB-4244(a)-1 shall be met, where

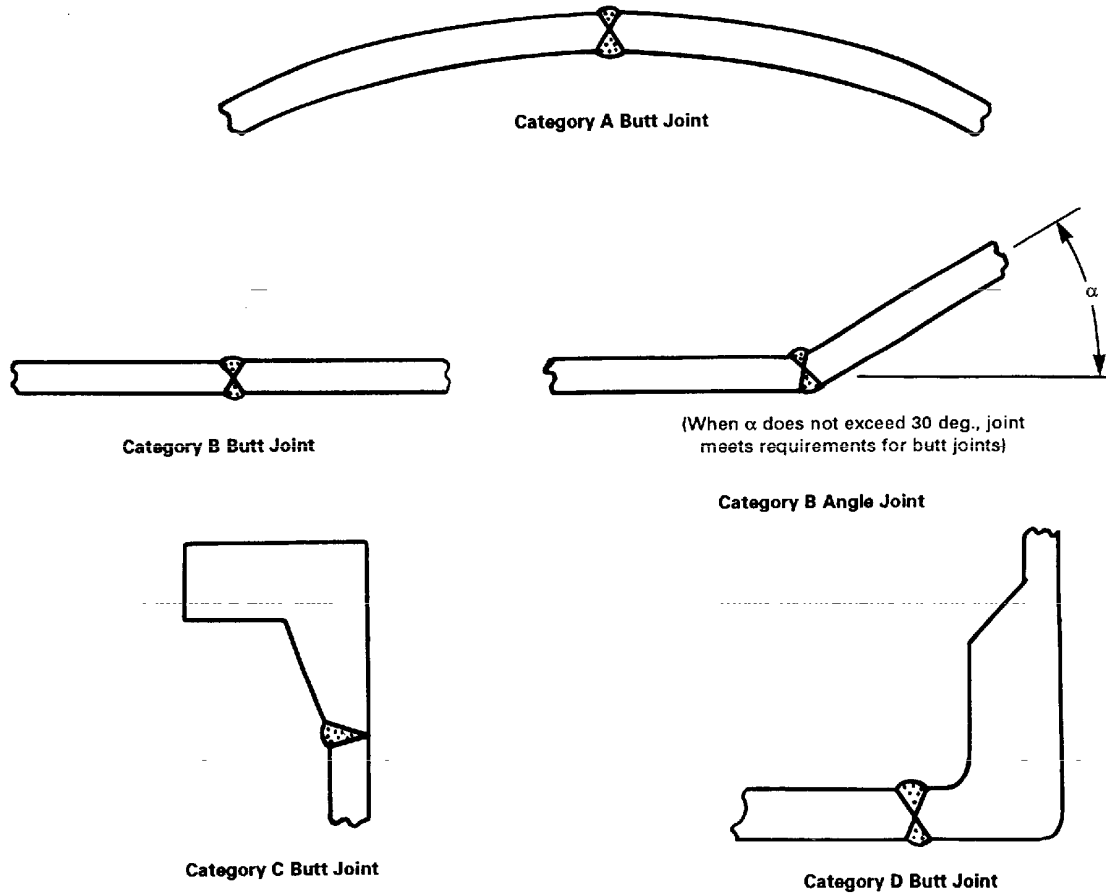


FIG. WB-3342-1 TYPICAL BUTT JOINTS

FIG. WB-3342-1 TYPICAL BUTT JOINTS

r_1	= $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2	= $\frac{1}{4}$ in. minimum
t	= nominal thickness of part penetrated, in.
t_n	= nominal thickness of penetrating part, in.

(b) Full Penetration Corner Welded Connections.

Connections shall meet the fabrication requirements of WB-4244(b) and shall be capable of being examined as required in WB-5243. The minimum dimensions of Fig. WB-4244(b)-1 shall be met, where

r_1	= $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2	= $\frac{1}{4}$ in. (102 mm) minimum
t	= nominal thickness of part penetrated, in.

t_c	= $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_n	= nominal thickness of penetrating part, in.

(c) Use of Deposited Weld Metal for Openings and Connections

(1) Connections shall meet the fabrication requirements of WB-4244(c) and shall be capable of being examined in accordance with WB-5244.

(2) When the deposited weld metal is used as reinforcement, the coefficients of thermal expansion of the base metal, the weld metal, and the connection shall not differ by more than 15% of the lowest coefficient involved.

(3) The minimum dimensions of Fig. WB-4244(c)-1 shall be met, where

r_1	= $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
t	= nominal thickness of part penetrated, in.
t_c	= $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_n	= nominal thickness of penetrating part, in.

(4) The corners of the end of each connection extending less than $\sqrt{dt_n}$ beyond the inner surface of

Page 128

the part penetrated shall be rounded to a radius of one-half the thickness t_n of the connection or $\frac{3}{4}$ in. (19 mm), whichever is smaller.

(d) Attachment of Connections Using Partial Penetration Welds

(1) Partial penetration welds used for connections as permitted in WB-3337.3 shall meet the fabrication requirements of WB-4244(d) and shall be capable of being examined in accordance with the requirements of WB-5245.

(2) The minimum dimensions of Fig. WB-4244(d)-1 shall be met, where

d	= outside diameter of the connecting item
r_1	= $\frac{1}{4}t_n$ or $\frac{3}{4}$ in. (19 mm), whichever is less
t	= nominal thickness of part penetrated, in.
t_c	= $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_n	= nominal thickness of penetrating part or the lesser of t_{n1} or t_{n2} in Fig. WB-4244(d)-2, in.

(3) The corners of the end of each connecting item, extending less than $\sqrt{dt_n}$ beyond the inner surface of the part penetrated, shall be rounded to a radius of one-half of the thickness t_n of the penetrating part or $\frac{3}{4}$ in. (19 mm), whichever is smaller.

(4) Weld groove design for partial penetration joints attaching connecting item may require special consideration to achieve the $1.25t_n$ minimum depth of weld and adequate access for welding examination. The welds shown in the sketches of Fig. WB-4244(d)-1 may be on either the inside or the outside of the containment vessel shell. Weld preparation may be J-groove, as shown in the figures, or straight bevel.

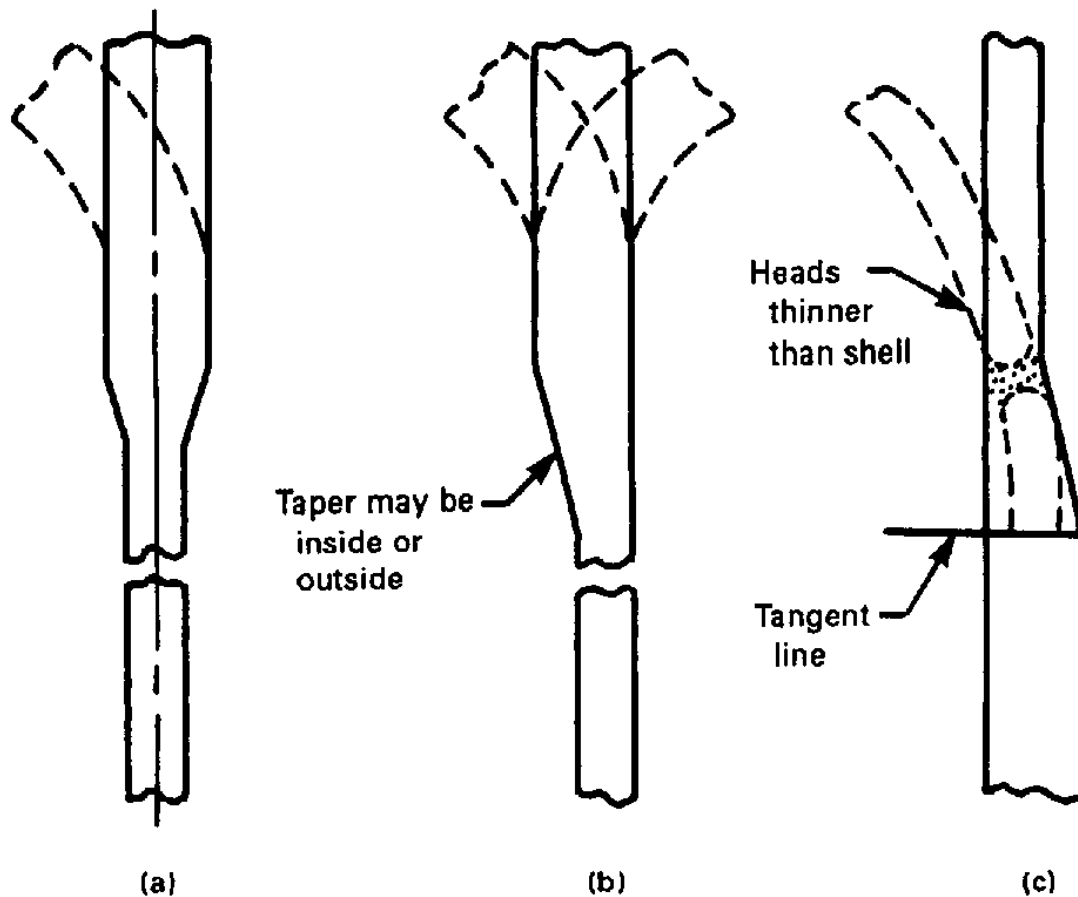
(5) A fatigue strength reduction factor of not less than four shall be used when fatigue analysis is required.

WB-3344 Structural Attachment Welds

Welds for structural attachments shall meet the requirements of WB-4430.

WB-3345

The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration, except as otherwise permitted in WB-3342.4.



GENERAL NOTE:
Length of taper may include the width of the weld.

FIG. WB-3351-1 CATEGORY A AND B JOINTS BETWEEN SECTIONS OF UNEQUAL THICKNESS

FIG. WB-3351-1 CATEGORY A AND B JOINTS BETWEEN SECTIONS OF UNEQUAL THICKNESS

WB-3346 Thermal Treatment

All vessels and vessel parts shall be given the appropriate postweld heat treatment prescribed in WB-4620.

WB-3350 SPECIAL CONTAINMENT VESSEL REQUIREMENTS

WB-3351 Category A or B Joints Between Sections of Unequal Thickness

In general, a tapered transition section as shown in Fig. WB-3351-1, which is a type of gross structural discontinuity (WB-3213.2), shall be provided at joints of Categories A and B between sections that differ in thickness by more than one-fourth the thickness of the thinner section. The transition section may be formed by any process that will provide a uniform taper. An ellipsoidal or hemispherical head that has a greater thickness than a cylinder of the same inside diameter may be machined to the outside diameter of the cylinder, provided the remaining thickness is at least as great as that required for a shell of the same diameter. A uniform taper is not required for flanged hubs. The adequacy of the transition shall be evaluated by stress analysis. Stress intensity limitations are given in WB-3220. The requirements of this paragraph do not apply to flange hubs.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D3 WB-4000

ARTICLE WB-4000 FABRICATION AND INSTALLATION

Page 129

WB-4100 GENERAL REQUIREMENTS

WB-4110 INTRODUCTION

Components, parts, and appurtenances shall be fabricated and installed in accordance with the requirements of this Article and shall be manufactured from materials which meet the requirements of WB-2000.

WB-4120 CERTIFICATION OF MATERIALS AND FABRICATION BY CERTIFICATE HOLDER

WB-4121 Means of Certification

The Certificate Holder for an item shall certify, by application of the appropriate Code Symbol and completion of the appropriate Data Report in accordance with NCA-8000, that the materials used comply with the requirements of WB-2000 and that the fabrication or installation complies with the requirements of this Article.

WB-4121.1 Certification of Treatments, Tests, and Examinations.

If the Certificate Holder or Subcontractor performs treatments, tests, repairs, or examinations required by this Division, the Class TP Certificate Holder shall certify that this requirement has been fulfilled (WA-3862). Reports of all required treatments and of the results of all required tests, repairs, and examinations performed shall be available to the Inspector.

WB-4121.2 Repetition of Tensile or Impact Tests.

If during the fabrication or installation of the item the material is subjected to heat treatment that has not been covered by treatment of the test coupons (WB-2200) and that may reduce either tensile or impact properties below the required values, the tensile and impact tests shall be repeated by the Certificate Holder on test specimens taken from test coupons which have been taken and treated in accordance with the requirements of WB-2000.

WB-4121.3 Repetition of Surface Examination After Machining.

If, during the fabrication or installation of an item, materials for pressure containing parts are machined, then the Certificate Holder shall reexamine the surface of the material in accordance with WB-2500 when:

(a) the surface was required to be examined by the magnetic particle or liquid penetrant method in accordance with WB-2500; and

(b) the amount of material removed from the surface exceeds the lesser of $\frac{1}{8}$ in. (3.2 mm) or 10% of the minimum required thickness of the part.

WB-4122 Material Identification

(a) Material for pressure retaining parts shall carry identification markings which will remain distinguishable until the component is assembled or installed. If the original identification markings are cut off or the material is divided, the marks shall either be transferred to the parts cut or a coded marking shall be used to ensure identification of each piece of material during subsequent fabrication or installation. In either case, an as-built sketch or a tabulation of materials shall be made identifying each piece of material with the Certified Material Test Report, where applicable, and the coded marking. For studs, bolts, nuts, and heat exchanger tubes it is permissible to identify the Certified Material Test Reports for material in each component in lieu of identifying each piece of material with the Certified Material Test Report and the coded marking. Material supplied with a Certificate of Compliance, and welding and brazing material, shall be identified and controlled so that they can be traced to each component or installation of a piping system, or else a control procedure shall be employed which ensures that the specified materials are used.

Page 136

(b) Material from which the identification marking is lost shall be treated as non-conforming material until appropriate tests or other verifications are made and documented to assure material identification. Testing is required unless positive identification can be made by other documented evidence. The material may then be re-marked upon establishing positive identification.

WB-4122.1 Marking Material.

Material shall be marked in accordance with WB-2150.

WB-4123 Examinations

Visual examination activities that are not referenced for examination by other specific Code paragraphs, and are performed solely to verify compliance with requirements of WB-4000, may be performed by the persons who perform or supervise the work. These visual examinations are not required to be performed by personnel and procedures qualified to WB-5500 and WB-5100, respectively, unless so specified.

WB-4125 Testing of Welding and Brazing Material

All welding and brazing material shall meet the requirements of WB-2400.

WB-4130 REPAIR OF MATERIAL

WB-4131 Elimination and Repair of Defects

Material originally accepted on delivery in which defects exceeding the limits of WB-2500 are known or discovered during the process of fabrication or installation is unacceptable. The material may be used provided the condition is corrected in accordance with the requirements of WB-2500 for the applicable product form, except:

(a) the limitation on the depth of the weld repair does not apply;

(b) the time of examination of the weld repairs to weld edge preparations shall be in accordance with WB-5130;

(c) radiographic examination is not required for weld repairs to seal membrane material when the material thickness is $\frac{1}{4}$ in. (6 mm) or less.

WB-4132 Documentation of Repair Welds of Base Material

The Certificate Holder who makes a repair weld exceeding in depth the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section

thickness, shall prepare a report which shall include a chart which shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results of repair welds.

WB-4200 FORMING, FITTING, AND ALIGNING

WB-4210 CUTTING, FORMING, AND BENDING

WB-4211 Cutting

Materials may be cut to shape and size by mechanical means, such as machining, shearing, chipping, or grinding, or by thermal cutting.

WB-4211.1 Preheating Before Thermal Cutting.

When thermal cutting is performed to prepare weld joints or edges, to remove attachments or defective material, or for any other purpose, consideration shall be given to preheating the material, using preheat schedules such as suggested in Appendix D.

WB-4212 Forming and Bending Processes

Any process may be used to hot or cold form or bend pressure retaining material (WB-4223), including weld metal, provided the required dimensions are attained (see WB-4214 and WB-4220), and provided the impact properties of the material, when required, are not reduced below the minimum specified values, or they are effectively restored by heat treatment following the forming operation. *Hot forming* is defined as forming with the material temperature higher than 100°F (38°C) below the lower transformation temperature of the material. When required, the process shall be qualified for impact properties as outlined in WB-4213. When required, the process shall be qualified to meet thickness requirements as outlined in WB-4223.1.

WB-4213 Qualification of Forming Processes for Impact Property Requirements

A procedure qualification test shall be conducted using specimens taken from material of the same specification, grade or class, heat treatment, and with similar impact properties, as required for the material in the component. These specimens shall be subjected to the equivalent forming or bending process and heat treatment as the material in the component.

Applicable tests

Page 137

shall be conducted to determine that the required impact properties of WB-2300 are met after straining.

WB-4213.1 Exemptions.

Procedure qualification tests are not required for materials listed in (a) through (f) below:

- (a) hot formed material, such as forgings, in which the hot forming is completed by the Material Organization prior to removal of the impact test specimens;
- (b) hot formed material represented by test coupons required in either WB-2211 or WB-4121.2, which have been subjected to heat treatment representing the hot forming procedure and the heat treatments to be applied to the parts;
- (c) material which does not require impact tests in accordance with WB-2300;
- (d) material which has a final strain less than 0.5%;
- (e) material where the final strain is less than that of a previously qualified procedure for that material;
- (f) material from which the impact testing is required by WB-2300 is performed on each heat and lot, as applicable, after forming.

WB-4213.2 Procedure Qualification Test.

The procedure qualification test shall be performed in the manner stipulated in (a) through (f) below.

(a) The tests shall be performed on three different heats of material both before straining and after straining and heat treatment to establish the effects of the forming and subsequent heat treatment operations.

(b) Specimens shall be taken in accordance with the requirements of WB-2000 and shall be taken from the tension side of the strained material.

(c) The percent strain shall be established by the following formulas.

For cylinders:

$$\% \text{ strain} = \frac{50t}{R_f} \left(1 - \frac{R_f}{R_o} \right)$$

For spherical or dished surfaces:

$$\% \text{ strain} = \frac{75t}{R_f} \left(1 - \frac{R_f}{R_o} \right)$$

For pipe:

$$\% \text{ strain} = \frac{100r}{R}$$

where

R	= nominal bending radius to the center line of the pipe, in.
R_f	= final radius to center line of shell, in.
R_o	= original radius (equal to infinity for a flat part), in.
r	= nominal radius of the pipe, in.
t	= nominal thickness, in.

(d) The procedure qualification shall simulate the maximum percent surface strain, employing a bending process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient C_v test specimens shall be taken from each of the three heats of material to establish a transition curve showing both the upper and lower shelves. On each of the three heats, tests consisting of three impact specimens shall be conducted at a minimum of five different temperatures distributed throughout the transition region. The upper and lower shelves may be established by the use of one test specimen for each shelf. Depending on the product form, it may be necessary to plot the transition curves using both lateral expansion and energy level data (WB-2300). In addition, drop weight tests shall be made when required by WB-2300.

(f) Using the results of the impact test data from each of three heats, taken both before and after straining, determine either:

(1) the maximum change in *NDT* temperature along with:

(a) the maximum change of lateral expansion and energy at the temperature under consideration; or

(b) the maximum change of temperature at the lateral expansion and energy levels under consideration; or

(2) when lateral expansion is the acceptance criterion (WB-2300), either the maximum change in temperature or the maximum change in lateral expansion.

WB-4213.3 Acceptance Criteria for Formed Material.

To be acceptable, the formed material used in the component shall have impact properties before forming sufficient to compensate for the maximum loss of impact properties due to the qualified forming processes used.

WB-4213.4 Requalification.

A new procedure qualification test is required when any of the changes in (a), (b), or (c) below are made.

(a) The actual postweld heat treatment time at temperature is greater than previously qualified considering WB-2211. If the material is not postweld heat treated, the procedure must be qualified without postweld heat treatment.

Page 138

(b) The maximum calculated strain of the material exceeds the previously qualified strain by more than 0.5%.

(c) Preheat over 250°F (121°C) is used in the forming or bending operation but not followed by a subsequent postweld heat treatment.

WB-4214 Minimum Thickness of Fabricated Material

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of WB-3000, the material may be repaired in accordance with WB-4130.

WB-4220 FORMING TOLERANCES

WB-4221 Tolerance for Vessel Shells

Cylindrical, conical, or spherical shells of a completed containment vessel, except formed heads covered by WB-4222, shall meet the requirements of the following subparagraphs at all cross sections, where not further limited by design.

WB-4221.1 Maximum Difference in Cross-Sectional Diameters.

The difference in inches between the maximum and minimum diameters at any cross section shall not exceed the smaller of $(D + 50)/200$ and $D/100$, where D is the nominal inside diameter, in., at the cross section under consideration. The diameters may be measured on the inside or outside of the containment vessel. If measured on the outside, the diameters shall be corrected for the plate thickness at the cross section under consideration (Fig. WB-4221.1-1). When the cross section passes through an opening, the permissible difference in inside diameters given herein may be increased by 2% of the inside diameter of the opening.

WB-4221.2 Maximum Deviation From True Theoretical Form for External Pressure.

Containment vessels designed for external pressure shall meet the tolerances given in (a) through (c) below.

(a) The maximum plus or minus deviation from the true circular form of cylinders or the theoretical form of other shapes, measured radially on the outside or inside of the component, shall not exceed the maximum permissible deviation obtained from Fig. WB-4221.2(a)-1. Measurements shall be made from a segmental circular template having the design inside or outside radius depending on where the measurements are taken and a chord length equal to twice the arc length obtained from Fig. WB-4221.2(a)-2. For Fig. WB-4221.2(a)-1, the maximum permissible deviation e need not be less than $0.3t$. For Fig. WB-4221.2(a)-2, the arc length need not be greater than $0.30D_o$. Measurements shall not be taken on welds or other raised parts.

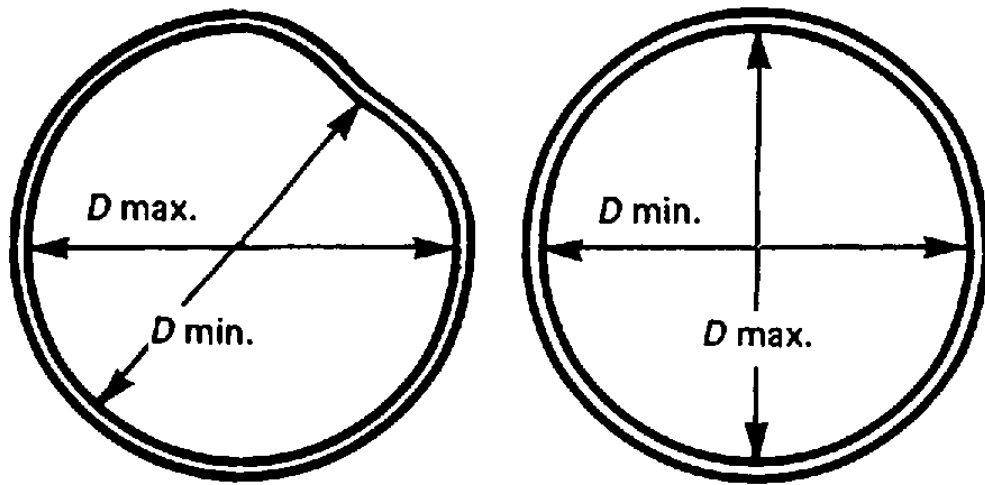


FIG. WB-4221.1-1 MAXIMUM DIFFERENCE IN CROSS-SECTIONAL DIAMETERS

FIG. WB-4221.1-1 MAXIMUM DIFFERENCE IN CROSS-SECTIONAL DIAMETERS

(b) The value of t , in., at any cross section is the nominal plate thickness less corrosion allowance for sections of constant thickness and the nominal thickness of the thinnest plate less corrosion allowance for sections having plates of more than one thickness.

(c) The value of L in Figs. WB-4221.2(a)-1 and WB-4221.2(a)-2 is determined by (1) through (3) below.

(1) For cylinders, L is the total length, in., of the design length of a containment vessel section, taken as the largest of the following:

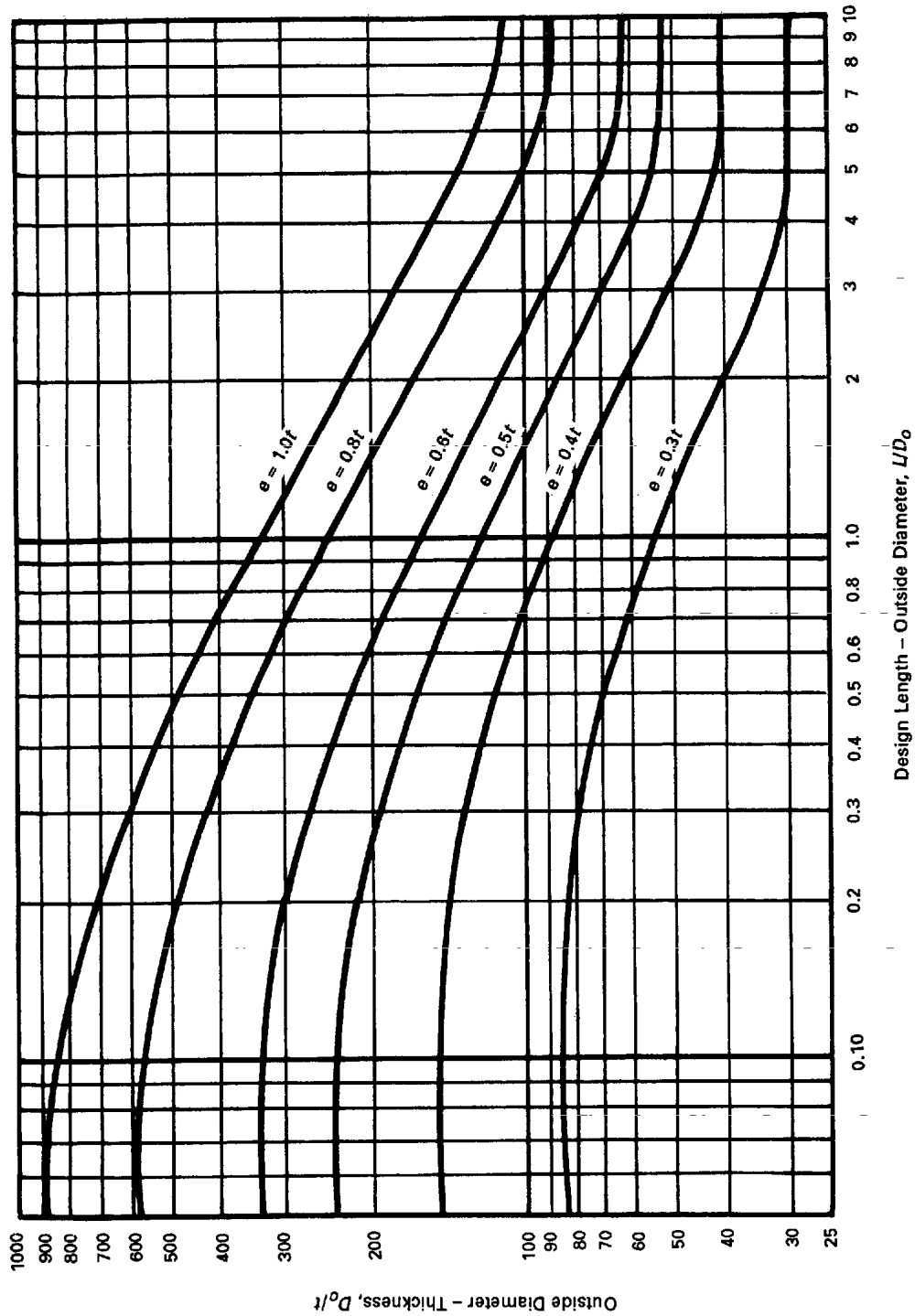
- (a) the distance between head tangent lines plus one-third of the depth of each head if there are no stiffening rings;
- (b) the greatest center-to-center distance between any two adjacent stiffening rings; or
- (c) the distance from the center of the first stiffening ring to the head tangent line plus one-third of the depth of the head, all measured parallel to the axis of the vessel, in.

(2) For cones, L is the axial length of the conical section if no stiffener rings are used or, if stiffener rings are used, the axial length from the head bend line at the large end of the cone to the first stiffener ring, with D_o taken as the outside diameter in inches of the cylinder at the large end of the cone.

(3) For spheres, L is one-half of the outside diameter D_o , in.

(d) The dimensions of a completed containment vessel may be brought within the requirements by any process which will not impair the strength of the material.

(e)

FIG. WB-4221.2(a)-1 MAXIMUM PERMISSIBLE DEVIATION e FROM A TRUE CIRCULAR FORM

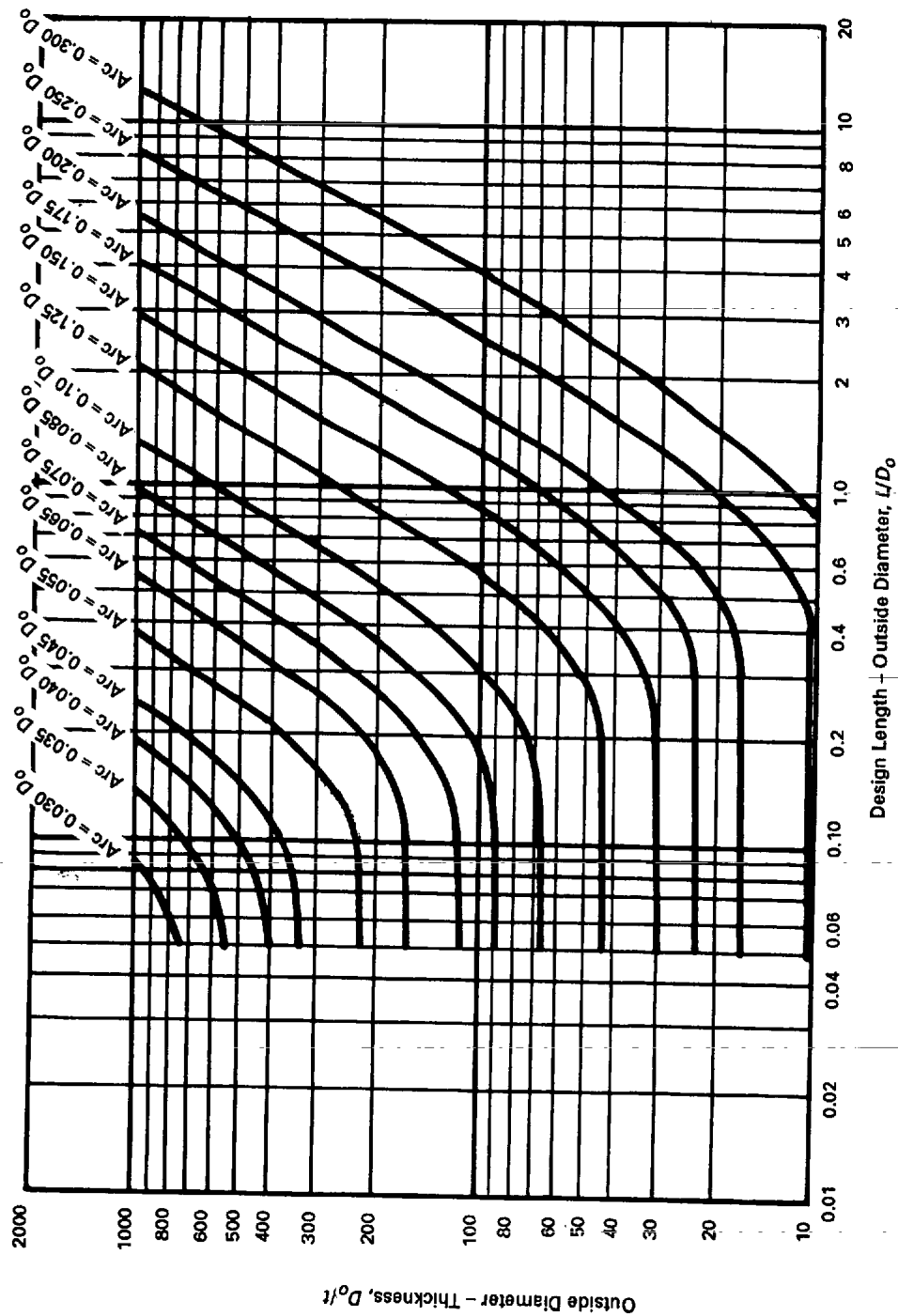


FIG. WB4221.2(a)-2 MAXIMUM ARC LENGTH FOR DETERMINING PLUS OR MINUS DEVIATION

FIG. WB-4221.2(a)-2 MAXIMUM ARC LENGTH FOR DETERMINING PLUS OR MINUS DEVIATION

WB-4221.3 Deviations From Tolerances.

Deviations from the tolerance requirements stipulated in WB-4221.1 and WB-4221.2 are permitted, provided the drawings are modified and deviations are reconciled with the calculations and the licensing documents. Design Documents (WA-3261) and corrective actions shall be identified in the Construction Report [WA-3561(b)].

WB-4221.4 Tolerance Deviations for Vessel Parts Fabricated From Pipe.

Vessel parts subjected to either internal or external pressure and fabricated from pipe, meeting all other requirements of this Division, may have variations of diameter and deviations from circularity permitted by the specification for such pipe.

WB-4221.5 Localized Thin Areas.

Localized thin areas are permitted if the adjacent areas surrounding each have sufficient thickness to provide the necessary reinforcement according to the rules for reinforcement in WB-3330.

WB-4222 Tolerances for Formed Vessel Heads

The tolerance for formed vessel heads shall be as set forth in the following subparagraphs.

WB-4222.1 Maximum Difference in Cross-Sectional Diameters.

The skirt or cylindrical end of a formed head shall be circular to the extent that the difference in inches between the maximum and minimum diameters does not exceed the lesser of $(D + 50)/200$ and $(D + 12)/100$, where D is the nominal inside diameter, in., and shall match the cylindrical edge of the adjoining part within the alignment tolerance specified in WB-4232.

WB-4222.2 Deviation From Specified Shape

(a) The inner surface of a torispherical or ellipsoidal head shall not deviate outside the specified shape by more than $1\frac{1}{4}\%$ of D , inside the specified shape by more than $\frac{5}{8}\%$ of D , where D is the nominal inside diameter of the vessel. Such deviations shall be measured perpendicular to the specified shape and shall not be abrupt. The knuckle radius shall not be less than specified. For 2:1 ellipsoidal heads, the knuckle radius may be considered to be 17% of the diameter of the vessel.

(b) Hemispherical heads and any spherical portion of a formed head shall meet the local tolerances for spheres as given in WB-4221.2, using L as the outside spherical radius, in., and D_o as two times L .

(c) Deviation measurements shall be taken on the surface of the base material and not on welds.

WB-4223 Tolerances for Formed or Bent Piping

The tolerances for formed or bent piping shall be as set forth in the following subparagraphs.

WB-4223.1 Minimum Wall Thickness

(a) In order to assure that the wall thickness requirements of the design calculations are met, the actual thickness shall be measured, or the process shall be qualified by demonstrating that it will maintain the required wall thickness.

(b) As an alternative to (a) above, the requirements of Table WB-3642.1(b)-1 shall be followed.

WB-4223.2 Ovality Tolerance.

Unless otherwise justified by the Design Report, the ovality of piping after bending shall not exceed 8% as determined by:

$$100 \times (D_{\max} - D_{\min})/D_o$$

where

D_o

= nominal pipe outside diameter, in.

$D_{\min}$

= minimum outside diameter after bending or forming, in.

$D_{\max}$

= maximum outside diameter after bending or forming, in.

WB-4230 FITTING AND ALIGNING

WB-4231 Fitting and Aligning Methods

Parts that are to be joined by welding may be fitted, aligned, and retained in position during the welding operation by the use of bars, jacks, clamps, tack welds, or temporary attachments.

WB-4231.1 Tack Welds.

Tack welds used to secure alignment shall either be removed completely, when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified welders using qualified welding procedures. When tack welds are to become part of the finished weld, they shall be visually examined and defective tack welds shall be removed.

WB-4232 Alignment Requirements When Components Are Welded From Two Sides

(a) Alignment of sections which are welded from two sides shall be such that the maximum offset of the finished weld will not be greater than the applicable

Page 142

amount listed in Table WB-4232-1, where t is the nominal thickness of the thinner section at the joint.

TABLE WB-4232-1
MAXIMUM ALLOWABLE OFFSET IN
FINAL WELDED JOINTS

Section Thickness, in.	Direction of Joints	
	Longitudinal	Circumferential
Up to $\frac{1}{2}$, incl.	$\frac{1}{4}t$	$\frac{1}{4}t$
Over $\frac{1}{2}$ to $\frac{3}{4}$, incl.	$\frac{1}{8}$ in.	$\frac{1}{4}t$
Over $\frac{3}{4}$ to $1\frac{1}{2}$, incl.	$\frac{1}{8}$ in.	$\frac{3}{16}$ in.
Over $1\frac{1}{2}$ to 2, incl.	$\frac{1}{8}$ in.	$\frac{1}{8}t$
Over 2	Lesser of $\frac{1}{16}t$ or $\frac{3}{8}$ in.	Lesser of $\frac{1}{16}t$ or $\frac{3}{8}$ in.

TABLE WB-4232-1 MAXIMUM ALLOWABLE OFFSET IN FINAL WELDED JOINTS

(b) Joints in spherical vessels, joints within heads, and joints between cylindrical shells and hemispherical heads shall meet the requirements in Table WB-4232-1 for longitudinal joints.

WB-4232.1 Fairing of Offsets.

Any offset within the allowable tolerance provided above shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld. In addition, offsets greater than those stated in Table WB-4232-1 are acceptable provided the requirements of WB-3200 are met.

WB-4233 Alignment Requirements When Inside Surfaces Are Inaccessible

(a) When the inside surfaces of items are inaccessible for welding or fairing in accordance with WB-4232, alignment of sections shall meet the requirements of (1) and (2) below:

(1)(a) For circumferential joints the inside diameters shall match each other within $\frac{1}{16}$ in. (1.6 mm). When the items are aligned concentrically, a uniform mismatch of $\frac{1}{32}$ in. (0.8 mm) all around the joint can result as shown in Fig. WB-4233(a)-1 sketch (a). However, other variables not associated with the diameter of the item often result in alignments that are offset rather than concentric. In these cases, the maximum misalignment at any one point around the joint shall not exceed $\frac{3}{32}$ in. (2.4 mm) as shown in Fig. WB-4233(a)-1 sketch (b). Should tolerances on diameter, wall thickness, out-of-roundness, etc., result in inside diameter variations which do not meet these limits, the inside diameters shall be counterbored, sized, or ground to produce a bore within these limits, provided the requirements of WB-4250 are met.

(b) Offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary,

by adding additional weld metal.

(2) For longitudinal joints the misalignment of inside surfaces shall not exceed $\frac{3}{32}$ in. (2.4 mm) and the offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(b) Single welded joints may meet the alignment requirements of (a)(1) and (a)(2) above in lieu of the requirements of WB-4232.

WB-4240 REQUIREMENTS FOR WELD JOINTS IN COMPONENTS

WB-4241 Category A Weld Joints in Vessels and Longitudinal Weld Joints in Other Components

Category A weld joints in vessels and longitudinal weld joints in other components shall be full penetration butt joints. Joints that have been welded from one side with backing that has been removed and those welded from one side without backing are acceptable as full penetration welds provided the weld root side of the joints meets the requirements of WB-4424.

WB-4242 Category B Weld Joints in Vessels and Circumferential Weld Joints in Other Components

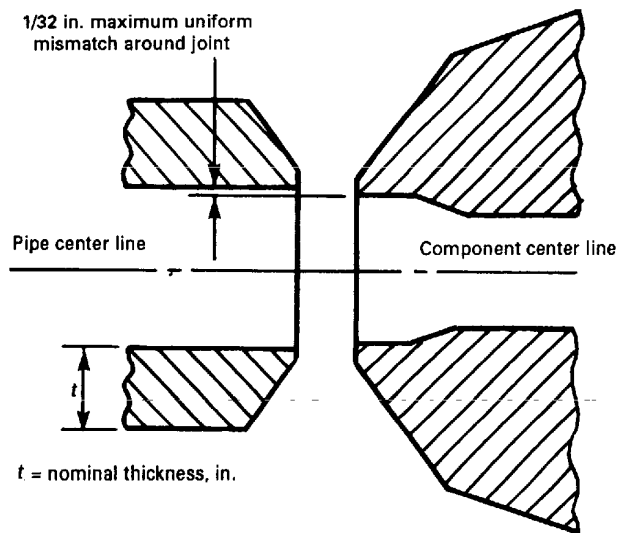
Category B weld joints in vessels and circumferential weld joints in other components shall be full penetration butt joints, except that piping NPS 2 (DN 50) and smaller may be socket welded. When used, backing strips shall be continuous in cross section. Joints prepared with opposing lips to form an integral backing strip and joints with backing strips which are not later removed are acceptable provided the requirements of WB-3342.2 are met.

WB-4243 Category C Weld Joints in Vessels and Similar Weld Joints in Other Components

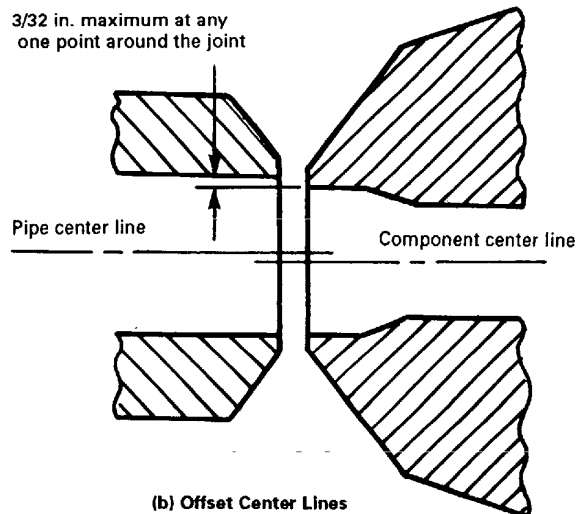
Category C weld joints in vessels and similar weld joints in other components shall be full penetration joints, except that NPS 2 (DN 50) and smaller socket welded joints may be used on component nozzles and in piping. Joints that have been welded from one side with backing that has been removed and those welded

Page 143

from one side without backing are acceptable as full penetration welds provided the weld root side of the joints meets the requirements of WB-4424. Either a butt welded joint or a full penetration corner joint as shown in Fig. WB-4243-1 shall be used.



(a) Concentric Center Lines



(b) Offset Center Lines

GENERAL NOTE:
The weld transitions are typical and are not intended as requirements. Refer to WB-4250 for weld end transition requirements.

FIG. WB-4233(a)-1 BUTT WELD ALIGNMENT AND MISMATCH TOLERANCES FOR UNEQUAL I.D. AND O.D. WHEN COMPONENTS ARE WELDED FROM ONE SIDE AND FAIRING IS NOT PERFORMED

FIG. WB-4233(a)-1 BUTT WELD ALIGNMENT AND MISMATCH TOLERANCES FOR UNEQUAL I.D. AND O.D. WHEN COMPONENTS ARE WELDED FROM ONE SIDE AND FAIRING IS NOT PERFORMED

WB-4244 Category D Weld Joints in Vessels and Branch Piping Weld Joints in Other Components

Category D weld joints in vessels and similar weld joints in other components shall be full or partial penetration weld joints using one of the details of (a) through (e) below.

(a) *Butt Welded Nozzles and Branch Piping Connections.* Nozzles and branch piping connections shall be attached by full penetration butt welds through the wall of the component, nozzle, or branch as shown in Fig. WB-4244(a)-1. Backing strips, if used, shall be removed.

(b) *Corner Welded Nozzles and Branch Piping Connections.* Nozzles and branch piping connections shall be joined to the component by full penetration welds through the wall of the component, nozzle, or branch similar to those shown in Fig. WB-4244(b)-1. Backing strips, if used, shall be removed.

(c) *Deposited Weld Metal of Openings for Nozzles and Branch Piping Connections.* Nozzles and branch piping connections shall be joined to the component by full penetration weld to built-up weld deposits applied to the component, nozzle, or branch as shown in Fig. WB-4244(c)-1. Backing strips, if used, shall be removed. Fillet welds shall be used only to provide a transition between the parts joined or to provide a seal. The fillet welds, when used, shall be finished by grinding to provide a smooth surface having a transition radius at its intersection with either part being joined.

(d) *Partial Penetration Welded Nozzles and Branch Piping Connections.* Partial penetration welds in components and branch piping connections shall meet the weld design requirements of WB-3342.4(d) for vessels or WB-3643 for piping branch connections. Nozzles shall be attached as shown in Figs. WB-4244(d)-1 and WB-4244(d)-2.

(e) *Oblique Nozzles and Piping Connections.* Oblique nozzles and piping connections shall be joined to the component by full penetration welds through the nozzle or pipe connections as shown in Fig. WB-4244(e)-1. Backing rings, if used, shall be removed.

WB-4250 WELDING END TRANSITIONS - MAXIMUM ENVELOPE

The welding ends of items shall provide a gradual change in thickness from the item to the adjoining item. Any welding end transition which lies entirely within the envelope shown in Fig. WB-4250-1 is acceptable provided:

- (a) the wall thickness in the transition region is not less than the minimum wall thickness of the adjoining pipe; and
- (b) sharp reentrant angles and abrupt changes in slope in the transition region are avoided. When the included angle between any two adjoining surfaces of a taper transition is less than 150 deg., the intersection or corner (except for the weld reinforcement) shall be provided with a radius of at least $0.05t_{\min}$.

WB-4300 WELDING QUALIFICATIONS

WB-4310 GENERAL REQUIREMENTS

WB-4311 Types of Processes Permitted

Only those welding processes which are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Division may be used for welding pressure retaining material or attachments thereto. Any process used shall be such that the records required by WB-4320 can be prepared, except that records for stud welds shall be traceable to the welders and welding operators and not necessarily to each specific weld.

WB-4311.1 Stud Welding Restrictions.

Stud welding is acceptable only for nonstructural and temporary attachments (WB-4435). Studs shall be limited to 1 in. (25 mm) maximum diameter for round studs and an equivalent cross-sectional area for studs of other shapes when welding in the flat position and $\frac{3}{4}$ in. (19 mm) diameter for all other welding positions. Postweld heat treatment shall

comply with WB-4600, except that time at temperature need not exceed $\frac{1}{2}$ hr regardless of base material thickness. Welding procedure and performance qualification shall comply with the requirements of Section IX.

WB-4311.2 Capacitor Discharge Welding.

Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments provided:

Page 145

Page 146

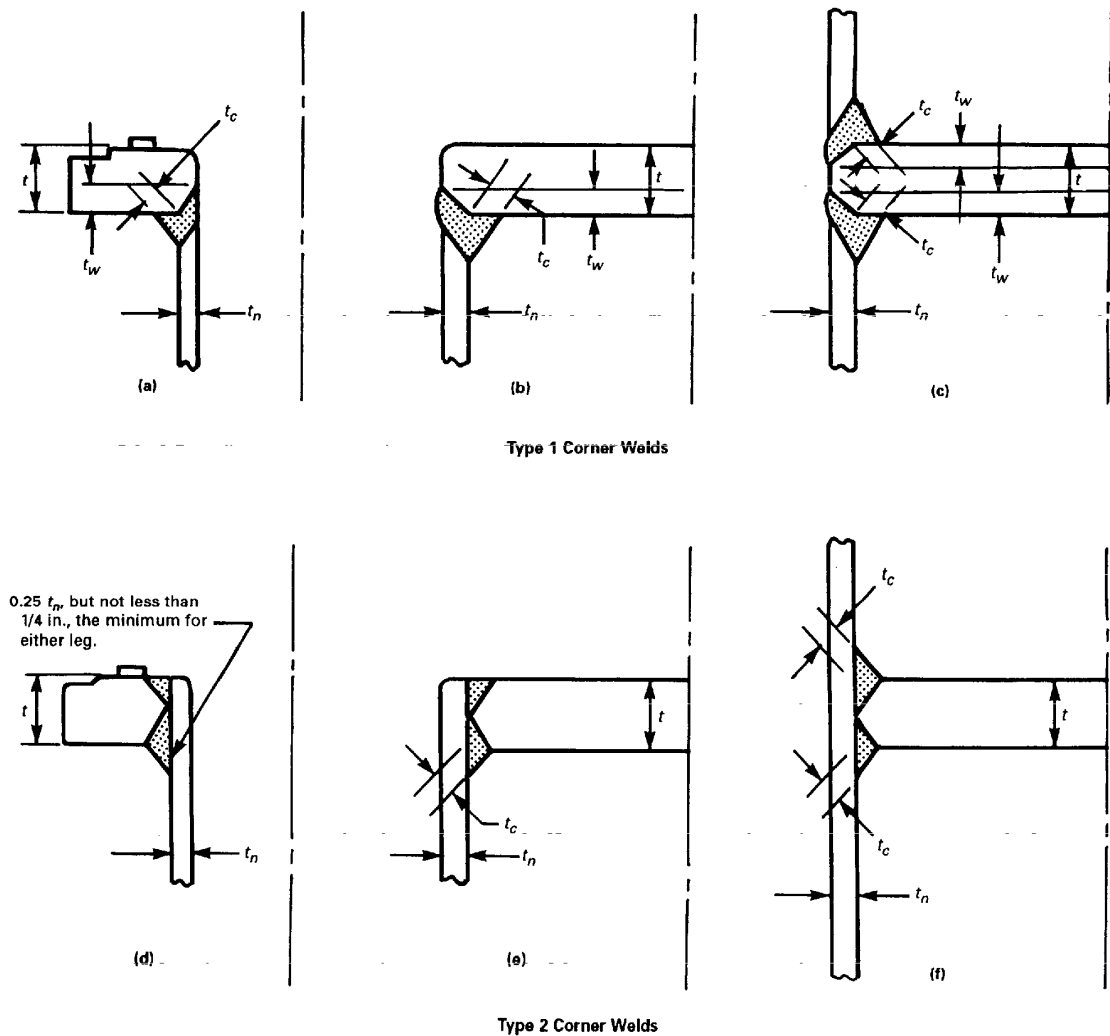
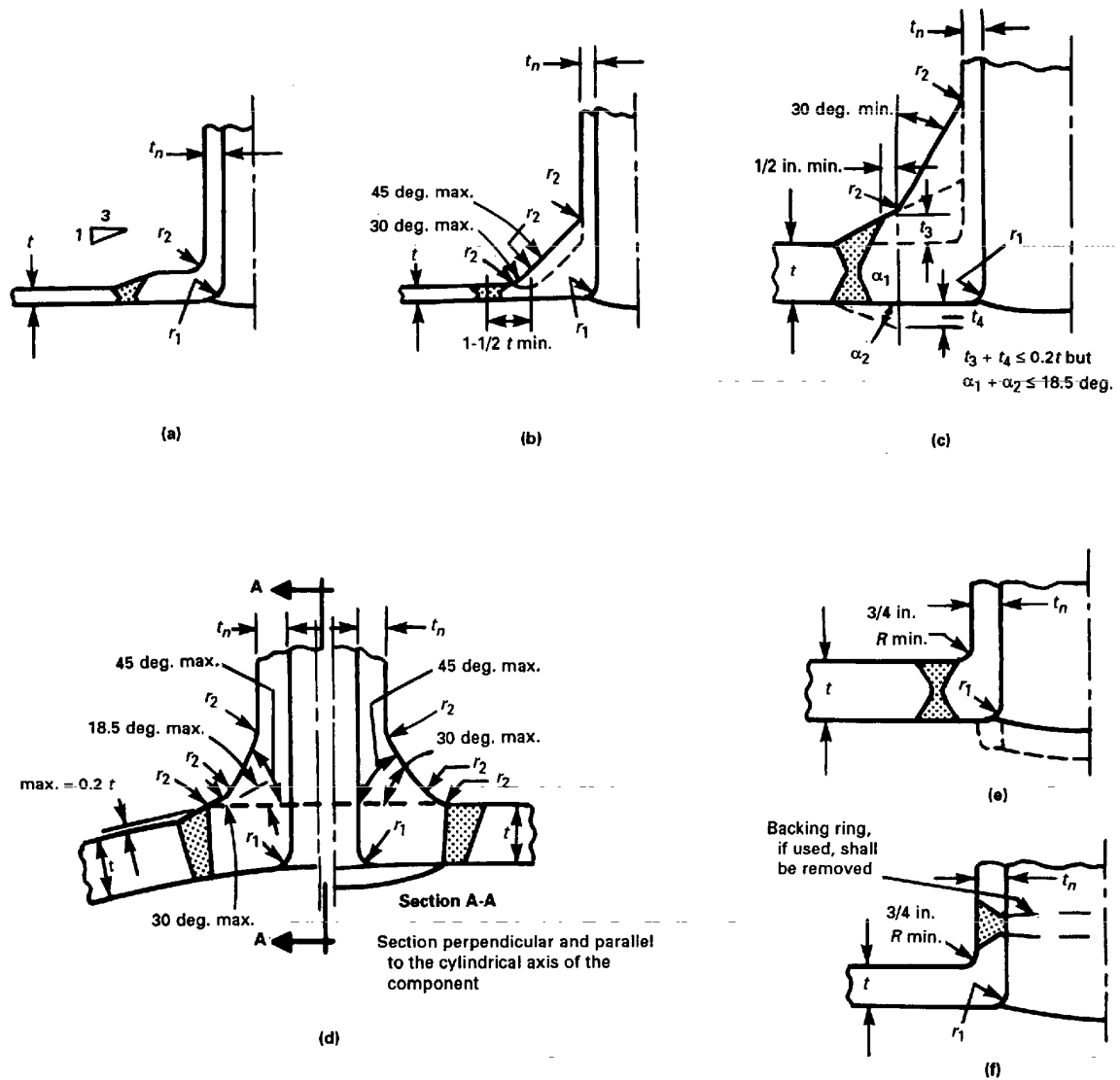


FIG. WB-4243-1 ACCEPTABLE FULL PENETRATION WELD DETAILS FOR CATEGORY C JOINTS (WB-3342.3)

FIG. WB-4243-1 ACCEPTABLE FULL PENETRATION WELD DETAILS FOR CATEGORY C JOINTS (

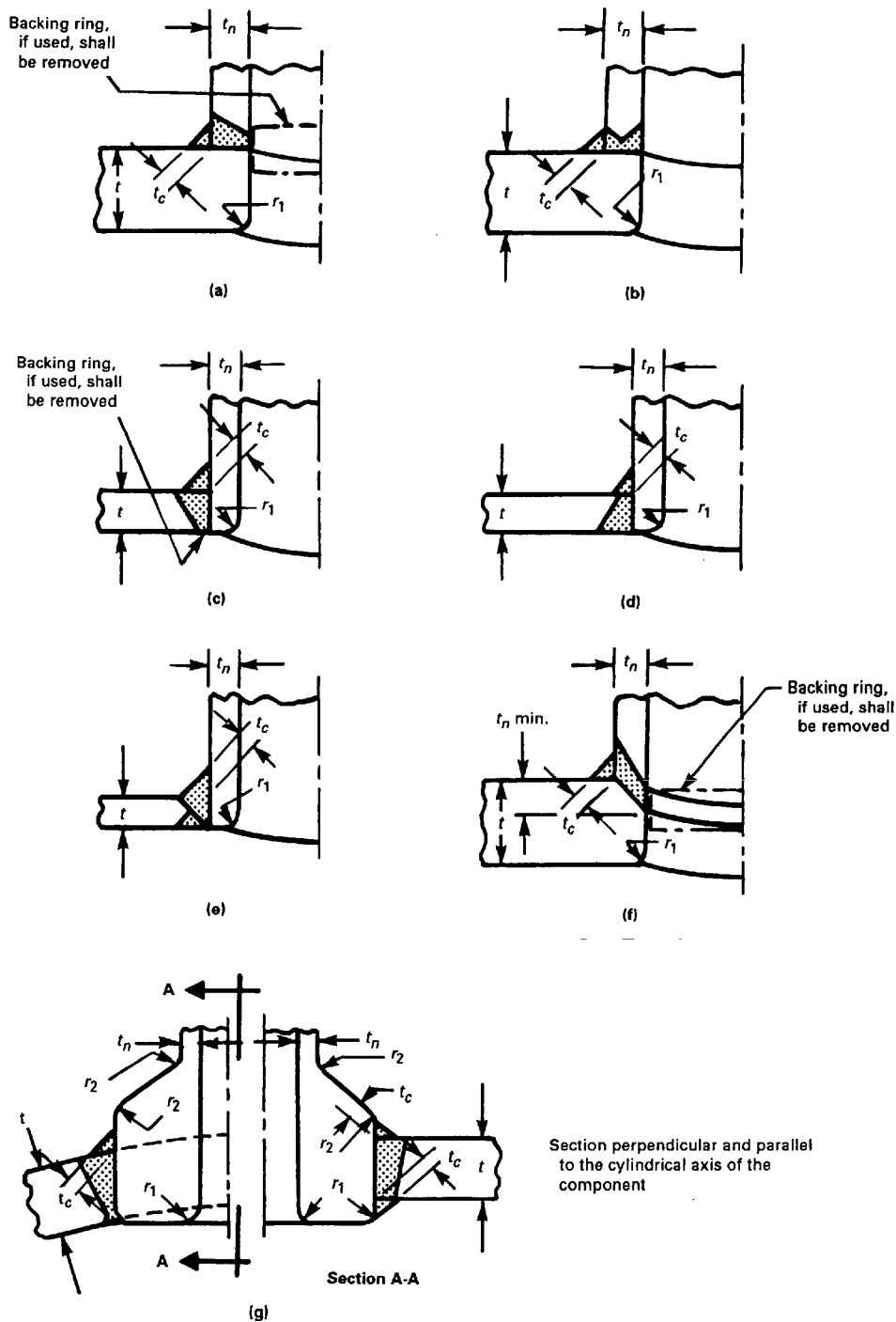


GENERAL NOTES:

- (a) For definitions of symbols, see WB-4244 for vessels and NB-3643 for piping.
 (b) Reinforcement may be distributed within the limits prescribed by the Code.

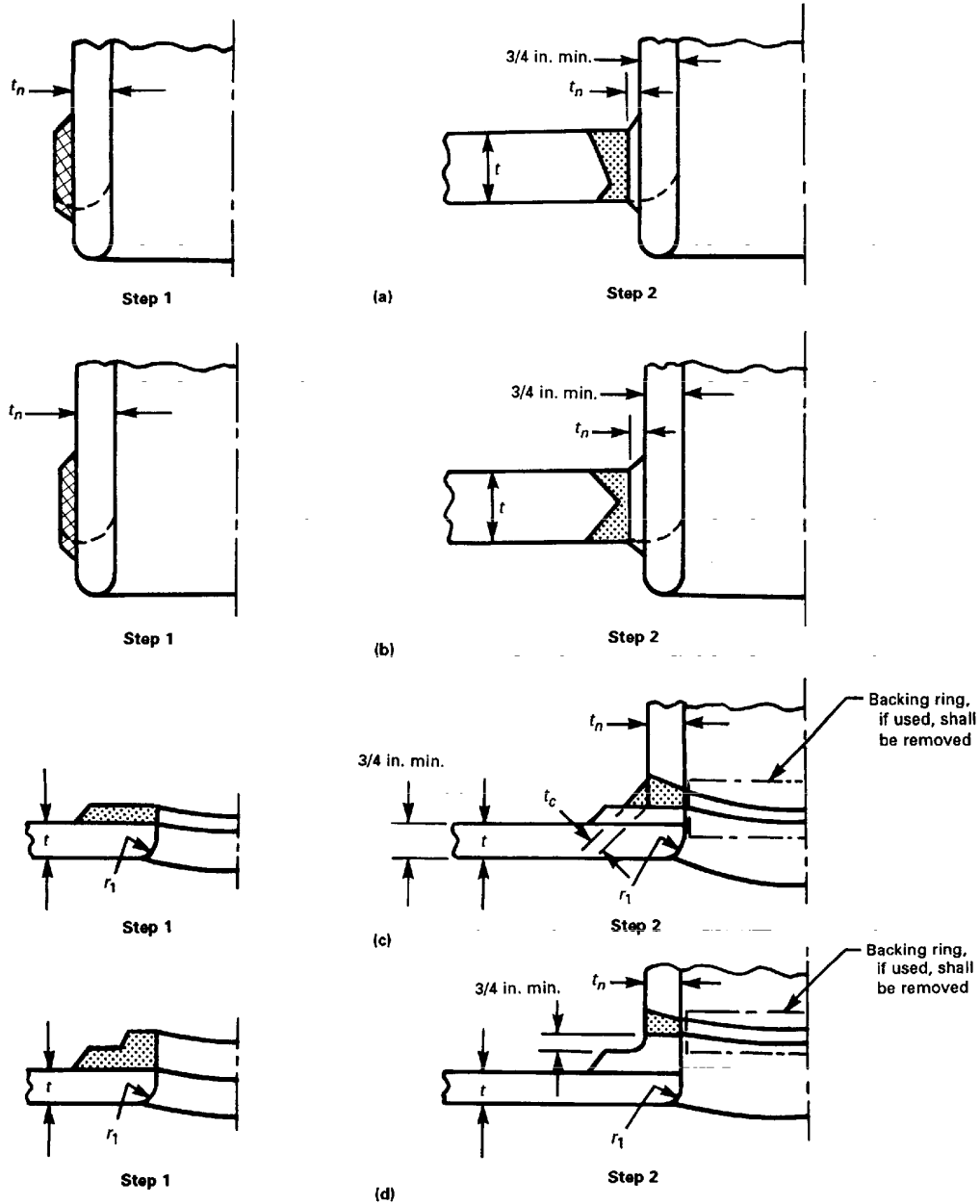
FIG. WB-4244(a)-1 NOZZLE, BRANCH, AND PIPING CONNECTIONS JOINED BY FULL PENETRATION BUTT WELDS

FIG. WB-4244(a)-1 NOZZLE, BRANCH, AND PIPING CONNECTIONS JOINED BY FULL PENETRATION BUTT WELDS



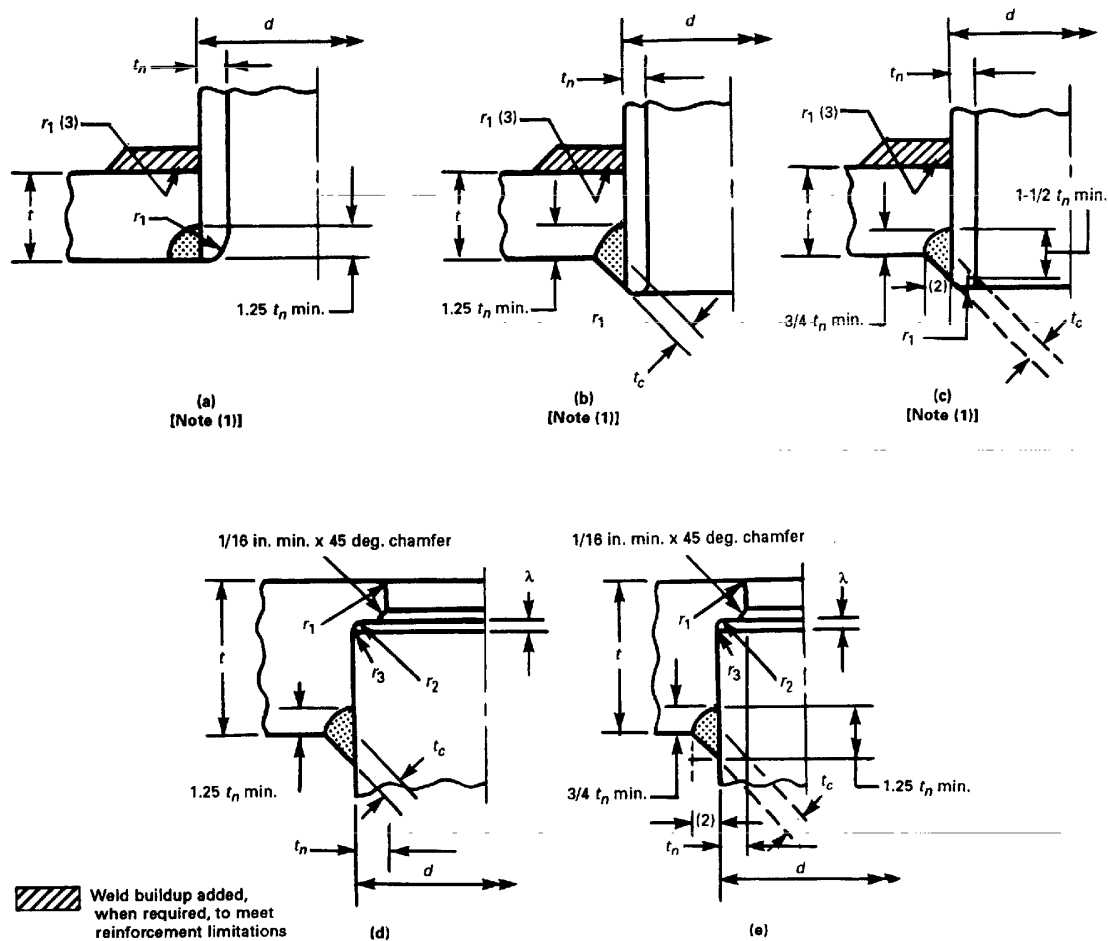
GENERAL NOTE: For definitions of symbols, see WB-4244.4 for vessels and NB-3643 for piping.

FIG. WB-4244(b)-1 NOZZLE, BRANCH, AND PIPING CONNECTIONS JOINED BY FULL PENETRATION CORNER WELDS



GENERAL NOTE: For definitions of symbols, see NB-3352.4(c) for vessels and NB-3643 for piping.

FIG. WB-4244(c)-1 DEPOSITED WELD METAL USED AS REINFORCEMENT OF OPENINGS FOR NOZZLE AND PIPING CONNECTIONS



GENERAL NOTES:

- (a) Weld deposit reinforcement, if used, shall be examined as required in WB-5244.
- (b) The $3/4 t_n$ min. dimension applies to the fillet leg and the J-groove depth.
- (c) Weld groove design for oblique nozzles of this type requires special consideration to achieve the $1.25 t_n$ minimum depth of weld and adequate access for welding inspection. With due regard to the requirements in Fig. WB-4244(c)-1, the welds shown in the sketches may be on either the inside or the outside. Weld preparation may be J-groove as shown or straight bevel. If weld deposit reinforcement is not used, r shall apply to I.D. of base material instead of I.D. of weld buildup.
- (d) For definitions of symbols, see NB-3352.4(d) for vessels and NB-3643 for piping.

FIG. WB-4244(d)-1 PARTIAL PENETRATION NOZZLE AND PIPING CONNECTIONS

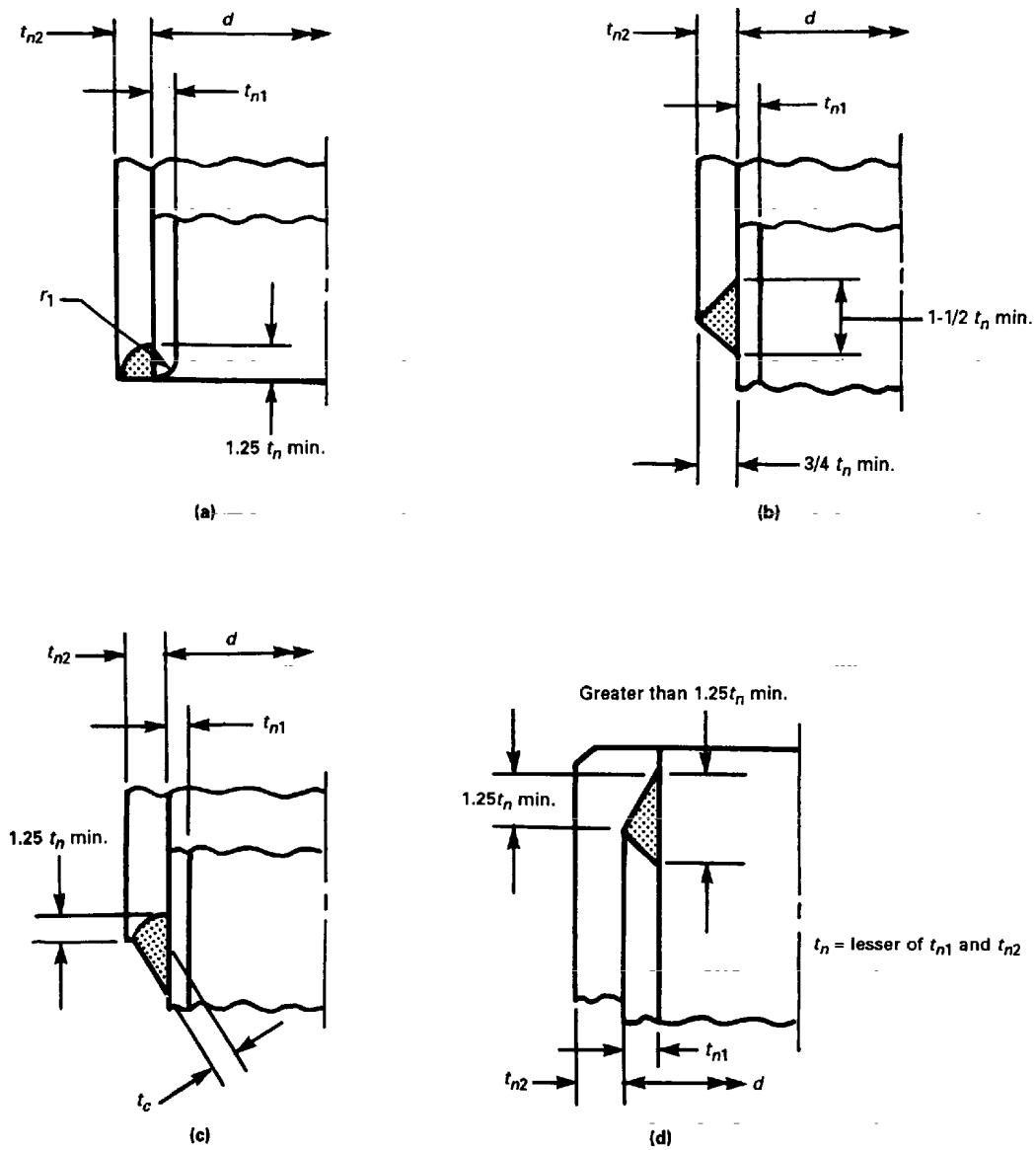
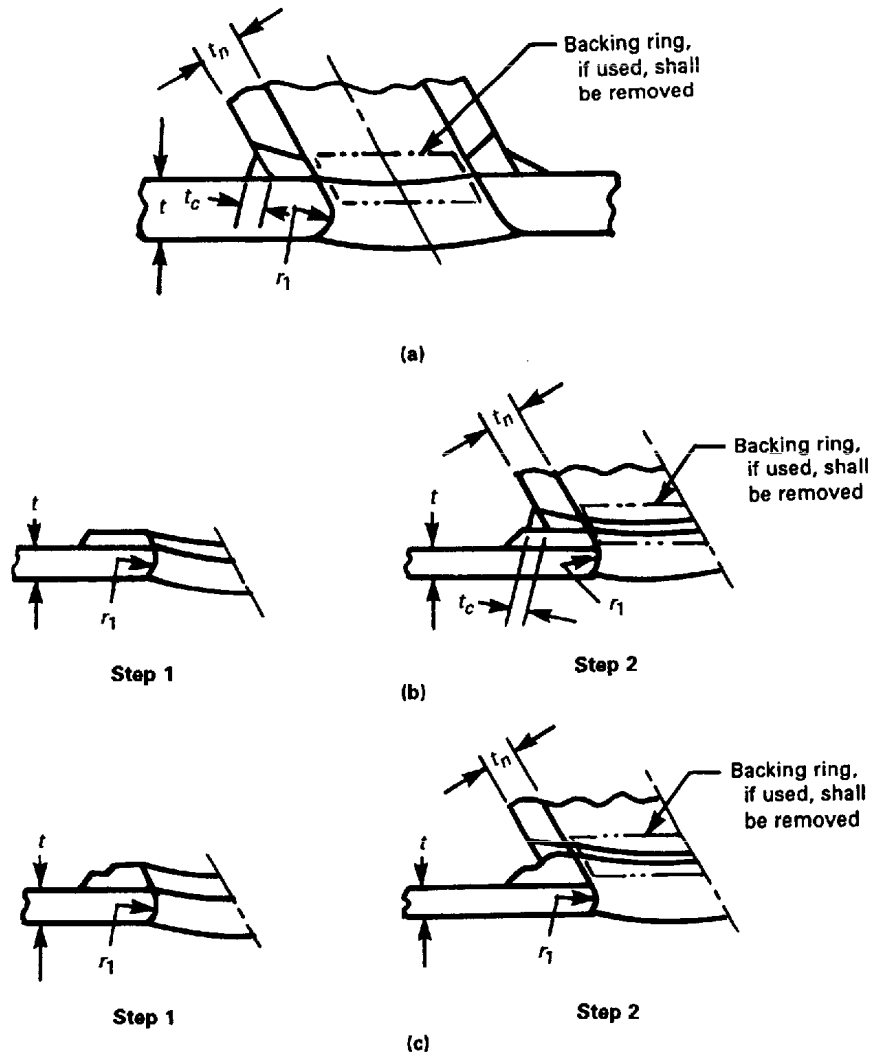


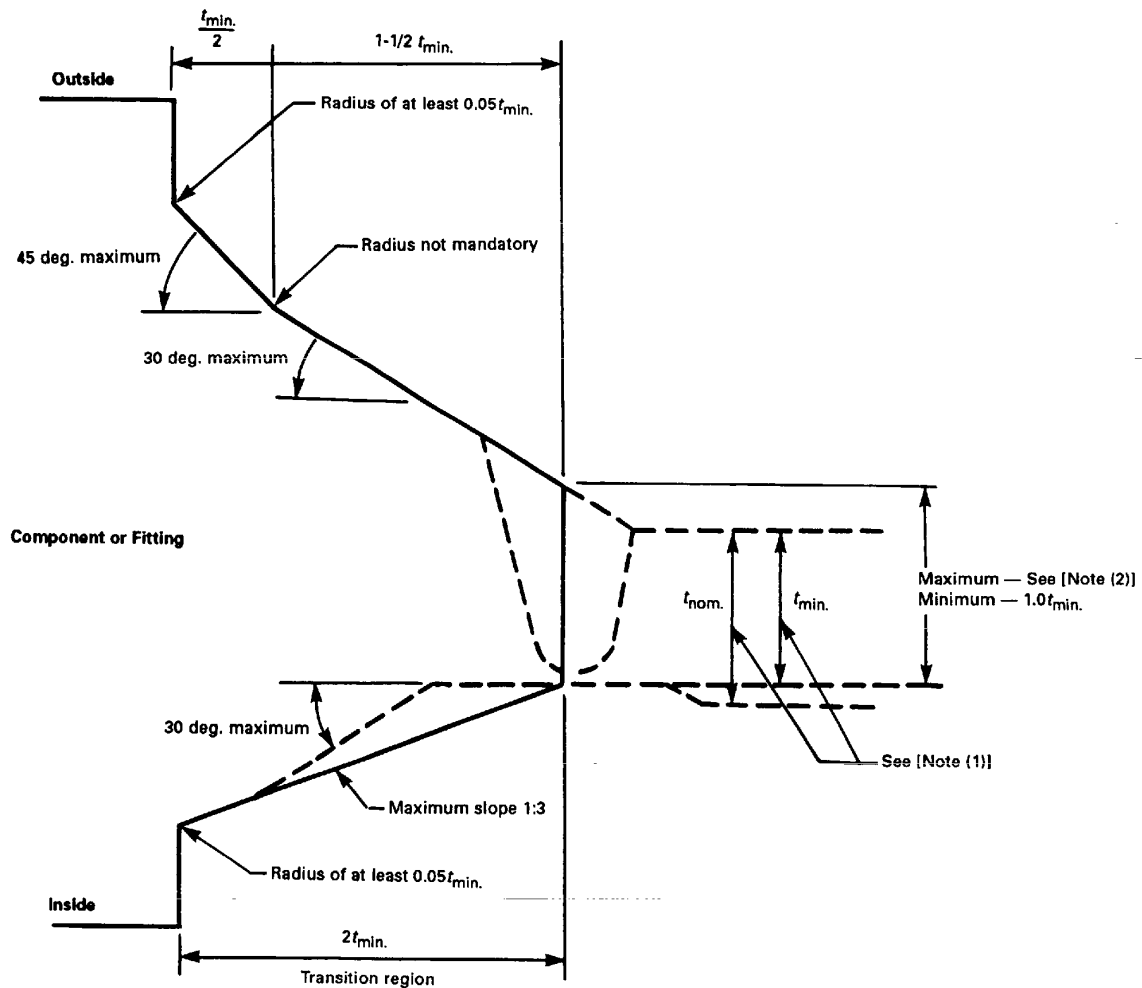
FIG. WB-4244(d)-2 PARTIAL PENETRATION NOZZLE FOR COAXIAL CYLINDERS

FIG. WB-4244(d)-2 PARTIAL PENETRATION NOZZLE FOR COAXIAL CYLINDERS



GENERAL NOTES:
 (a) Step 1 examination required before assembly.
 (b) For definitions of symbols, see NB-3352.4(e) for vessels and NB-3643 for piping.

FIG. WB-4244(e)-1 OBLIQUE CONNECTIONS



GENERAL NOTES:

- (a) Weld bevel is shown for illustration only.
- (b) The weld reinforcement permitted by NC-4426 may lie outside the maximum envelope.

NOTES:

- (1) The value $t_{min.}$ is whichever of the following is applicable:
 - (a) the minimum ordered wall thickness of the pipe;
 - (b) 0.875 times the nominal wall thickness of pipe ordered to a pipe schedule wall thickness which has an under tolerance of 12.5%;
 - (c) the minimum ordered wall thickness of the cylindrical welding end of a component or fitting (or the thinner of the two) when the joint is between two components.
- (2) The maximum thickness at the end of the component is:
 - (a) the greater of $t_{min.} + 0.15$ in. or $1.15 t_{min.}$ when ordered on a minimum wall basis;
 - (b) the greater of $t_{min.} + 0.15$ in. or $1.0 t_{nom.}$ when ordered on a nominal wall basis.

FIG. WB-4250-1 WELDING END TRANSITIONS — MAXIMUM ENVELOPE

FIG. WB-4250-1 WELDING END TRANSITIONS - MAXIMUM ENVELOPE

- (a) temporary attachments are removed in accordance with the provisions of WB-4435(b); and
- (b) the energy output for permanent nonstructural attachments such as strain gages and thermocouples is limited to 125 W-sec, and the minimum thickness of the material to which the attachment is made is greater than 0.09 in. (2.3 mm); and
- (c) a Welding Procedure Specification is prepared describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required.

WB-4311.4 Inertia and Continuous Drive Friction Welding

- (a) Inertia and continuous drive friction welding shall not be used for the fabrication of vessels and piping.
- (b) The weld between the two members shall be a full penetration weld.

WB-4320 WELDING QUALIFICATIONS, RECORDS, AND IDENTIFYING STAMPS

WB-4321 Required Qualifications

- (a) Each Certificate Holder is responsible for the welding done by his organization, and each Certificate Holder shall establish the procedure and conduct the tests required by this Article and by Section IX in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures.
- (b) Procedures, welders, and welding operators used to join permanent or temporary attachments to pressure parts and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Article.
- (c) When making procedure test plates for butt welds, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. This applies particularly to material and weld metal of 80.0 ksi (552 MPa) tensile strength or higher and heavy sections of both low and high tensile strength material. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.
- (d) WA-3131 provides specific additional requirements when welding services are subcontracted to or through organizations not holding an appropriate Certificate of Accreditation.

WB-4322 Maintenance and Certification of Records

The Certificate Holder shall maintain a record of the qualified welding procedures and of the welders and welding operators qualified by him, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and signed by any authorized individual assigned by the Certificate Holder, and they shall be accessible to the Owner and to the Inspector.

WB-4322.1 Identification of Joints by Welder or Welding Operator

- (a) Each welder or welding operator shall apply the identification mark assigned by the Certificate Holder on or adjacent to all permanent welded joints or series of joints on which he welds. The marking shall be at intervals of 3 ft or less and shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps. As an alternative, the Certificate Holder shall keep a record of permanent welded joints in each item and of the welders and welding operators used in making each of the joints.
- (b) When a multiple number of permanent structural attachment welds, nonstructural welds, fillet welds, socket welds, welds of specially designed seals, weld metal cladding, hard surfacing, and tube-to-tubesheet welds are made on an item, the Certificate Holder need not identify the welder or welding operator who welded each individual joint, provided:
 - (1) the Certificate Holder maintains a system that will identify the welders or welding operators who made such welds on each item so that the Inspector can verify that the welders or welding operators were all properly qualified;
 - (2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification.

WB-4323 Welding Prior to Qualifications

No welding shall be undertaken until after the welding procedures which are to be used have been qualified. Only welders and welding operators who are qualified in accordance with WB-4320 and Section IX shall be used.

WB-4324 Transferring Qualifications

The welding procedure qualifications and the performance qualification tests for welders and welding operators conducted by one Certificate Holder shall not qualify welding procedures and shall not qualify welders

Page 154

or welding operators to weld for any other Certificate Holder, except as provided in Section IX, QW-201 and QW-300.2.

WB-4330 GENERAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION TESTS

WB-4331 Conformance to Section IX Requirements

All welding procedure qualification tests shall be in accordance with the requirements of Section IX as supplemented or modified by the requirements of this Article.

WB-4333 Heat Treatment of Qualification Welds for Ferritic Materials

Postweld heat treatment of procedure qualification welds shall conform to the applicable requirements of WB-4600 and Section IX. The postweld heat treatment time at temperature shall be at least 80% of the maximum time to be applied to the component weld material. The postweld heat treatment total time may be applied in one heating cycle.

WB-4334 Preparation of Test Coupons and Specimens

(a) Removal of test coupons from the test weld and the dimensions of specimens made from them shall conform to the requirements of Section IX, except that the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with (b) below.

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test specimens. When each process cannot be included in the full-size impact test specimen at the $\frac{1}{4}t$ location required by this Division, additional full-size specimens shall be obtained from locations in the test weld that will ensure that at least a portion of each process has been included in full-size test specimens. As an alternative, additional test welds can be made with each process so that full-size specimens can be tested for each process.

WB-4334.1 Coupons Representing the Weld Deposit.

Impact test specimens and testing methods shall conform to WB-2321. The impact specimen shall be located so that the longitudinal axis of the specimen is at least $0.25t$ and, where the thickness of the test assembly permits, not less than $\frac{3}{8}$ in. (10 mm) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified in WB-4620 and the test assembly is cooled at an accelerated rate, the longitudinal axis of the specimen shall be a minimum of t from the edge of the test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the weld. The length of the notch of the Charpy V-notch specimen shall be normal to the surface of the weld. Where drop weight specimens are required, the tension surface of the specimen shall be oriented parallel to the surface of the test weld assembly.

WB-4334.2 Coupons Representing the Heat Affected Zone.

Where impact tests of the heat affected zone are required by WB-4335.2, specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through below.

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented in the direction parallel to the principal direction of rolling or forging.

(b) The heat affected zone impact test specimens and testing methods shall conform to the requirements of WB-2321.2. The specimens shall be removed from a location as near as practical to a depth midway between the surface and center

thickness. The coupons for heat affected zone impact specimens shall be taken transverse to the axis of the weld and etched to define the heat affected zone. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much heat affected zone as possible in the resulting fracture. Where the material thickness permits, the axis of a specimen may be inclined to allow the root of the notch to align parallel to the fusion line. When a grain refining heat treatment is not performed on welds made by the electroslog or electrogas welding process, the notch for the impact specimens shall be located in the grain coarsened region.

(c) For the comparison of heat affected zone values with base material values [WB-4335.2(b)], Charpy V-notch specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the heat affected zone specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the heat affected zone specimens, and the axis of the notch shall be normal to the surface of the base material. When required by WB-4335.2(b)(1), drop-weight specimens shall be removed from a depth as near as practical

Page 155

to midway between the surface and center thickness of the unaffected base material and shall be tested in accordance with the requirements of WB-2321.1.

WB-4335 Impact Test Requirements

When materials are required to be impact tested per WB-2300, impact tests of the weld metal and heat affected zone shall be performed in accordance with the following subparagraphs. The weld procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of WB-2330 and WB-4334. Retests in accordance with the provisions of WB-2350 are permitted.

WB-4335.1 Impact Tests of Weld Metal

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding $\frac{5}{8}$ in. (16 mm) in thickness when the weld will be made on the surface or penetrate base material that requires impact testing in accordance with WB-2310. In addition, such testing of the weld metal is required for the welding procedure qualification tests for any weld repair to base material that requires impact testing in accordance with WB-2310, regardless of the depth of the repair. Exemption from impact testing under WB-2311(a) does not apply to weld metal of welding procedure qualification tests for either production weld joints or base metal repairs unless the specific weld metal used is A-No. 8.

(b) The impact test requirements and acceptance standards for welding procedure qualification weld metal shall be the same as specified in WB-2330 for the base material to be welded or repaired. Where two materials are to be joined by welding and have different fracture toughness requirements, the test requirements and acceptance standards of either material may be used for the weld metal except where this is otherwise specified by WA-1280 or other parts of this Subsection.

(c) Impact tests are not required for austenitic and nonferrous weld metal.

(d) A Welding Procedure Specification qualified to the impact testing requirements of Subsection NB or NE may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Division.

WB-4335.2 Impact Tests of Heat Affected Zone

(a) Charpy V-notch tests of the heat affected zone of the welding procedure qualification test assembly are required whenever the thickness of the weld exceeds $\frac{5}{8}$ in. (16 mm) and either of the base materials require impact testing in accordance with the rules of WB-2310. Exemption of base materials by WB-2311(a) does not apply to the welding procedure qualification heat affected zone or unaffected base material for such materials. The only exceptions to the requirements are the following:

(1) the qualification for welds in P-Nos. 1 and 3 and SA-336 F12 materials that are postweld heat treated and are made by any process other than electroslog, electrogas, or thermit;

(2) the qualification for weld deposit cladding.

(b) Impact testing of the welding procedure qualification test heat affected zone, where required by WB-4335 shall be conducted in accordance with (b)(1) through (b)(3), or (b)(4) through (b)(6), and (c), if applicable.

(1) For tests of welding procedure qualifications for material that requires testing in accordance with WB-2331.1, the three Charpy V-notch heat affected zone specimens and three Charpy V-notch unaffected base material specimens shall be tested at a temperature in accordance with WB-2331.1(a)(1). The Charpy V-notch impact tests of the unaffected base material shall meet the requirements of Table WB-2331.2-1 or Table WB-2331.2-2. If the average lateral expansion values of the three HAZ specimens are equal to or greater than the average value for the unaffected base material Charpy V-notch specimens, the qualification test shall be considered acceptable, and the values and testing temperature shall be recorded on the Welding Procedure Qualification Record.

(2) If the heat affected zone Charpy V-notch average toughness values of (b)(1) above is less than that for the unaffected base material, and the qualification test meets the other criteria of acceptance, the Charpy V-notch test results may be recorded on the Welding Procedure Qualification Record. Data shall then be obtained as specified in (b)(3) below to provide an additive temperature for the adjustment of the lowest service temperature (LST) of the base material that is to be welded in production with the welding procedure that is being qualified. Alternatively, the welding procedure qualification may be rewelded and retested.

(3) The data for use in (b)(2) above shall be developed by performing additional Charpy V-notch tests on either the welding procedure qualification heat affected zone or the unaffected base material, or both, at temperatures which provide toughness values that meet or exceed those required for the thickness or thickness-strength combination of the material to be welded in production. The toughness data for the heat affected zone and unaffected base material shall be plotted on a property temperature chart. The temperatures at which these two sets of data exhibit a common acceptable value of toughness for the production thickness

Page 156

or thickness-strength combination involved shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the heat affected zone. This difference shall be used in (b)(2) above as the adjustment temperature. The adjustment temperature shall be added to the highest LST established by the tests of WB-2331.1 for all of the base material to be welded by this procedure in production. If the temperature difference is zero or is a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by the tests for WB-2331.1 will still apply as stated in (b)(1) above. Where the actual LRT is not required for the production material to be welded, for example, where a testing temperature is established by the Design Specification to determine that the material has adequate toughness to meet the requirements at the specified test temperature, the adjustment temperature determined by the curves shall be used to establish a reduction in the specified testing temperature for the production material. The adjustment temperature shall be used to lower the specified testing temperature for any production material on which the procedure will be used.

(4) For tests of welding procedure qualifications for materials that require tests in accordance with WB-2332(a), the three Charpy V-notch heat affected zone specimens and three Charpy V-notch unaffected base material specimens shall be tested at a temperature lower than or equal to the LST. The Charpy V-notch impact test of the unaffected base material shall meet or exceed the applicable over $2\frac{1}{2}$ in. (64 mm) thickness requirements of Table WB-2331.2-1 or Table WB-2331.2-2. If the average lateral expansion values of the three heat affected zone specimens are equal to or greater than the average value of the unaffected base material Charpy V-notch specimens, the test shall be considered acceptable, and the values and testing temperature shall be recorded on the Welding Procedure Qualification Record.

(5) If the average Charpy V-notch toughness value for the heat affected zone of (b)(4) above is less than the unaffected base material and the welding procedure qualification test meets the other criteria of acceptance, the Charpy V-notch test results may be recorded on the Welding Procedure Qualification Record. Data shall then be obtained as specified in (b)(6) below to provide an additive temperature for the adjustment of the lowest service temperature of the base material that is to be welded in production with the welding procedure that is being qualified. Alternatively, the welding procedure qualification may be rewelded and retested.

(6) The data for use in (b)(5) above shall be developed by performing additional Charpy V-notch tests on either the welding procedure qualification heat affected zone or the unaffected base material, or both, at temperatures which provide toughness values equal to or greater than the applicable over $2\frac{1}{2}$ in. (64 mm) thickness requirements of Table WB-2331.2-1 or Table WB-2331.2-2. The average toughness data for the heat affected zone and unaffected base material shall be plotted on a property-temperature chart. The temperatures at which these two sets of data exhibit a

common toughness value equal to or greater than the applicable over $2\frac{1}{2}$ in. (64 mm) thickness requirements of Table WB-2331.2-2 or Table WB-2331.2-1 shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the heat affected zone. The difference, if a positive number, shall be used in (b)(5) above as the adjustment temperature. The adjustment temperature shall be added to the highest T_{NDT} established by the tests of WB-2331.1 for all of the base material to be welded by this procedure in production. If the temperature difference is zero or a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by the tests for WB-2331.1 will still apply as stated in (b)(4) above.

Where the actual T_{NDT} is not required for the product material to be welded, for example, where a testing temperature is established by the Design Specification to determine that T_{NDT} is at or below the specified temperature, the adjustment temperature determined by the curves shall be used to establish a reduction in the specified testing temperature for the production material. The adjustment temperature shall be used to lower the specified testing temperature for any production material upon which the procedure will be used.

(c) Should the unaffected base material Charpy V-notch impact test results fail to meet the applicable requirements referenced in (b)(1) or (b)(4) above, additional unaffected base material Charpy V-notch impact tests shall be tested at higher temperatures until the applicable requirements are met. Charpy V-notch impact specimens of the heat affected zone shall be tested at the same temperature at which acceptable unaffected base material properties were achieved. The rules governing the average lateral expansion of the heat affected zone relative to the average lateral expansion of the unaffected base material shall be followed as in (b)(1) through (b)(3) or (b)(4) through (b)(6) above, as applicable, to determine the data which are to be recorded on the Welding Procedure Qualification Record.

Page 157

(d) A Welding Procedure Specification qualified to the impact testing requirements of Subsection NB or NE may be accepted as an alternative to the Welding Procedure impact testing requirements of this Division.

WB-4336 Qualification Requirements for Built-Up Weld Deposits

Built-up weld deposits for base metal reinforcement shall be qualified in accordance with the requirements of WB-4331 through WB-4335.

WB-4360 QUALIFICATION REQUIREMENTS FOR WELDING SPECIALLY DESIGNED WELDED SEALS

WB-4361 General Requirements

(a) Specially designed welded seals are defined as the walls or membranes, such as an omega shaped seal membrane, which confine the fluid and where strength is provided by a separate device.

(b) The welding procedure shall be qualified as a new procedure specification and shall be completely requalified when any of the essential variables specified or listed in the following paragraphs are made in the procedure. Changes other than those so given may be made in the procedure without the necessity for requalification provided the procedure is amended to show these changes. In addition, the essential variables specified in Section IX shall apply for both procedure and performance qualification.

WB-4362 Essential Variables for Automatic, Machine, and Semiautomatic Welding

The welding procedure shall be qualified as a new procedure specification and shall be completely requalified when any of the changes listed in this paragraph or the applicable portions of Section IX are made:

(a) when preplaced filler metal is melted to form all or part of a weld, a change from one alloy type or classification to any other alloy type or classification of base material or filler metal, even though previously qualified base materials and filler metals are of the same P-Number or A-Number;

(b) a change of any dimension of the weld joint for automatic or machine welding or a change of any dimension of the weld joint by more than 10% for semiautomatic welding beyond that qualified;

- (c) a change in the nominal size or shape of any filler metal added to the arc;
- (d) for automatic welding, an increase or decrease in the length of the seal weld by more than 30%;
- (e) for automatic welding, a change in the welding current greater than 50% of the difference between the maximum and minimum amperages used during qualification; only two test assemblies need to be welded for requalification;
- (f) any change in the angular relationship or distance between the welding electrode and the work and the filler metal beyond the range qualified;
- (g) the addition or deletion of the use of tack welds or locating fixtures to facilitate alignment or to maintain the root opening of the weld joint;
- (h) the addition or deletion of consumable inserts.

WB-4363 Essential Variables for Manual Welding

The welding procedure must be qualified as a new procedure specification and shall be completely requalified when any of the changes listed in (a) and (b) below are made in the procedure:

- (a) a change of more than $\pm 10\%$ of any dimension of the weld joint cross section other than the included angle of the groove, except that base material thickness may vary from minus 10% to 2.5 times the thickness qualified when welding parts of the same material thickness, or the thin member may vary from minus 10% to 2 times the thickness qualified when welding a thin seal membrane to a thick member;
- (b) when preplaced filler metal is melted to form all or part of a weld, a change from one alloy type or classification to any other alloy type or classification of base material or filler metal, even though previously qualified base materials and filler metals are of the same P-Number or A-Number.

WB-4366 Test Assembly

The test assembly shall consist of a duplicate of the production weld except that tolerances as stated in WB-4362(b) or WB-4363(a) are permitted. Except for automatic welding, the Certificate Holder may use a 12 in. (305 mm) length to qualify, if the length of the production weld is considered to be greater than necessary to qualify.

WB-4366.1 Automatic Welding.

For automatic welding, at least six consecutive test assemblies representing the range of dimensions to be qualified shall be required to establish the reproducibility of the welding procedure. In addition, the Certificate Holder making the production welds shall verify this capability of

Page 158

making two consecutive test assemblies prior to production welding using the previously qualified procedure.

WB-4366.2 Manual, Machine, and Semiautomatic Welding.

For manual, machine, and semiautomatic welding, two test assemblies shall be required.

WB-4367 Examination of Test Assembly

- (a) Where 100% weld penetration is required, the test assembly shall be sectioned, if necessary, to permit examination of the entire underside weld surface.
- (b) A minimum of four cross sections shall be taken from each test assembly. One cross section shall be made in a weld start and stop area and the others shall be taken at random. Each cross section shall be examined at $\times 10$ to $\times 15$ magnification in accordance with ASTM Standard E 2. All surfaces shall be free of cracks, incomplete penetration, incomplete melting of insert on consumable type welds, and porosity or inclusions in excess of one rounded void with the maximum dimension not greater than 10% of the thickness of the weld. When doubt exists as to the acceptability of the weld, after examination of four cross sections, the Inspector may require that additional metallographic cross sections be prepared for examination of the weld and adjacent base material.

WB-4368 Performance Qualification Test

The performance qualification test assembly shall meet the same requirements specified for the procedure qualification test assembly in WB-4366 and shall be examined in accordance with WB-4367. Furthermore, welding operators shall qualify using the welding machine which will be used to make production welds and shall be required to set up the machine with regard to adjustments and settings which affect the welding characteristics. One test assembly is required.

WB-4400 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS

WB-4410 PRECAUTIONS TO BE TAKEN BEFORE WELDING

WB-4411 Identification, Storage, and Handling of Welding Material

Each Certificate Holder is responsible for control of the welding electrodes and other material which is used in the fabrication and installation of components (WB-4120). Suitable identification, storage, and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by electrodes and flux.

WB-4412 Cleanliness and Protection of Welding Surfaces

The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

WB-4420 RULES FOR MAKING WELDED JOINTS

WB-4421 Backing Rings

When used in components other than piping, backing rings shall conform to the requirements of WB-4240. Backing rings shall not be used in piping unless removed after welding and the inside surfaces of the roots are examined by a magnetic particle or liquid penetrant method, in accordance with WB-5110, and meeting the acceptance standards of WB-5340 or WB-5350. The material for backing rings, when used, shall be compatible with the base metal. Permanent backing rings, when permitted by WB-3352, shall be continuous, and any splices shall be made by full penetration welds. Spacer pins shall not be incorporated into the welds.

WB-4422 Peening

Controlled peening may be performed to minimize distortion. Peening shall not be used on the initial layer, root of the weld metal, or on the final layer unless the weld is postweld heat treated.

WB-4423 Miscellaneous Welding Requirements

(a) Before applying weld metal on the second side to be welded, the root of full penetration double welded joints shall be prepared by suitable methods, such as chipping, grinding, or thermal gouging, except for those processes of welding by which proper fusion and penetration are otherwise obtained and demonstrated to be satisfactory by welding procedure qualification.

(b) If the welding is stopped for any reason, extra care shall be taken in restarting to get the required

penetration and fusion. For submerged arc welding, chipping out a groove in the crater is recommended.

(c) Where single welded joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joint for its full length.

WB-4424 Surfaces of Welds

As-welded surfaces are permitted, except for inertia and continuous drive friction welding where the flash shall be removed to sound metal. For piping, the appropriate stress indices given in Table WB-3681(a)-1 shall be applied. However, the surface of welds shall be sufficiently free from coarse ripples, grooves, overlaps, and abrupt ridges and valleys to meet (a) through (e) below.

(a) The surface condition of the finished weld shall be suitable for the proper interpretation of radiographic and other required nondestructive examinations of the weld. In those cases where there is a question regarding the surface condition of the weld on the interpretation of a radiographic film, the film shall be compared to the actual weld surface for interpretation and determination of acceptability.

(b) Reinforcements are permitted in accordance with WB-4426.1 for vessels, pumps, and valves, and WB-4426.2 for piping.

(c) Undercuts shall not exceed $\frac{1}{32}$ in. (0.8 mm) and shall not encroach on the required section thickness.

(d) Concavity on the root side of a single-welded circumferential butt weld is permitted when the resulting thickness of the weld meets the requirements of WB-3000.

(e) If the surface of the weld requires grinding to meet the above criteria, care shall be taken to avoid reducing the weld or base material below the required thickness.

WB-4425 Welding Items of Different Diameters

When items of different diameters are welded together, there shall be a gradual transition between the two surfaces in accordance with WB-4250, unless greater slopes are shown to be acceptable by analysis in accordance with WB-3200. The length of the transition may include the weld.

WB-4426 Reinforcement of Welds

WB-4426.1 Thickness of Weld Reinforcement for Containment Vessels and Valves.

The surface of the reinforcement of all butt welded joints in containment vessels and valves may be flush with the base material or may have uniform crowns. The height of reinforcement on each face of the weld shall not exceed the thickness in the following tabulation.

Nominal Thickness, in.	Maximum Reinforcement, in.
Up to 1, incl.	$\frac{3}{32}$
Over 1 to 2, incl.	$\frac{1}{8}$
Over 2 to 3, incl.	$\frac{5}{32}$
Over 3 to 4, incl.	$\frac{7}{32}$
Over 4 to 5, incl.	$\frac{1}{4}$
Over 5	$\frac{5}{16}$

WB-4427 Shape and Size of Fillet Welds

Fillet welds may vary from convex to concave. The shape and size of the weld shall be in accordance with the requirements of Fig. WB-4427-1. A fillet weld in any single continuous weld may be less than the specified fillet weld dimension by not more than $\frac{1}{16}$ in. (1.6 mm), provided that the total undersize portion of the weld does not exceed 10% of the length of the weld. Individual undersize weld portions shall not exceed 2 in. (51 mm) in length. In making socket welds, a gap as shown in Fig. WB-4427-1 shall be provided prior to welding. The gap need not be present nor be verified after welding.

WB-4428 Seal Welds of Threaded Joints

Where seal welding of threaded pipe joints is performed, the exposed threads shall be either removed entirely or covered

with weld metal.

WB-4429 Welding of Clad Parts¹

The joint types and welding procedures used for cladding shall be such as to prevent the formation of brittle weld composition.

¹ Welds that are exposed to corrosive action should have a resistance to corrosion that is not substantially less than that of the cladding. The use of filler metal that will deposit weld metal which is similar to the composition of the cladding material is recommended. If weld metal of different composition is used, it should have properties compatible with the application.

Page 160

Page 161

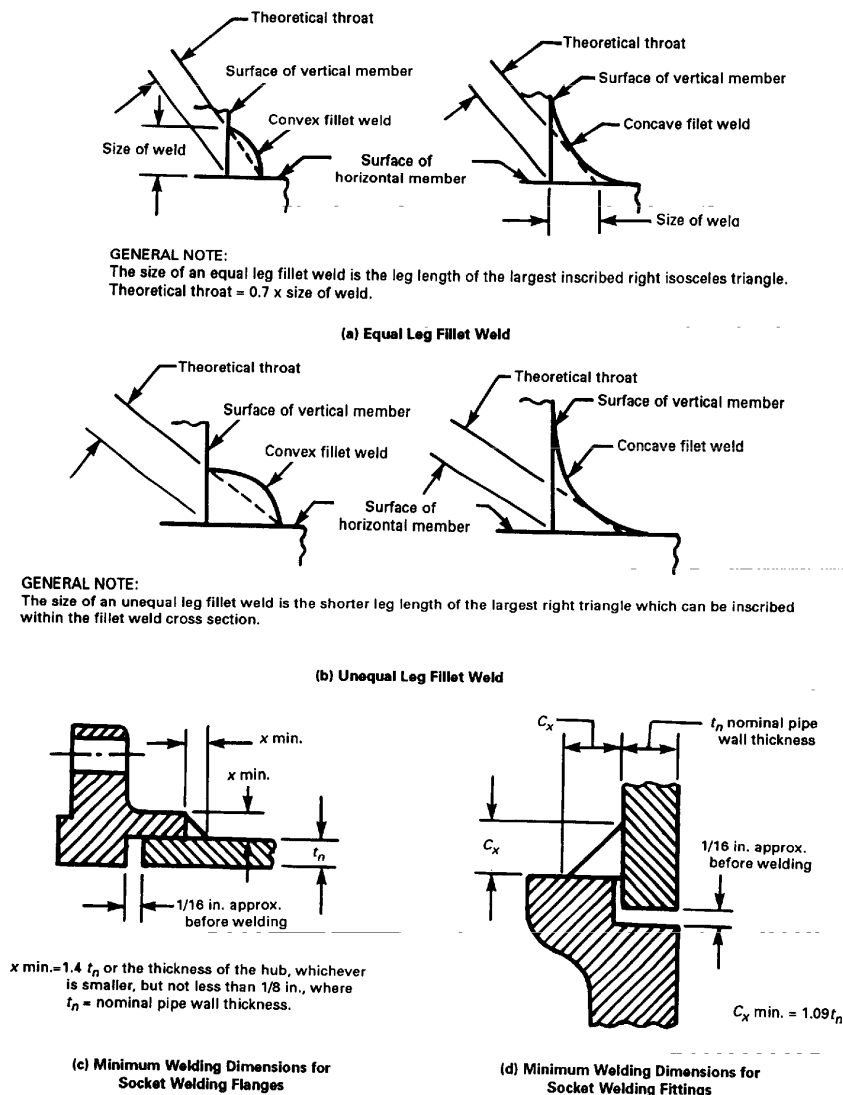


FIG. WB-4427-1 FILLET AND SOCKET WELD DETAILS AND DIMENSIONS
See WB-3661.2 for limitation on socket weld pipe size.

FIG. WB-4427-1 FILLET AND SOCKET WELD DETAILS AND DIMENSIONS

WB-4430 WELDING OF ATTACHMENTS

WB-4431 Materials for Attachments

Nonpressure-retaining attachments (WB-1132.1) welded to pressure retaining components shall be of materials which meet the requirements of WB-2121. Materials for pressure retaining attachments shall meet the requirements of WB-2120.

WB-4432 Welding of Structural Attachments

The rules of WB-4321 governing welding qualifications shall apply to the welding of structural attachments to pressure retaining material.

WB-4433 Structural Attachments

Structural attachments shall conform reasonably to the curvature of the surface to which they are to be attached and shall be attached by full penetration, fillet, or partial penetration continuous welds. When fillet and partial penetration welds are used on components, the requirements of WB-3123.2 shall be met. Attachments to the internal surfaces of containment vessels shall be made only with full penetration welds. Figure WB-4433-1 illustrates some of the typical details for attaching structural attachments to a component using full penetration welds. Valve seats may be attached to the pressure boundary part by fillet or partial penetration welds provided the valve seat is shouldered against the pressure boundary part.

WB-4434 Welding of Internal Structural Supports to Clad Components

Internal structural supports on clad components shall be welded to the base metal and not to the cladding, except for weld overlay cladding.

WB-4435 Welding of Nonstructural and Temporary Attachments and Their Removal

(a) Nonstructural attachments (WB-1132.1) welded to the pressure retaining portion of the component need not comply with WB-2000 and may be welded with continuous fillet or partial penetration welds, provided the requirements of (1) through (4) below are met.

- (1) The welding procedure and the welders have been qualified in accordance with WB-4321.
- (2) The material is identified and is compatible with the material to which it is attached.
- (3) The welding material is identified and compatible with the materials joined.
- (4) The welds are postweld heat treated when required by WB-4620.

(b) Removal of nonstructural attachments, when temporary, shall be accomplished as follows.

- (1) The immediate area around the temporary attachment is marked in a suitable manner so that after removal the area can be identified until after it has been examined in accordance with (3) below.
- (2) The temporary attachment is completely removed in accordance with the procedures of WB-4211.
- (3) After the temporary attachment has been removed, the marked area is examined by the liquid penetrant or magnetic particle method in accordance with the requirements of WB-5110, and meets the acceptance standards of WB-5340 or WB-5350, whichever is applicable.
- (4) As an alternative to (a)(4) above, postweld heat treatment may be deferred until after removal of the attachment.

WB-4436 Installation of Attachments to Piping Systems After Testing

Attachments may be welded to the piping system after performance of the pressure test provided that:

- (a) the welds do not require PWHT under WB-4622.7;
- (b) welds shall be restricted to fillet welds not exceeding $\frac{3}{8}$ in. (10 mm) throat thickness and to full penetration welds attaching materials not exceeding $\frac{1}{2}$ in. (13 mm) in thickness;
- (c) welds shall not exceed a total length of 24 in. (605 mm) for fillet welds or 12 in. (302 mm) for full penetration welds;
- (d) welds shall be examined as required by WB-5000.

WB-4450 REPAIR OF WELD METAL DEFECTS

WB-4451 General Requirements

Defects in weld metal detected by the examinations required by WB-5000, or by the tests of WB-6000, shall be eliminated and repaired when necessary.

WB-4452 Elimination of Surface Defects

Weld metal surface defects may be removed by grinding or machining, and need not be repaired by welding, provided that the requirements of (a) through (c) below are met.

Page 162

Page 163

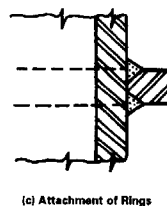
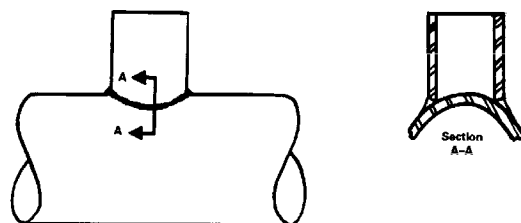
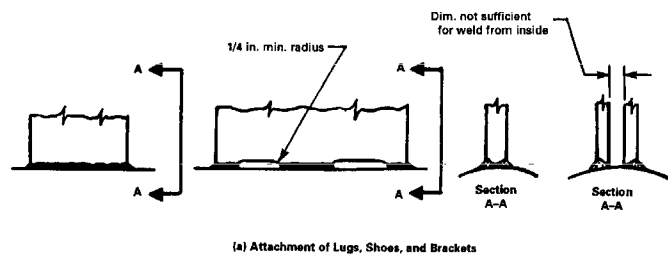


FIG. WB-4433-1 TYPES OF ATTACHMENT WELDS

FIG. WB-4433-1 TYPES OF ATTACHMENT WELDS

- (a) The remaining thickness of the section is not reduced below that required by WB-3000.
- (b) The depression, after defect elimination, is blended uniformly into the surrounding surface.
- (c) The area is examined by a magnetic particle or liquid penetrant method in accordance with WB-5110 after blending and meets the acceptance standards of WB-5300 to ensure that the defect has been removed or reduced to an imperfection of acceptable limit. Defects detected by visual or volumetric method and located on an interior surface need only be reexamined by the method which initially detected the defect when the interior surface is inaccessible for surface examination.

WB-4453 Requirements for Making Repairs of Welds

Excavations in weld metal, when repaired by welding, shall meet the following requirements.

WB-4453.1 Defect Removal.

Defects may be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined by a liquid penetrant or magnetic particle method in accordance with WB-5110, and meet the acceptance standards of WB-5340 or WB-5350. This examination is not required where defect elimination removes the full thickness of the weld and where the backside of the weld joint is not accessible for removal of examination materials.

WB-4453.2 Requirements for Welding Material, Procedures, and Welders.

The weld repair shall be made using welding material, welders, and welding procedures qualified in accordance with WB-4125 and WB-4300.

WB-4453.3 Blending of Repaired Areas.

After repair, the surface shall be blended uniformly into the surrounding surface.

WB-4453.4 Examination of Repair Welds

(a) The examination of a weld repair shall be repeated as required for the original weld, except that when the defect was originally detected by the liquid penetrant or magnetic particle method, and when the repair cavity does not exceed the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the thickness, it need only be reexamined by the liquid penetrant or magnetic particle method.

(b) When repairs to welds joining P-No. 1 and P-No. 3 materials require examination by radiography as required in (a) above, but construction assembly prevents meaningful radiographic examination, ultrasonic examination may be substituted provided:

- (1) the weld had been previously radiographed and met the applicable acceptance standards;
- (2) the ultrasonic examination is performed using a procedure in accordance with Section V, Article 5, to the acceptance standards of WB-5330;
- (3) the substitution is limited to Category A and B welds in vessels, and similar type welds in other items.

The absence of suitable radiographic equipment is not justification for the substitution.

WB-4453.5 Heat Treatment of Repaired Areas.

The area shall be heat treated in accordance with WB-4620.

WB-4500 BRAZING

WB-4510 RULES FOR BRAZING

WB-4511 Where Brazing May Be Used

(a) Brazing is permitted for the attachment of cladding to base material, of tubes to tubesheets, and as specified in WB-3671.6(a). Appurtenances and piping with outside diameter equal to that of 1 in. nominal pipe size and less may be fabricated using brazed joints in accordance with Fig. WB-4511-1.

(b) Valves with inlet piping connections of 4 in. nominal pipe size and less may have seats brazed to the valve body or bonnet provided the seat is shouldered against the pressure boundary part [Fig. WB-3544.1(c)-1].

WB-4512 Brazing Material

Where brazing is permitted, the brazing filler material and fluxes shall conform to the rules covering identification in WB-2150 and to the requirements of (a), (b), and (c) below.

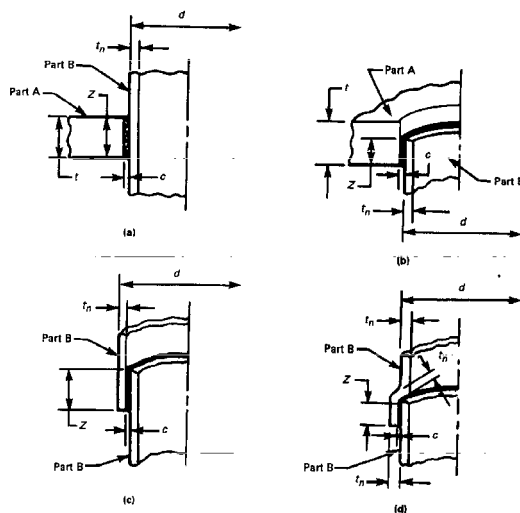
(a) The filler material used in brazing shall be a nonferrous metal or alloy with a solidus temperature above 800°F (427°C) and at least 500°F (278°C) above the highest temperature of the joint in service.

(b) The filler material shall melt and flow freely by capillary action within the desired temperature range, and, in conjunction with a suitable flux or controlled atmosphere, the filler material shall wet and adhere to the surfaces to be joined.

(c) Fluxes that are fluid and chemically active at the brazing temperature shall be used, when necessary, to prevent oxidation of the filler metal and the surfaces to be joined, and to promote free flowing of the filler material.

Page 164

Page 165



t = thickness of part penetrated
 t_n = nominal thickness of connecting part
 d = outside diameter of part B
 c = clearance or interference between mating parts and shall be in accordance with the brazing procedure specification
 Z = depth of engagement and shall be the lesser of $3t_n$ or d , but in no case less than $1/4$ in.

GENERAL NOTES:

- (a) Part A shall be attached to a component in accordance with the requirements for the component proper.
- (b) Part B shall be attached either to Part A or to another Part B by the joints shown above, or in accordance with the requirements of the component proper.
- (c) Grooves for preplaced filler metal are permitted, provided the reduction in cross section due to the grooves is considered in the design.

FIG. WB-4511-1 BRAZED CONNECTIONS FOR APPURTENANCES AND PIPING, 1 in. NOMINAL SIZE AND LESS

FIG. WB-4511-1 BRAZED CONNECTIONS FOR APPURTENANCES AND PIPING, 1 in. NOMINAL SIZE AND LESS

WB-4520 BRAZING QUALIFICATION REQUIREMENTS

WB-4521 Brazing Procedure and Performance Qualification

Qualification of the brazing procedure to be used and of the performance of brazers and brazing operators is required and shall comply with the requirements of Section IX, except that validation of the procedure qualification per QB-451.5 Note (1) is not required for the furnace brazing of seat rings to bodies or bonnets of valves having inlet piping connections of 4 in. (102 mm) nominal pipe size and less. When the Design Temperature is greater than 200°F (93°C), tension testing shall be performed at the Design Temperature.

WB-4522 Brazing Requalification Requirements

In addition to the requirements of Section IX, the brazing procedure shall be set up as a new procedure specification and shall be completely requalified when the construction of the brazed components includes reheating of any portion of the completed brazed joint to a temperature that is within 300°F (149°C) of the solidus temperature of the filler metal.

WB-4530 FITTING AND ALIGNING OF PARTS TO BE BRAZED

Parts to be joined by brazing shall be fitted, aligned, and retained in position during the brazing operation within the tolerances specified in the brazing procedure specification. Brazed joints shall be assembled in a sequence which will permit the maximum number of joints to be visually examined on both sides of the joint after brazing.

WB-4540 EXAMINATION OF BRAZED JOINTS

The completed brazed joints shall be visually examined on all accessible surfaces in accordance with WB-5275.

WB-4600 HEAT TREATMENT

WB-4610 WELDING PREHEAT REQUIREMENTS

WB-4611 When Preheat Is Necessary

The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, elevated temperature, physical properties, and material thicknesses. Some practices used for preheating are given in Appendix D as a general guide for the materials listed by P-Numbers of Section IX. It is cautioned that the preheating suggested in Appendix D does not necessarily ensure satisfactory completion of the welded joint and that the preheating requirements for individual materials within the P-Number may be more or less restrictive. The Welding Procedure Specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.

WB-4612 Preheating Methods

Preheat for welding or thermal cutting, when employed, may be applied by any method which does not harm the base material or any weld metal already applied, or which does not introduce deleterious material into the welding area which is harmful to the weld.

WB-4613 Interpass Temperature

Consideration shall be given to the limitations of interpass temperatures for quenched and tempered material to avoid detrimental effects on the mechanical properties.

WB-4620 POSTWELD HEAT TREATMENT

WB-4621

WB-4621 Heating and Cooling Methods

Postweld heat treatment (PWHT) may be accomplished by any suitable methods of heating and cooling, provided the required heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control are maintained.

Page 166

WB-4622 PWHT Time and Temperature Requirements

WB-4622.1 General Requirements.²

Except as otherwise permitted in WB-4622.7, all welds, including repair welds, shall be postweld heat treated. During postweld heat treatment, the metal temperature shall be maintained within the temperature range and for the minimum holding time specified in Table WB-4622.1-1, except as otherwise permitted in WB-4622.4(c). P-Number groups in Table WB-4622.1-1 are in accordance with QW-420 of Section IX. Except as provided in WB-4624.3, PWHT shall be performed in temperature-surveyed and -calibrated furnaces, or PWHT shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. In addition, the requirements of the following subparagraphs shall apply.

WB-4622.2 Time-Temperature Recordings.

Time-temperature recordings of all postweld heat treatments shall be made available for review by the Inspector. Identification on the time-temperature recording shall be to the weld, part, or component, as applicable. A summary of the time-temperature recording may be provided for permanent records in accordance with WA-4134.17.

WB-4622.3 Definition of Nominal Thickness Governing PWHT.

Nominal thickness in Table WB-4622.7(b)-1 is the thickness of the weld, the pressure retaining material for structural attachment welds or the thinner of the pressure retaining materials being joined, whichever is least. It is not intended that nominal thickness include material provided for forming allowance, thinning, or mill overrun when the excess material does not exceed $\frac{1}{8}$ in. (3.2 mm). For fillet welds the nominal thickness is the throat thickness, and for partial penetration and material repair welds the nominal thickness is the depth of the weld groove or preparation.

WB-4622.4 Holding Times at Temperature

(a) The holding time at temperature as specified in Table WB-4622.1-1 shall be based on the nominal thickness of the weld. The holding time need not be continuous. It may be an accumulation of the times of multiple postweld heat treat cycles.

2 Any postweld heat treatment time which is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

(b) Holding time at temperature in excess of the minimum requirements of Table WB-4622.1-1 may be used, provided that specimens so heat treated are tested in accordance with WB-2200, WB-2400, and WB-4300.

(c) Alternatively, when it is impractical to postweld heat treat at the temperature range specified in Table WB-4622.1-1, it is permissible to perform the postweld heat treatment of certain materials at lower temperatures for longer periods of time in accordance with Table WB-4622.4(c)-1 and (1), (2), and (3) below.

(1) Except for P-No. 1 materials, when welds in the materials listed in Table WB-4622.4(c)-1 are to be postweld heat treated at the lower minimum temperatures, the impact test specimens for the welding procedure qualification required by WB-4300 shall be made using the same minimum temperatures and increased minimum holding time. Welding procedures, qualified at the temperature range and minimum holding time specified in Table WB-4622.1-1 and at the lower temperature and increased minimum holding time permitted by Table WB-4622.4(c)-1, are also qualified for any temperature in between. When such an in-between temperature is used, the minimum holding time shall be interpolated from Table WB-4622.1-1 and the alternative requirements from Table WB-4622.4(c)-1.

(2) Except for P-No. 1 materials, when welds in the materials listed in Table WB-4622.4(c)-1 are to be postweld heat treated at these lower minimum temperatures, the welding material certification required by WB-2400 shall be made

using the same minimum temperature and increased minimum holding time. Welding material certified at the temperature range and minimum holding time specified in Table WB-4622.1-1 and at the lower minimum temperatures and increased minimum holding time permitted by Table WB-4622.4(c)-1 are also certified for any temperature in between.

(3) Base material certified in accordance with WB-2200 may be postweld heat treated at the lower minimum temperature ranges and increased minimum holding times without recertification. Postweld heat treatment at these lower minimum temperatures and increased minimum holding times may also be the tempering operation provided a higher tempering temperature is not required by the material specification.

WB-4622.5 PWHT Requirements When Different P-Number Materials Are Joined.

When materials of two different P-Number groups are joined by welding, the applicable postweld heat treatment shall be that specified in Table WB-4622.1-1 for the material requiring the higher PWHT temperature range.

WB-4622.6 PWHT Requirements for Nonpressure-Retaining Parts.

When nonpressure-retaining material is welded to pressure retaining material, the postweld

Page 167

heat treatment temperature range of the pressure retaining material shall control.

TABLE WB-4622.1-1
MANDATORY REQUIREMENTS FOR POSTWELD HEAT TREATMENT OF WELDS [Note (1)]

P-No. (QW-420, Sect. IX)	Holding Temperature Range, °F [Note (2)]	Minimum Holding Time at Temperature for Weld Thickness (Nominal)			
		½ in. or less	Over ½ in. to 2 in.	Over 2 in. to 5 in.	Over 5 in.
1, 3	1100–1250	30 min	1 hr/in.	2 hr plus 15 min each additional inch over 2 in.	2 hr plus 15 min each additional inch over 2 in.
4	1100–1250	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
5A, 5B, 5C, 6 except P-No. 6 Gr. 4	1250–1400	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
6 Gr. 4	1050–1150				
7	1300–1400	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
9A Gr. 1	1100–1250	30 min	1 hr/in.	1 hr/in.	5 hr plus 15 min each additional inch over 5 in.
9B Gr. 1	1100–1175				
10F Gr. 1	1100–1250				
10I Gr. 1	1300–1400				
11A Gr. 4	1000–1050	30 min	1 hr/in.	1 hr/in.	1 hr/in.
P-Nos. 8, 34, 42, 43, 45, and hard surfacing on P-No. 1 base metal whose reported carbon content is not more than 0.30%	PWHT neither required nor prohibited				

NOTES:

- (1) Exemptions to the mandatory requirements of this Table are defined in NB-4622.7.
(2) All temperatures are metal temperatures.

TABLE WB-4622.1-1 MANDATORY REQUIREMENTS FOR POSTWELD HEAT TREATMENT OF WELDS
[Note (1)]

**TABLE WB-4622.4(c)-1
ALTERNATIVE HOLDING TEMPERATURES AND
TIMES [Note (1)]**

Material P-No.	Alternative Minimum Holding Temperatures, °F	Alternative Minimum Holding Times [Note (1)]
1, 3, 9A Gr. 1, 9B Gr. 1	1050	2 hr/in. thick
1, 3, 9A Gr. 1, 9B Gr. 1	1000	4 hr/in. thick

NOTE:

(1) All other requirements of NB-4622 shall apply.

TABLE WB-4622.4(c)-1 ALTERNATIVE HOLDING TEMPERATURES AND TIMES [Note (1)]

WB-4622.7 Exemptions to Mandatory Requirements.

Postweld heat treatment in accordance with this Subarticle is not required for:

- (a) nonferrous material;
- (b) welds exempted in Table WB-4622.7(b)-1;
- (c) welds subjected to temperatures above the PWHT temperature range specified in Table WB-4622.1-1, provided the Welding Procedure Specification is qualified in accordance with Section IX and the base material and the deposited weld filler material have been heat treated at the higher temperature;
- (d) welds connecting nozzles to components or branch to run piping provided the requirements in WB-4622.8 are met;
- (e) weld repairs to vessels provided the requirements of WB-4622.9 are met;
- (f) weld repairs to cladding after final postweld heat treatment provided the requirements of WB-4622.10 are met;
- (g) weld repairs to dissimilar metal welds after final postweld heat treatment provided the requirements of WB-4622.11 are met.

WB-4622.8 Requirements for Exempting PWHT of Nozzles to Component Welds and Branch to Run Piping Welds.

Welds connecting nozzles or branch piping of P-No. 1 materials to components or run piping of P-No. 1 or P-No. 3 materials that are not exempted from PWHT in Table WB-4622.7(b)-1 need not be given a postweld heat treatment if the requirements of (a) below are met for partial penetration and (b) below are met for full penetration welds.

(a) The partial penetration welds are made with A-No. 8 or non-air-hardening nickel-chromium-iron weld metal after:

(1) the ferritic materials to be joined are buttered or built-up with A-No. 8 or non-air-hardening nickel-chromium-iron weld metal having a minimum thickness of $\frac{1}{4}$ in. (6 mm), and

(2) the heat affected zones of the buttered or built-up ferritic materials are postweld heat treated in accordance with WB-4620, without the PWHT exemptions being applied, prior to making the final welds.

(b) The full penetration welds are made with A-No. 1 or A-No. 2 weld metal provided that:

(1) the component or run pipe is built-up or buttered in the area of the attachment with A-No. 1 or A-No. 2 metal having a minimum thickness of $\frac{1}{4}$ in. (6 mm);

(2) the A-No. 1 or A-No. 2 weld metal buildup or buttering is postweld heat treated in accordance with WB-4620 for P-No. 1 or P-No. 3 materials without the PWHT exemptions being applied;

(3) the welds do not penetrate through the component or run pipe thickness;

(4) weld metal with A-No. 1 or A-No. 2 analysis is used to join the nozzle or branch pipe of P-No. 1 material to the weld buildup or buttering;

(5) the nominal thickness of the weld joining the nozzle or branch pipe to the component or run pipe does not exceed $1\frac{1}{2}$ in. (38 mm) and the maximum reported carbon content of the nozzle or branch piping connection does not exceed 0.30%;

(6) a 200°F (93°C) minimum preheat is maintained during welding whenever the nominal thickness of the weld exceeds:

(a) $1\frac{1}{4}$ in. (32 mm) and the maximum reported carbon content of the material of the nozzle or branch pipe is 0.30% or less, or

(b) $\frac{3}{4}$ in. (19 mm) and the maximum reported carbon content of material of the nozzle or branch pipe connection exceeds 0.30%.

WB-4622.9 Temper Bead Weld Repair.

Limited weld repairs to P-No. 1 and P-No. 3 material, and A-Nos. 1, 2, 10, or 11 weld filler metal (QW-442 of Section IX), may be made without PWHT or after the final PWHT, provided it is impossible or impractical to postweld heat treat the area after repair, and provided the requirements of the following subparagraphs are met.

(a) *Examination of Area to Be Repaired.* Before repair, the area shall be examined by either the magnetic particle or liquid penetrant method in accordance with WB-5000.

(b) *Maximum Extent of Repair.* The maximum area of an individual repair based on the finished surface shall be 100 sq in. (3,871 mm²) and the depth of repair

Page 169

shall not be greater than one-third of the base material thickness. Pages 170-171

**TABLE WB-4622.7(b)-1
EXEMPTIONS TO MANDATORY PWHT [Note (1)]**

P-No. (Sect. IX, QW-420)		Type of Weld [Note (2)]	Nominal Thickness (NB-4622.3)	Max. Reported Carbon, % [Note (3)]	Min. Preheat Req'd, °F
1	Vessels	Circumferential butt and socket welds connecting pipe and tubes to nozzles where the materials being joined are 1½ in. and less	1¼ in. and less Over 1¼ in. to 1½ in. ¾ in. or less Over ¾ in. to 1½ in.	0.30 or less 0.30 or less Over 0.30 Over 0.30	... 200 ... 200
		Fillet welds	¾ in. or less	...	200
		All welds, except repair welds and fillet welds, provided welding procedure qualification is made using equal or greater thickness base material than the production weld	⅝ in. or less	0.25 or less	200
	Other components	All welds where the materials being joined are 1½ in. and less	1¼ in. and less Over 1¼ in. to 1½ in. ¾ in. or less Over ¾ in. to 1½ in.	0.30 or less 0.30 or less Over 0.30 Over 0.30	... 200 ... 200
		All welds in material over 1½ in.	¾ in. or less	...	200
	1, 3	For repair without required PWHT, see WB-4622.9, WB-4622.10, and WB-4622.11	...	...	350
1 Gr. 1 or Gr. 2		Cladding or repair of cladding [Note (4)] with A-No. 8 or F-No. 43 filler metal on base material of: 1½ in. or less over 1½ in. to 3 in. over 3 in.		0.30 0.30 0.30	100 200 [Note (5)] 250 [Note (6)]
3 except Gr. 3		All welds, except repair welds in vessels, provided welding procedure qualification is made using equal or greater thickness base material than the production weld	⅝ in. or less	0.25 or less	200
		Attachment welds joining nonpressure-retaining material to pressure-retaining material	½ in. or less	0.25 or less	200
		Circumferential butt welds in pipe and tubes	½ in. or less	0.25 or less	200
		Socket welds in pipe and tubes with nominal O.D. 2⅜ in. or less	½ in. or less	0.25 or less	200
4		Circumferential butt welds in pipe and tubes with nominal O.D. 4 in. or less and attachment welds	½ in. or less	0.15 or less	250

(Table continued)

TABLE WB-4622.7(b)-1 EXEMPTIONS TO MANDATORY PWHT [Note (1)]

TABLE WB-4622.7(b)-1 (CONT'D)
EXEMPTIONS TO MANDATORY PWHT [Note (1)]

P-No. (Sect. IX, QW-420)		Type of Weld [Note (2)]	Nominal Thickness (NB-4622.3)	Max. Reported Carbon, % [Note (3)]	Min. Preheat Req'd, °F
4		Socket welds in pipe and tubes with nominal O.D. $2\frac{3}{8}$ in. or less	$\frac{1}{2}$ in. or less	0.15 or less	250
5A, 5B, 5C		Circumferential butt welds in pipe and tubes with maximum reported chromium 3.00% or less and nominal O.D. 4 in. or less and attachment welds	$\frac{1}{2}$ in. or less	0.15 or less	300
		Socket welds in pipe and tubes with maximum reported chromium 3.00% or less and nominal O.D. $2\frac{3}{8}$ in. or less	$\frac{1}{2}$ in. or less	0.15 or less	300
6 (for Type 410) or 7 Gr. 1 (for Type 405)		Type 405 and 410S welded with A-No. 8, A-No. 9, or F-No. 43 filler metal	$\frac{3}{8}$ in. or less	0.08 or less	...
9A Gr. 1		All welds, provided the procedure qualification is made using equal or greater thickness base material than the production weld	$\frac{5}{8}$ in. or less	...	200
		Attachment welds joining nonpressure-retaining material to pressure-retaining material over $\frac{5}{8}$ in.	$\frac{1}{2}$ in. or less	...	200
		Circumferential butt welds in pipe and tubes with nominal O.D. 4 in. or less and attachment welds	$\frac{1}{2}$ in. or less	0.15 or less	250
		Socket welds in pipe and tubes with nominal O.D. $2\frac{3}{8}$ in. or less	$\frac{1}{2}$ in. or less	0.15 or less	250
9B Gr. 1		All welds, provided the procedure qualification is made using equal or greater thickness base material than the production weld	$\frac{5}{8}$ in. or less	...	200
		Attachment welds joining nonpressure-retaining material to pressure-retaining material over $\frac{5}{8}$ in.	$\frac{1}{2}$ in. or less	...	200
		Circumferential butt welds in pipe and tubes with nominal O.D. 4 in. or less and attachment welds	$\frac{1}{2}$ in. or less	0.15 or less	250
		Socket welds in pipe and tubes with nominal O.D. $2\frac{3}{8}$ in. or less	$\frac{1}{2}$ in. or less	0.15 or less	250
10I Gr. 1		All welds in material $\frac{1}{2}$ in. and less	$\frac{1}{2}$ in. or less	...	...
11A Gr. 4		All welds in material $\frac{1}{2}$ in. and less	$\frac{1}{2}$ in. or less	...	250

TABLE WB-4622.7(b)-1 (CONT'D) EXEMPTIONS TO MANDATORY PWHT [Note (1)]

TABLE WB-4622.7(b)-1 (CONT'D)

NOTES:

- (1) The exemptions noted in this Table do not apply to the following:
 - (a) electron beam welds in ferritic materials over $\frac{1}{8}$ in. in thickness;
 - (b) inertia and friction welds in material of any thickness of P-No. 3, P-No. 4, P-No. 5, P-No. 7 (except for Types 405 and 410S), P-No. 10, and P-No. 11 materials.
- (2) Where the thickness of material is identified in the Type of Weld column, it is the thickness of the base material at the welded joint.
- (3) Carbon level of the pressure-retaining materials being joined.
- (4) Maximum process heat input = 150,000 J/in. The maximum resulting hardness in the procedure qualification test plate shall not exceed 35 Rc.
- (5) Intermediate postweld soak at not less than 200°F for 2 hr minimum.
- (6) Intermediate postweld soak at not less than 300°F for 2 hr minimum.

TABLE WB-4622.7(b)-1 (CONT'D)

(c) *Repair Welding Procedure.* The welding procedure shall be in accordance with Section IX and this Division and shall include the requirements of (1) through (6) below.

- (1) The area to be repaired shall be suitably prepared for welding in accordance with a written procedure.
- (2) The weld metal shall be deposited by the manual shielded metal arc process using low hydrogen type electrode. The maximum bead width shall be four times the electrode core diameter.
- (3) The low hydrogen covered electrodes shall be baked and otherwise cared for as required by (a) through (d) below.

(a) The Certificate Holder shall bake all covered electrodes before use at a temperature of 750°F-850°F (399°C-454°C) for 30 min to 1 hr. The temperature of the oven shall not exceed 300°F (149°C) when the electrodes are placed in the oven for baking. During the baking cycle, the temperature shall not be raised more than 300°F/hr (167°C/hr) when oven temperatures are above 500°F (260°C) and the total time above 500°F (260°C), including the holding time, shall not exceed 5 hr.

(b) After baking and before the electrodes are allowed to cool below 225°F (107°C), they shall be transferred to holding ovens operating in temperature ranges of 225°F-350°F (107°C-177°C).

(c) Suitable heated portable containers shall be used at 225°F-350°F (107°C-177°C). Electrodes turned in after exposure shall be returned to the holding ovens and held at temperatures given in (b) above for a period of not less than 8 hr before reissue.

(d) Electrodes shall not be rebaked more than once, except if tests establish that the electrodes, after multiple rebakings, meet all specification requirements.

(e) If the repair area is to be subjected to a significant fast neutron fluence (greater than 10^{19} nvt $E_0 > 1$ MeV), electrode shall be limited to Cu content of 0.10% maximum (as deposited).

(4) The weld area plus a band around the repair area of at least $1\frac{1}{2}$ times the component thickness or 5 in. (127 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 350°F (177°C) during welding. The maximum interpass temperature shall be 450°F (232°C). Thermocouples and recording instruments shall be used to monitor the process temperatures. Their removal shall be in accordance with WB-4435(b).

(5) The cavity shall be buttered, using a $\frac{3}{32}$ in. (2.4 mm) diameter electrode as shown in Fig. WB-4622.9(c)(5)-1. The weld bead crown surface shall be removed by grinding or machining before depositing the second layer [see Fig. WB-4622.9(c)(5)-1, Step 2]. The second layer shall be deposited with a $\frac{1}{8}$ in. (3.2 mm) diameter electrode. Subsequent layers shall be deposited with a welding electrode no larger than $\frac{5}{32}$ in. (4 mm) diameter. Bead deposition shall be performed in a manner shown in Fig. WB-4622.9(c)(5)-1, Step 3. The completed weld shall have at least one layer of weld reinforcement deposited and then this reinforcement shall be removed by mechanical means, making the finished surface of the repair substantially flush with the surface of the vessel surrounding the repair [Fig. WB-4622.9(c)(5)-2].

The technique described in this paragraph shall be performed in the procedure qualification test.

(6) The weld area shall be maintained at a temperature of 450°F-550°F (232°C-288°C) for a minimum period of 2 hr after completion of the weld repair in P-No. 1 materials. For P-No. 3 materials, the holding time shall be a minimum of 4 hr.

(d) Examination of Repair Welds. The second (temper bead) layer shall be examined by the magnetic particle

Page 172

or liquid penetrant method. The completed weld shall have the weld reinforcement, including the final layer, removed substantially flush with the surface prior to performing the required nondestructive examination. The nondestructive examination shall be performed after the completed weld has been at ambient temperature for a minimum period of 48 hr to detect the presence of possible delayed cracking of the weldment. The nondestructive examination of the repair welded and preheated region shall be in accordance with WB-4453.4. In addition, all repairs shall be ultrasonically examined. All nondestructive examination shall be in accordance with WB-5000.

(e) Documentation of Weld Repairs. Documentation of weld repairs shall be in accordance with WB-4130, exclusive of the size requirements.

(f) Welding Procedure Qualification Test Plate. The test assembly materials for the welding procedure qualification shall be of the same P-Number and Group Number, including a postweld heat treatment that is at least equivalent to the time and temperature applied to the materials being repaired. The depth of cavity in the test assembly shall be a minimum of one-half the depth of actual repair, but not less than 1 in. (25 mm). The test assembly thickness shall be a minimum of twice the depth of cavity in the test assembly. The test assembly shall be large enough to permit removal of the required test specimens. In order to simulate the restraint that the weld metal will experience in the repair section of the component, the test assembly dimensions surrounding the cavity shall be equal to the test assembly thickness, but not less than 6 in. (152 mm). The qualification test plate shall be prepared in accordance with Fig. WB-4622.9(f)-1.

(g) This test assembly may be used to qualify procedures for weld buildup repairs of pressure retaining materials. In this case, the depth of the cavity shall not be less than the thickness of the weld buildup or 1 in. (25 mm), whichever is greater, and the area of the weld buildup to be applied or 54 sq in. (34,839 mm²), whichever is less.

(h) In all cases, the test assembly and cavity shall be of sufficient size to permit removal of the required test specimens.

(i) Performance Qualifications. If the repair weld is to be performed where physical obstructions impair the welder's ability to perform, the welder shall also demonstrate the ability to deposit sound weld metal in the positions required, using the same parameters and simulated physical obstructions as are involved in the repair.

WB-4622.10 Repair Welds to Cladding After Final Postweld Heat Treatment.

Nonpostweld heat treated weld repairs may be made to P-No. 8 or P-No. 43 cladding of P-No. 1 and P-No. 3 material after final PWHT, provided it is impossible or impractical to postweld heat treat the area after repair, and provided the requirements of the following subparagraphs are met.

(a) Maximum Extent of Repair. This procedure may be used with the base material exposed to a depth not greater than ¹/₄ in. (6 mm) or 10% of the base material thickness, whichever is less, nor to an individual area greater than 100 sq in. Areas with greater base material exposure depth shall be repaired in accordance with WB-4622.9 to within this limit before implementing the cladding repair.

(b) Repair Welding Procedure. The welding procedure shall be in accordance with Section IX and this Division, and shall include the requirements of (1) through (7) below.

(1) The repairs shall be made using A-No. 8 weld metal (Section IX, QW-442) for P-No. 8 cladding or F-No. 43 weld metal (Section IX, QW-432) for either P-No. 8 or P-No. 43 cladding.

(2) The manual shielded metal arc process shall be used for welding with a bead width not to exceed four times the electrode core diameter.

(3) All covered electrodes used for qualification test and repair welding shall be from unopened, hermetically sealed packages or heated ovens maintained between 225°F (107°C) and 350°F (177°C). Electrodes withdrawn from

hermetically sealed containers or ovens for longer than 8 hr shall be discarded.

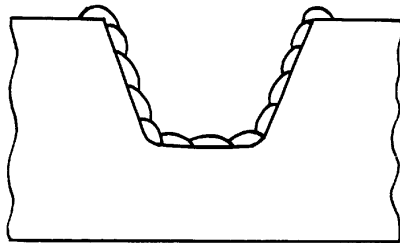
(4) During the repair, the electrodes may be maintained in heated ovens in the repair area. The oven temperature shall be maintained between 225°F (107°C) and 350°F (177°C). Electrodes exposed to the atmosphere for more than 8 hr shall be discarded.

(5) The weld area plus a band around the clad repair of $1\frac{1}{2}$ times the component thickness or 5 in. (127 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 350°F (177°C) during welding. The maximum interpass temperature shall be 450°F (232°C). Thermocouples and recording instruments shall be used to monitor the process temperatures. Their removal shall be in accordance with WB-4435.

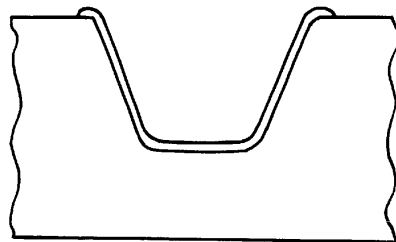
(6) All areas of the base material on which weld metal is to be deposited shall be covered with a single layer of weld deposit using $\frac{3}{32}$ in. (2.4 mm) diameter electrode, followed by a minimum of one layer of weld deposit using $\frac{1}{8}$ in. (3.2 mm) diameter electrode. Subsequent layers may be deposited with electrode no

Page 173

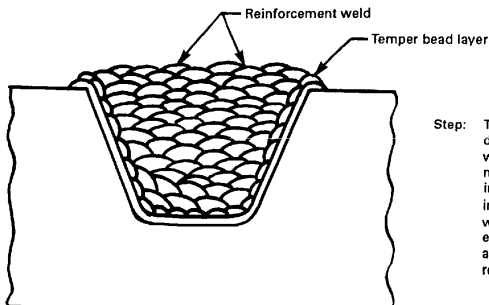
larger than $\frac{5}{32}$ in. (4 mm). The weld bead crown surface of the first layer shall be removed by grinding.



Step 1: Butter cavity with one layer of weld metal using $\frac{3}{32}$ in. diameter coated electrode.



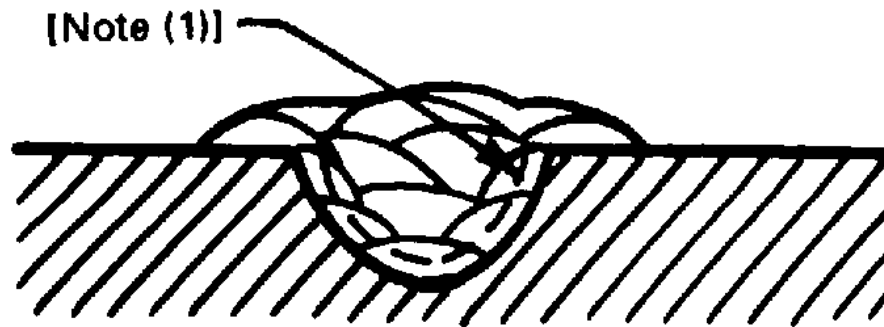
Step 2: Remove the weld bead crown of the first layer of grinding.



Step: The second layer shall be deposited with a $\frac{1}{8}$ in. diameter electrode. Subsequent layers shall be deposited with welding electrodes no larger than $\frac{5}{32}$ in. maximum diameter. Bead deposition shall be performed in a manner as shown. Particular care shall be taken in the application of the temper bead reinforcement weld at the tie-in points as well as its removal to ensure that the heat affected zone of the base metal and the deposited weld metal is tempered and the resulting surface is substantially flush.

FIG. WB-4622.9(c)(5)-1 TEMPER BEAD WELD REPAIR AND WELD TEMPER BEAD REINFORCEMENT

FIG. WB-4622.9(c)(5)-1 TEMPER BEAD WELD REPAIR AND WELD TEMPER BEAD REINFORCEMENT



NOTE:

- (1) Apply temper bead reinforcement weld metal to a level above the surface and then remove it substantially flush to the surface as required by NB-4622.9(c)(5).**

**FIG. WB-4622.9(c)(5)-2 TEMPER
BEAD
REINFORCEMENT**

FIG. WB-4622.9(c)(5)-2 TEMPER BEAD REINFORCEMENT

(7) After completion of welding, the weld area shall be maintained at a temperature of 450°F-550°F (232°C-288°C) for a period of 2 hr for P-No. 1 material and 4 hr for P-No. 3 material.

(c) *Examination of Repair Welds.* The weld repair as well as the preheated band shall be examined by the liquid penetrant method. All nondestructive examination shall be in accordance with WB-5000.

(d) *Documentation of Weld Repairs.* Documentation of weld repairs shall be in accordance with WB-4130, exclusive of the size requirements.

(e) *Welding Procedure Qualification Test Plate*

(1) The test assembly material for the welding procedure qualification test shall be of the same P-Number and Group Number, including a postweld heat treatment that is at least equivalent to the time and temperature of that applied to the material being repaired. If the repair involves two different P-Number or Group Number materials, the test assembly shall duplicate the combination.

(2) The test assembly base material shall be at least 12 in. (305 mm) by 12 in. (305 mm), 2 in. (51 mm) min. thickness, with a clad surface area of at least 8 in. (203 mm) by 8 in. (203 mm), in the area from which the bend test specimens will be removed.

(3) The qualification test plate assembly shall be prepared and tested in accordance with the requirements of Section IX. The guided bend test acceptance standards described in Section IX for cladding shall also be applicable to the HAZ of the base material.

(f) *Performance Qualifications.* If the repair weld is to be performed where physical obstructions impair the welder's ability to perform, the welder shall also demonstrate the ability to deposit sound weld metal in the positions required, using the same parameters and simulated physical obstructions as are involved in the repair.

WB-4622.11 Temper Bead Weld Repair to Dissimilar Metal Welds or Buttering.

Whenever PWHT is impractical or impossible, limited weld repairs to dissimilar metal welds of P-No. 1 and P-No. 3 material or weld filler metal A-No. 8 (Section IX, QW-442) or F-No. 43 (Section IX, QW-432) may be made without PWHT or after the final PWHT provided the requirements of the following subparagraphs are met.

(a) *Examination of Area to Be Repaired.* Before repair, the area shall be examined by either the magnetic particle or liquid penetrant method in accordance with WB-5000.

(b) *Maximum Extent of Repair.* Repairs made to this paragraph are limited to those along the fusion line of a nonferritic weld to ferritic base material where $\frac{1}{8}$ in. (3.2 mm) or less of nonferritic weld deposit exists above the original fusion line after defect removal. If the defect penetrates into the ferritic base material, repair of the base material may be performed in accordance with WB-4622.11 provided the depth of repair in the base material does not exceed $\frac{3}{8}$ in. (10 mm). The repairs to a completed joint shall not exceed one-half the joint thickness. The surface of the completed repair shall not exceed 100 sq in. (65,000 mm²).

(c) *Repair Welding Procedure.* The welding procedure and welder qualification shall meet all of the requirements of Section IX and the additional requirements of this Article. In addition, the Welding Procedure Specification shall include the following requirements.

(1) The area to be repaired shall be suitably prepared for welding in accordance with the written procedure to be used for the repair.

(2) The weld metal shall be deposited by the shielded metal arc welding process (SMAW) using A-No. 8 weld metal (Section IX, QW-442) for P-No. 8 to P-No. 1 or P-No. 3 weld joints or F-No. 43 weld metal (Section IX, QW-432) for either P-No. 8 or P-No. 43 to P-No. 1 or P-No. 3 weld joints. The maximum bead width shall be four times the electrode core diameter.

(3) All covered electrodes used for qualification test and repair welding shall be from unopened, hermetically sealed packages or heated ovens maintained between 225°F (107°C) and 350°F (177°C). Electrodes withdrawn from hermetically sealed containers or ovens for longer than 8 hr shall be discarded.

(4) During the repair, the electrode may be maintained in heated ovens in the repair area. The oven

Page 175

temperature shall be maintained between 225°F (107°C) and 350°F (177°C). Electrodes exposed to the atmosphere for more than 8 hr shall be discarded.

monitor the metal temperature during welding. Their removal shall be in accordance with WB-4435.

(6) All areas of the ferritic base material, exposed or not, on which weld metal is to be deposited, shall be covered with a single layer of weld deposit using $\frac{3}{32}$ in. (2.4 mm) diameter electrode. The weld bead crown surface shall be removed by grinding before depositing the second layer. The second layer shall be deposited with $\frac{1}{8}$ in. (3.2 mm) diameter electrode. Subsequent layers may be deposited with $\frac{5}{32}$ in. (4 mm) maximum diameter electrode. The techniques described in this paragraph shall be duplicated in the procedure qualification. [See Fig. WB-4622.11(c)(6)-1].

(7) After at least $\frac{3}{16}$ in. (4.8 mm) of weld metal has been deposited, the preheated area as defined in (c)(5) above shall be maintained in the range of 450°F-550°F (232°C-288°C) for 4 hr as a minimum.

(8) Subsequent to the above heat treatment, the balance of the welding may be performed at a minimum preheat temperature of 100°F (38°C) and at a maximum interpass temperature of 350°F (177°C).

(d) Examination of Repair Areas

(1) After the heat treatment specified in (c)(7) above has been completed, the repaired area shall be examined by the liquid penetrant method.

(2) The repaired area and the preheated band as defined in (c)(5) above shall be examined by the liquid penetrant method after the completed weld has been at ambient temperature for a minimum of 48 hr. The repaired region shall be examined by the radiographic method and, if practical, by the ultrasonic method.

(3) For repairs to partial penetration welds, the radiographic and ultrasonic examinations specified in (d)(2) above need not be performed, if meaningful results cannot be obtained. For these cases, liquid penetrant examination only shall be performed. For weld repair depths approximately $\frac{3}{16}$ in. (4.8 mm), liquid penetrant examination shall be performed at the time specified in (d)(2) above. For weld repair depths greater than $\frac{3}{16}$ in. (4.8 mm), liquid penetrant examination shall be performed after approximately $\frac{3}{16}$ in. (4.8 mm) thickness has been deposited and the post heat specified in (c)(7) above has been completed. Additional incremental deposit thicknesses shall be liquid penetrant examined in accordance with WB-5245. The final weld surface shall be liquid penetrant examined at the time specified in (d)(2) above.

(4) All nondestructive examination shall be in accordance with WB-5000.

(e) Documentation of Weld Repairs. Documentation of weld repairs shall be in accordance with WB-4130, exclusive of the size requirements.

(f) Welding Procedure Qualification Test Plate. The test assembly materials for the welding procedure qualification shall be of the same P-Number and Group Number, including a postweld heat treatment that is at least equivalent to the time and temperature applied to the materials being repaired. The depth of cavity in the test assembly shall be a minimum of one-half the depth of actual repair but not less than 1 in. (25 mm). The test assembly thickness shall be a minimum of twice the depth of cavity in the test assembly. The test assembly shall be large enough to permit removal of the required test specimens. In order to simulate the restraint that the weld metal will experience in the repaired section of the component, the test assembly dimensions surrounding the cavity shall be equal to the test assembly thickness, but not less than 6 in. The qualification test plate shall be prepared in accordance with Fig. WB-4622.9(f)-1.

(g) Performance Qualifications. If the repair weld is to be performed where physical constructions impair the welder's ability to perform, the welder shall also demonstrate the ability to deposit sound weld metal in the positions required, using the same parameters and simulated physical obstructions as are involved in the repair.

WB-4623 PWHT Heating and Cooling Rate Requirements

Above 800°F the rate of heating and cooling in any hourly interval shall not exceed 400°F divided by the maximum thickness in inches of the material being heat treated, but shall not exceed 400°F and need not be less than 100°F in any hourly interval. During the heating and cooling period there shall not be a greater variation in temperature than 250°F within any 15 ft interval of weld length. The exceptions of (a) and (b) below are permitted.

(a) P-No. 6 material may be cooled in air from the postweld heat treatment holding temperature specified in Table

(b) For P-No. 7 material the cooling rate at temperatures above 1200°F shall not exceed 100°F/hr, after

which the rate of cooling shall be sufficiently rapid to prevent embrittlement.

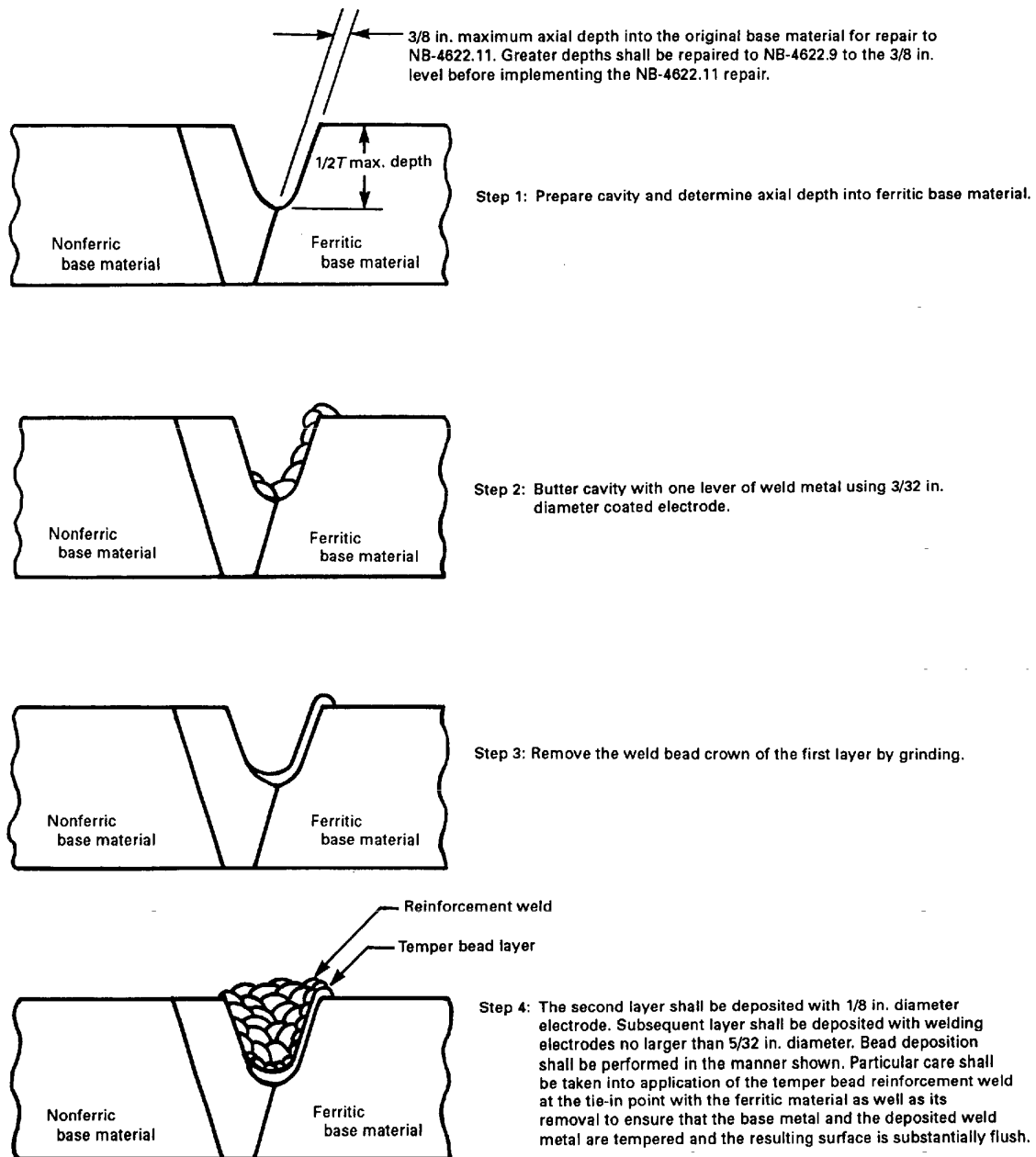


FIG. WB-4622.11(c)(6)-1 TEMPER BEAD WELD REPAIR AND WELD TEMPER BEAD REINFORCEMENT OF DISSIMILAR METAL WELDS OR BUTTERING

FIG. WB-4622.11(c)(6)-1 TEMPER BEAD WELD REPAIR AND WELD TEMPER BEAD REINFORCEMENT OF DISSIMILAR METAL WELDS OR BUTTERING

WB-4624 Methods of Postweld Heat Treatment

The postweld heat treatment shall be performed in accordance with the requirements of one of the following subparagraphs.

WB-4624.1 Furnace Heating - One Heat.

Heating the item in a closed furnace in one heat is the preferred procedure and should be used whenever practical. The furnace atmosphere shall be controlled so as to avoid excessive oxidation and direct impingement of flame on the component or item is prohibited.

WB-4624.2 Furnace Heating - More Than One Heat.

The item may be heated in more than one heat in a furnace, provided the furnace atmosphere control requirements of WB-4624.1 apply and overlap of the heated sections of the component or item is at least 5 ft (1.5 m). When this procedure is used, the portion of the component or item outside the furnace shall be shielded so that the temperature gradient is not harmful. The cross section where the component or item projects from the furnace shall not intersect a nozzle or other structural discontinuity.

WB-4624.3 Local Heating.

Welds may be locally postweld heat treated when it is not practical to heat treat the entire component or item. Local postweld heat treatment shall consist of heating a circumferential band around the component or item at temperature within the ranges specified in this Subarticle. The minimum width of the controlled band at each side of the weld, on the face of the greatest weld width, shall be the thickness of the weld or 2 in. (51 mm), whichever is less. The temperature of the component or item from the edge of the controlled band outward shall be gradually diminished so as to avoid harmful thermal gradients. This procedure may also be used for postweld heat treatment after repairs.

WB-4624.4 Heating Items Internally.

The component or item may be heated internally by any appropriate means and with adequate indicating and recording temperature devices to aid in the control and maintenance of a uniform distribution of temperature in the item. Previous to this operation, the item should be fully enclosed with insulating material.

WB-4630 HEAT TREATMENT OF WELDS OTHER THAN THE FINAL POSTWELD HEAT TREATMENT

The holding temperature, the time at temperature, the heating rate, and the cooling rate need not conform to the requirements of this Article for heat treatments other than the final postweld heat treatment.

WB-4650 HEAT TREATMENT AFTER BENDING OR FORMING FOR PIPES, PUMPS, AND VALVES

WB-4651 Conditions Requiring Heat Treatment After Bending or Forming

(a) Ferritic alloy steel pipe or formed portions of pumps or valves that have been heated for bending or other forming operations shall receive a heat treatment in accordance with WB-4620, a full anneal, a normalizing and tempering treatment, or a quenching and tempering treatment.

(b) Carbon steel pipe or formed portions of pumps or valves with a wall thickness greater than $\frac{3}{4}$ in. (19 mm) included in group P-No. 1 in Section IX that have been cold bent or formed shall receive heat treatment in accordance with WB-4620.

(c) Ferritic alloy pipe or formed portions of pumps or valves with an outside diameter greater than 4 in. (102 mm) and a wall thickness greater than $\frac{1}{2}$ in. (13 mm) included in groups P-No. 3 through P-No. 5 in Section IX that have been cold

bent or formed shall require a heat treatment in accordance with WB-4620.

WB-4652 Exemptions From Heat Treatment After Bending or Forming

If the conditions described in (a) through (d) below are met, heat treatment after bending or forming is not required.

(a) Carbon steel pipe or portions of pumps and valves that have been bent or formed at a temperature of 1650°F (900°C) or higher shall require no subsequent heat treatment, provided the requirements of WB-4213 have been met.

(b) Austenitic stainless steel pipe, or portions of pumps or valves that have been heated for bending or other forming operations, may be used in the as-bent condition unless the Design Specifications require a heat treatment following bending or forming.

(c) Austenitic stainless steel pipe, or portions of pumps or valves that have been cold bent or formed, may be used in the as-bent condition unless the Design

Page 179

Specifications require a heat treatment following bending or forming.

(d) Carbon steel and ferritic alloy steel pipe, or portions of pumps or valves with sizes and wall thicknesses less than specified in WB-4651(b) and WB-4651(c), may be cold bent or formed without a heat treatment following bending.

WB-4660 HEAT TREATMENT OF ELECTROSLAG WELDS

Electroslag welds in ferritic materials over 1½ in. (38 mm) in thickness at the joints shall be given a grain refining heat treatment.

WB-4700 MECHANICAL JOINTS

WB-4710 BOLTING AND THREADING

WB-4711 Thread Engagement

The threads of all bolts or studs shall be engaged in accordance with the design.

WB-4712 Thread Lubricants

Any lubricant or compound used in threaded joints shall be suitable for the service conditions and shall not react unfavorably with either the service fluid or any component material in the system.

WB-4713 Removal of Thread Lubricants

All threading lubricants or compounds shall be removed from surfaces which are to be seal welded.

WB-4720 BOLTING FLANGED JOINTS

In bolting gasketed flanged joints, the contact faces of the flanges shall bear uniformly on the gasket and the gasket shall be properly compressed in accordance with the design principles applicable to the type of gasket used. All flanged joints shall be made up with relatively uniform bolt stress.

WB-4730 ELECTRICAL AND MECHANICAL PENETRATION ASSEMBLIES

Tubes or pipes of NPS 2 (DN 50) and less may be joined to a penetration assembly in accordance with the rules of WB-4350.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D3 WB-5000

ARTICLE WB-5000 EXAMINATION

Page 181

WB-5100 GENERAL REQUIREMENTS FOR EXAMINATION

WB-5110 PROCEDURES, QUALIFICATIONS, AND EVALUATION

WB-5111 General Requirements

Nondestructive examinations shall be conducted in accordance with the examination methods of Section V, except as they may be modified by the requirements of this Article. Radiographic examination shall be by film radiography or real time radioscopy in accordance with Section V, Article 2, except that fluorescent screens are not permitted for film radiography, the geometric unsharpness shall not exceed the limits of T-285, and the penetrameters of Table WB-5111-1 shall be used in lieu of those shown in Table T-276. The requirements for the retention of radioscopy images are the same as for film radiography. Ultrasonic examination shall be in accordance with Section V, Article 5; magnetic particle examination shall be in accordance with Section V, Article 7; liquid penetrant examination shall be in accordance with Section V, Article 6; and leak testing shall be in accordance with Section V, Article 10, T-1030. The examinations required by this Article, or by reference to this Article, shall be performed by personnel who have been qualified as required by this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards of this Article.

WB-5112 Nondestructive Examination Procedures

All nondestructive examinations required by this Article shall be performed in accordance with detailed written procedures which have been proven by actual demonstration to the satisfaction of the Inspector. The procedures shall comply with the appropriate Article of Section V for the particular examination method. The digitization of radiographic film and radioscopy images shall meet the requirements of Section V, Article 2, Mandatory Appendix III, "Digital Image Acquisition, Display, and Storage for Radiography and Radioscopy." Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Inspector on request. At least one copy of the procedure shall be readily available to all applicable nondestructive examination personnel for reference and use.

WB-5113 Post-Examination Cleaning

Following any nondestructive examination in which examination materials are applied to the piece, the piece shall be thoroughly cleaned in accordance with applicable material or procedure specifications.

WB-5120 TIME OF EXAMINATION OF WELDS AND WELD METAL CLADDING

Acceptance examinations of welds and weld metal cladding required by WB-5200 shall be performed at the times stipulated in (a) through (g) below during fabrication and installation.

(a) Radiographic examination of welds shall be performed after an intermediate¹ or final postweld heat treatment, when required, except as provided in (1) and (2) below.

(1) Radiographic examination of welds in piping, pumps, and valves fabricated of P-No. 1 materials may be performed prior to any required postweld heat treatment.

¹ An intermediate postweld heat treatment for this purpose is defined as a postweld heat treatment performed on a weld within a temperature range not lower than the minimum holding temperature range to which the weld shall be subjected during the final postweld heat treatment.

(2) Radiographic examination of welds in vessels fabricated of P-No. 1 materials and all welds in components fabricated of P-No. 3 materials may be performed

Page 184

prior to an intermediate or final postweld heat treatment, provided the welds are ultrasonically examined after an intermediate or final postweld heat treatment. The ultrasonic examination and acceptance standards shall be in accordance with this Article.

**TABLE WB-5111-1
THICKNESS, PENETRAMETER DESIGNATIONS, ESSENTIAL HOLES, AND WIRE DIAMETERS**

Single Wall Material Thickness Range, in.	Penetrameter(s) — Hole or Wire Type [Note (1)]							
	Source Side				Film Side			
	Designation	Hole Size	Essential Hole	Required Wire Diameter — IQI	Designation	Hole Size	Essential Hole	Required Wire Diameter — IQI
Up to 0.25 incl.	5	0.040	4T	0.006	5	0.040	4T	0.006
Over 1/4–3/8	7	0.040	4T	0.006	7	0.040	4T	0.006
Over 3/8–1/2	10	0.040	4T	0.010	10	0.040	4T	0.010
Over 1/2–5/8	12	0.050	4T	0.013	12	0.050	4T	0.013
Over 5/8–3/4	15	0.060	4T	0.016	12	0.050	4T	0.013
Over 3/4–1	20	0.040	2T	0.016	17	0.035	2T	0.013
Over 1–1 1/4	25	0.050	2T	0.020	17	0.035	2T	0.013
Over 1 1/4–1 1/2	30	0.060	2T	0.025	20	0.040	2T	0.016
Over 1 1/2–2	35	0.070	2T	0.032	25	0.050	2T	0.020
Over 2–2 1/2	40	0.080	2T	0.040	30	0.060	2T	0.025
Over 2 1/2–3	45	0.090	2T	0.040	35	0.070	2T	0.032
Over 3–4	50	0.100	2T	0.050	40	0.080	2T	0.040
Over 4–6	60	0.120	2T	0.063	45	0.090	2T	0.040
Over 6–8	80	0.160	2T	0.100	50	0.100	2T	0.050
Over 8–10	100	0.200	2T	0.126	60	0.120	2T	0.063
Over 10–12	120	0.240	2T	0.160	80	0.160	2T	0.100
Over 12–16	160	0.320	2T	0.250	100	0.200	2T	0.126
Over 16–20	200	0.400	2T	0.320	120	0.240	2T	0.160

NOTE:

(1) Hole (plaque) type penetrameters may be used on flat plates and on objects with geometries such that the penetrameter hole image is not distorted.

TABLE WB-5111-1 THICKNESS, PENETRAMETER DESIGNATIONS, ESSENTIAL HOLES, AND WIRE DIAMETERS

(b) Magnetic particle or liquid penetrant examinations of welds shall be performed after any required postweld heat treatment, except that welds in P-No. 1 material may be examined either before or after postweld heat treatment. The magnetic particle or liquid penetrant examination of welds at progressive stages of welding, as required in WB-5245 and WB-5246, may be performed before PWHT.

(c) All dissimilar metal weld joints, such as in austenitic or high nickel to ferritic material, or using austenitic or high nickel alloy filler metal to join ferritic materials which penetrate the wall, shall be examined after final postweld heat treatment.

(d) The magnetic particle or liquid penetrant examination of weld surfaces that are to be covered with weld metal cladding shall be performed before the weld metal cladding is deposited. The magnetic particle or liquid penetrant examination of weld surfaces that are not accessible after a postweld heat treatment shall be performed prior to the operation which caused this inaccessibility. These examinations may be performed before PWHT.

(e) Weld metal cladding shall be examined after either an intermediate¹ or final postweld heat treatment, except the examination of weld metal cladding on P-Nos. 1, 3, and 11 materials may be performed before or after the intermediate¹ or final postweld heat treatment.

(f) All of the joints in austenitic stainless steel and nonferrous material shall be examined by the liquid penetrant method after an intermediate or final postweld heat treatment, if any, is performed. This requirement does not apply to tube-to-tubesheet joints.

(g) Ultrasonic examination of electroslog welds in ferritic materials shall be performed after a grain refining heat treatment, when performed, or after final postweld heat treatment.

WB-5130 EXAMINATION OF WELD EDGE PREPARATION SURFACES

material 2 in. (51 mm) or more in thickness shall be examined by the magnetic particle or liquid penetrant method. Indications shall be evaluated in accordance with the acceptance standards of (a), (b), and (c) below.

(a) Only indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Laminar-type imperfections are acceptable without repair if they do not exceed 1 in. (25 mm) in length. The extent of all laminar-type imperfections exceeding 1 in. (25 mm) in length shall be determined by ultrasonic examination. Imperfections exceeding 1 in. (25 mm) in length shall be repaired by welding to a depth of $\frac{3}{8}$ in. (10 mm) or the depth of the imperfection, whichever is less, unless the ultrasonic examination reveals that additional depth of repair is required to meet the ultrasonic examination requirement for the product form.

(c) Indications of nonlaminar imperfections of (1) through (3) below are unacceptable:

(1) any linear indications greater than $\frac{3}{16}$ in. (4.8 mm) long;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);

(3) four or more indications, in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less, edge to edge.

(d) Weld repairs made to weld edge preparations for Category A, B, C, D, or similar type welds shall be examined by the magnetic particle or liquid penetrant method before the surfaces become inaccessible. The examination may be performed before or after postweld heat treatment.

WB-5140 EXAMINATION OF ADJACENT BASE MATERIAL

When performing the surface examinations of weld joint Categories A, B, C, and D and the equivalent welded joints in piping and valves as required by WB-5200, the external and accessible internal weld surfaces and adjacent base material for at least $\frac{1}{2}$ in. (13 mm) on each side of the weld shall be included in the examination. Acceptance standards for the weld shall be as stated in this Article while the acceptance standards for base material shall be as stated in WB-2500.

WB-5200 REQUIRED EXAMINATION OF WELDS

WB-5210 CATEGORY A VESSEL WELDED JOINTS AND LONGITUDINAL WELDED JOINTS IN OTHER COMPONENTS

Category A welded joints in vessels and longitudinal welded joints in other components shall be examined by the radiographic and either the liquid penetrant or magnetic particle method.

WB-5220 CATEGORY B VESSEL WELDED JOINTS AND CIRCUMFERENTIAL WELDED JOINTS IN PIPING AND VALVES

WB-5221 Vessel Welded Joints

Category B welded joints in vessels shall be examined by the radiographic and either the liquid penetrant or magnetic particle method.

WB-5222 Piping and Valve Circumferential Welded Joints

(a) Butt welded joints shall be examined by the radiographic and either the liquid penetrant or magnetic particle method.

(b) Fillet and partial penetration welded joints shall be examined by either the liquid penetrant or magnetic particle method.

WB-5230 CATEGORY C VESSEL WELDED JOINTS AND SIMILAR WELDED JOINTS IN OTHER COMPONENTS

WB-5231

(a) Category C full penetration butt welded joints in vessels and similar welded joints in other components shall be examined by the radiographic and either the liquid penetrant or magnetic particle method.

(b) Category C full penetration corner welded joints and similar welded joints in other components shall be ultrasonically or radiographically examined and either liquid penetrant or magnetic particle examined.

(c) Type 2 Category C full penetration corner welded joints similar to Fig. WB-4243-1 sketches (d), (e), and (f) also require the fusion zone and the parent metal beneath the attachment surface to be ultrasonically

Page 186

examined after welding to verify freedom from lack of fusion and laminar defects.

(d) Category C partial penetration and fillet welded joints, and similar welded joints in other components shall be examined by either the magnetic particle or liquid penetrant method on all accessible surfaces.

WB-5240 CATEGORY D VESSEL WELDED JOINTS AND BRANCH AND PIPING CONNECTIONS IN OTHER COMPONENTS

WB-5241 General Requirements

All Category D welded joints in vessels and similar welded joints in other components shall be examined as stated in the following paragraphs.

WB-5242 Full Penetration Butt Welded Nozzles, Branch, and Piping Connections

Nozzles, branch, and piping connections attached by full penetration butt welded joints as shown in Fig. WB-4244(a)-1 shall be examined by the radiographic and either the liquid penetrant or magnetic particle method.

WB-5243 Corner Welded Nozzles, Branch, and Piping Connections

(a) Full penetration corner welded nozzles in vessels as shown in Fig. WB-4244(b)-1 shall be examined by either the ultrasonic or the radiographic method, and either the liquid penetrant or magnetic particle method. If radiographed, the weld fusion zone and the parent metal beneath the attachment surface for details shown in Fig. WB-4244(b)-1 sketches (a), (b), (c), (d), (e), and (g) shall be ultrasonically examined after welding to assure freedom from lack of fusion and laminar defects.

(b) Full penetration corner welded branch and piping connections exceeding NPS 4 (DN 100) in piping, pumps, and valves, as shown in Fig. WB-4244(b)-1, shall be examined by either the ultrasonic or the radiographic method, and either the liquid penetrant or magnetic particle method.

(c) Full penetration corner welded branch and piping connections with NPS 4 (DN 100) and less in piping, pumps, and valves shall be examined by either the magnetic particle or liquid penetrant method.

WB-5244 Weld Metal Buildup at Openings for Nozzles, Branch, and Piping Connections

(a) When weld metal buildup is made to a surface as shown in Step 1 of Fig. WB-4244(c)-1, the weld metal buildup, the fusion zone, and the parent metal beneath the weld metal buildup shall be ultrasonically examined to ensure freedom from lack of fusion and laminar defects. Nozzles, branch, and piping connections may then be attached by a full penetration weld as shown in Step 2 of Fig. WB-4244(c)-1. The full penetration butt welded joint shall be examined by either the ultrasonic or radiographic method, and either the liquid penetrant or magnetic particle method.

(b) For branch and piping connections with NPS 4 (DN 100) and less in piping, pumps, and valves, full penetration welds shown in sketch (c) of Fig. WB-4244(c)-1 shall be examined in accordance with WB-5243(c).

WB-5245 Partial Penetration Welded Joints

Partial penetration welded joints, as permitted in WB-3352.4(d), and as shown in Figs. WB-4244(d)-1 and WB-4244(d)-2, shall be examined progressively using either the magnetic particle or liquid penetrant methods. The

increments of examination shall be the lesser of one-half of the maximum welded joint dimension measured parallel to the center line of the connection or $\frac{1}{2}$ in. (13 mm). The surface of the finished welded joint shall also be examined by either method.

WB-5246 Oblique Full Penetration Nozzles, Branch, and Piping Connections

(a) Full penetration oblique nozzles in vessels as shown in Fig. WB-4244(e)-1 shall be examined by either the ultrasonic or radiographic method, and either the liquid penetrant or magnetic particle method. In addition, the weld, the fusion zone, and the parent metal beneath the attachment surface for details shown in Fig. WB-4244(e)-1, sketches (a), (b), and (c) shall be ultrasonically examined after welding to assure freedom from lack of fusion and laminar defects.

(b) Full penetration oblique welded joint branch and piping connections in piping, pumps, and valves, as shown in Fig. WB-4244(e)-1, shall be examined in accordance with the requirements for corner welded branch and piping connections specified in WB-5243(b) and (c), as applicable.

Page 187

WB-5260 FILLET, PARTIAL PENETRATION, SOCKET, AND ATTACHMENT WELDED JOINTS

WB-5261 Fillet, Partial Penetration, and Socket Welded Joints

Fillet and partial penetration welded joints, except for nonstructural attachments (WB-1132.1), and socket welds shall be examined by the magnetic particle or liquid penetrant method.

WB-5262 Structural Attachment Welded Joints

Structural attachment welded joints made to pressure retaining material shall be examined by either the magnetic particle or liquid penetrant method.

WB-5270 SPECIAL WELDED JOINTS

WB-5271 Welded Joints of Specially Designed Seals

Welded joints of this type shall be examined by either the magnetic particle or liquid penetrant method.

WB-5272 Weld Metal Cladding

Weld metal cladding shall be examined by the liquid penetrant method.

WB-5273 Hard Surfacing

Hard surfacing weld metal shall be examined by the liquid penetrant method in accordance with WB-2546, and the acceptance standards applicable to materials less than $\frac{5}{8}$ in. (16 mm) thick shall apply. Penetrant examination is not required for hard surfacing on valves with inlet connections NPS 4 (DN 100) or less.

WB-5274 Tube-to-Tubesheet Welded Joints

Tube-to-tubesheet welded joints shall be examined by the liquid penetrant method.

WB-5275 Brazed Joints

Flux and flux residue shall be removed from all surfaces prior to examination. Joints shall be visually examined on all accessible surfaces to determine whether there has been adequate flow of brazing metal through the joint. Optical aids may be employed for indirect visual examination of joints which cannot be directly examined.

WB-5276 Inertia and Continuous Drive Friction Welds

(a) When radiographic examination is required by this Article, inertia and continuous drive friction welds shall also be

examined by the ultrasonic method to verify bonding over the entire area.

(b) The materials used shall be those assigned a P-Number by Section IX, but shall not include rimmed or semikilled steel.

(c) One of the two parts to be joined must be held in a fixed position and the other part rotated. The two faces to be joined must be symmetrical with respect to the axis of rotation.

(d) The weld between the two members shall be a full penetration weld.

WB-5277 Electron Beam Welds

In addition to the requirements for the type of weld being examined, all complete penetration welds made by the electron beam welding process shall be ultrasonically examined.

WB-5278 Electroslag Welds

In addition to the requirements for the type of weld being examined, all complete penetration welds made by the electroslag welding process in ferritic materials shall be ultrasonically examined.

WB-5279 Special Exceptions

When the joint detail does not permit radiographic examination to be performed in accordance with procedures of this Subsection for joints attaching penetration assemblies, which are fabricated as appurtenances or of the closing seam within an electrical penetration assembly, not necessarily fabricated as an appurtenance, ultrasonic examination plus liquid penetrant or magnetic particle examination of the completed weld may be substituted for the radiographic examination. The absence of suitable radiographic equipment shall not be justification for such substitution. The substitution of ultrasonic examination can be made provided the examination is performed using a detailed written procedure which has been proven by actual demonstration to the satisfaction of the Inspector as capable of detecting and locating defects described in this Division. The nondestructive examination shall be in accordance with Section V and meet the acceptance standards of WB-5300.

Page 188

WB-5300 ACCEPTANCE STANDARDS

WB-5320 RADIOGRAPHIC ACCEPTANCE STANDARDS

Indications shown on the radiographs of welds and characterized as imperfections are unacceptable under the following conditions:

(a) any indication characterized as a crack or zone of incomplete fusion or penetration;

(b) any other elongated indication which has a length greater than:

(1) $\frac{1}{4}$ in. for t up to $\frac{3}{4}$ in., inclusive

(2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. to $2\frac{1}{4}$ in., inclusive

(3) $\frac{3}{4}$ in. for t over $2\frac{1}{4}$ in.

where t is the thickness of the thinner portion of the weld;

(c) internal root weld conditions are acceptable when the density change as indicated in the radiograph is not abrupt; elongated indications on the radiograph at either edge of such conditions shall be unacceptable, as provided in (b) above;

(d) any group of aligned indications having an aggregate length greater than t in a length of $12t$, unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication;

(e) rounded indications in excess of that shown as acceptable in Appendix VI.

WB-5330 ULTRASONIC ACCEPTANCE STANDARDS

All imperfections which produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and evaluate them in terms of the acceptance standards given in (a) and (b) below.

(a) Imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths exceeding:

- (1) $\frac{1}{4}$ in. for t up to $\frac{3}{4}$ in., inclusive
- (2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. to $2\frac{1}{4}$ in., inclusive
- (3) $\frac{3}{4}$ in. for t over $2\frac{1}{4}$ in.

where t is the thickness of the weld being examined; if a weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses.

(b) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

WB-5340 MAGNETIC PARTICLE ACCEPTANCE STANDARDS

WB-5341 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication that is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. After an indication has been verified to be nonrelevant, it is not necessary to reinvestigate repetitive nonrelevant indications of the same type. Nonrelevant indications that would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

WB-5342 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

- (1) any cracks and linear indications;
- (2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);
- (3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;
- (4) ten or more rounded indications in any 6 sq in. (3,871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) with the area taken in the most unfavorable location relative to the indications being evaluated.

WB-5350 LIQUID PENETRANT ACCEPTANCE STANDARDS

WB-5351 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities, such as may occur from machining marks, surface conditions, or an incomplete

bond between base metal and cladding, may produce similar indications which are nonrelevant.

(b) Any indication which is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

WB-5352 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $\frac{1}{16}$ in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks or linear indications;

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (4.8 mm);

(3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (1.6 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 sq in. (3,871 mm²) of surface with the major dimension of this area not to exceed 6 in. (152 mm) with the area taken in the most unfavorable location relative to the indications being evaluated.

WB-5360 VISUAL ACCEPTANCE STANDARDS FOR BRAZED JOINTS

Braze metal shall give evidence of having flowed uniformly through a joint by the appearance of an uninterrupted, narrow visible line of brazing alloy at the end of the joint.

WB-5380 BUBBLE FORMATION TESTING

Bubble formation testing shall be in accordance with Section V, Article 10. When vacuum box testing is used, the soak time shall be a minimum of 10 sec. Any indication of leaking, by the formation of bubbles or by the breaking of the continuous soap film by leaks, shall be evidence of an unacceptable condition.

WB-5400 FINAL EXAMINATION OF VESSELS

WB-5410 EXAMINATION AFTER HYDROSTATIC TEST

After the hydrostatic or pneumatic test of a vessel, all weld joints and heat affected zones of Categories A, B, C, and D, used to join ferritic material and repair welds in ferritic material that exceed in depth either $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness, whichever is less, shall be examined when physically accessible by the magnetic particle or liquid penetrant method.

WB-5500 QUALIFICATIONS AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

WB-5510 GENERAL REQUIREMENTS

Organizations performing Code required nondestructive examinations shall use personnel competent and knowledgeable to the degree specified by WB-5520. When these services are subcontracted by the Certificate Holder or Quality System Certificate Holder, he shall verify the qualification of personnel to the requirements of WB-5520. All nondestructive examinations required by this Subsection shall be performed by and the results evaluated by qualified nondestructive examination personnel.

WB-5520 PERSONNEL QUALIFICATION, CERTIFICATION, AND VERIFICATION

WB-5521 Qualification Procedure

guidelines of SNT-TC-1A.^{2,3} The Employer's⁴ written practice, required by paragraph 5 of SNT-TC-1A, shall identify the requirements relative to the recommended guidelines. The recommended guidelines of SNT-TC-1A shall be considered as minimum requirements, except as modified in (1) through (5) below.

(1) Qualification of Level III nondestructive examination personnel shall be by examination.

(a) The basic and method examinations, paragraphs 8.3.3(1) and 8.3.3(2) of SNT-TC-1A, may be prepared and administered by Employer,⁴ ASNT, or an outside agency.

(b) The specific examination, paragraph 8.3.3(3) of SNT-TC-1A, shall be prepared and administered by the Employer or an outside agency. The Employer or outside agency administering the specific examination shall identify the minimum grade requirement in the written program when the basic and method examinations have been administered by ASNT, which issues grades on a pass/fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(2) The written practice identified in paragraph 5 of SNT-TC-1A and the procedures used for examination of personnel shall be referenced in the Employer's Quality Program.

(3) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform nondestructive examination of limited scope, may be less than that recommended in Table 6.3.1 of SNT-TC-1A. The time of training and experience shall be described in the written practice, and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate.

(4) For visual examination, the Jaeger Number 1 letters shall be used in lieu of the Jaeger Number 2 letters specified in paragraph 8.1.1(1) of SNT-TC-1A. The use of equivalent type and size letters is permitted.

2 SNT-TC-1A is a Recommended Practice for Nondestructive Testing Personnel Qualification and Certification published by the American Society for Nondestructive Testing, 4153 Arlingate Plaza, Columbus, OH 43228-0518. SNT-TC-1A-1984 is the applicable edition.

3 Personnel qualified by examination and certified to the previous editions of SNT-TC-1A are considered to be qualified to the 1984 edition when the recertification is based on continuing satisfactory performance. All reexaminations and new examinations shall be in accordance with the 1984 edition.

4 Employer as used in this Article shall include: N Certificate Holders; Quality System Certificate Holders; Material Organizations who are qualified in accordance with WA-3862.1(a) and organizations who provide subcontracted nondestructive examination services to organizations described above.

(5) A Level I individual shall be qualified to perform specific setups, calibrations, and tests, and to record and evaluate data by comparison with specific acceptance criteria defined in written instructions. The Level I individual shall implement these written NDE instructions under the guidance of a Level II or Level III individual. A Level I individual may independently accept the results of nondestructive examinations when the specific acceptance criteria are defined in the written instructions.

(b) For nondestructive examination methods not covered by SNT-TC-1A documents, personnel shall be qualified to comparable levels of competency by subjection to comparable examinations on the particular method involved.

(c) The emphasis shall be on the individual's ability to perform the nondestructive examination in accordance with the applicable procedure for the intended application.

(d) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use personnel qualified to perform one or more operations. As an example, one person may be used who is qualified to conduct radiographic examination and another may be used who is qualified to interpret and evaluate the radiographic film.

WB-5522 Certification of Personnel

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of Levels I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations [WB-5521(a)(1)(a)], the Employer may use a letter from ASNT as evidence on which to base the certification.

(c) When an outside agency is the examining agent for Level III qualification of the Employer's personnel, the examination results shall be included with the Employer's record.

WB-5523 Verification of Nondestructive Examination Personnel Certification

The Certificate Holder has the responsibility to verify the qualification and certification of nondestructive examination personnel employed by Material Organizations and qualified by them in accordance with

Page 191

WA-3820 and subcontractors who provide nondestructive examination services to them.

WB-5530 RECORDS

Personnel qualification records identified in paragraph 9.6.1 of SNT-TC-1A shall be retained by the Employer.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D3 WB-6000

ARTICLE WB-6000 TESTING

Page 193

Page 194

WB-6100 GENERAL REQUIREMENTS

WB-6110 PRESSURE TESTING OF COMPONENTS, APPURTENANCES, AND SYSTEMS

WB-6111 Scope of Pressure Testing

All pressure retaining components, appurtenances, and completed systems shall be pressure tested. The preferred method shall be a hydrostatic test using water as the test medium. Bolts, studs, nuts, washers, and gaskets are exempted from the pressure test.

WB-6112 Pneumatic Testing

A pneumatic test in accordance with WB-6300 may be substituted for the hydrostatic test when permitted by WB-6112.1 (a).

WB-6112.1 Pneumatic Test Limitations

(a) A pneumatic test may be used in lieu of a hydrostatic test only when any of the following conditions exists:

(1) when components, appurtenances, or systems are so designed or supported that they cannot safely be filled with liquid¹

(2) when components, appurtenances, or systems which are not readily dried are to be used in services where traces of the testing medium cannot be tolerated.

(b) A pneumatic test at a pressure not to exceed 25% of the MNOP may be applied, prior to either a hydrostatic or a pneumatic test, as a means of locating leaks.

1 These tests may be made with the item being tested partially filled with liquid, if desired.

WB-6112.2 Precautions to Be Employed in Pneumatic Testing.

Compressed gaseous fluid is hazardous when used as a testing medium. Therefore, it is recommended that special precautions for protection of personnel be taken when a gaseous fluid under pressure is used as a test medium.

WB-6113 Witnessing of Pressure Tests

Pressure testing required by this Article shall be performed in the presence of the Inspector, except that testing of each line valve and each pump having piping connections of NPS 4 (DN 100) and less need not be witnessed by the Inspector. For line valves NPS 4 (DN 100) and less, the Inspector's review and acceptance of the Certificate Holder's test records will be authorization to sign the Data Report Form and take precedence over WA-5280.

WB-6114 Time of Pressure Testing

WB-6114.1 System Pressure Test.

The installed system shall be pressure tested prior to initial operation.

(a) The pressure test may be performed progressively on erected portions of the system.

(b) Systems which are open ended, such as spray systems, may be pressure tested with the nozzle attachment opening plugged. The spray nozzles and their attachment weld joints or mechanical joints need not be pressure tested.

WB-6114.2 Component and Appurtenance Pressure Test

(a) Components and appurtenances shall be pressure tested prior to installation in a system, except as permitted in (b) below.

(b) The system pressure test may be substituted for a component or appurtenance pressure test, provided:

(1) the component can be repaired by welding in accordance with the rules of WB-4130 and WB-4450, if required, as a result of the system pressure test;

(2) the component repair weld can be postweld heat treated in accordance with WB-4620, if required, and nondestructively examined in accordance with the rules of WB-4130 and WB-4450, as applicable;

Page 196

(3) the component is resubjected to the required system pressure test following the completion of repair and examination if the repair is required to be radiographed by WB-4453.4.

(c) Valves require pressure testing prior to installation in a system in accordance with WB-3500.

(d) Items which, when assembled, form a completed valve may be tested in the form of subassemblies, provided:

(1) the test pressure is in accordance with the requirements of WB-6221;

(2) the pressure test is performed in a manner which, in the subassembly under test, will simulate the loadings present when the completed pump or valve is assembled and pressurized;

(3) the component Certificate Holder approves any pressure test of component subassemblies;

(4) the component Certificate Holder specifies the pressure test requirements and test pressure to be used;

(5) each subassembly pressure test is performed by a Certificate Holder and is performed in the presence of the Authorized Inspector;

(6) each subassembly pressure tested by other than the component Certificate Holder is stamped with the NPT symbol, except as provided in WA-8330. The test pressure shall be identified on the Partial Data Report Form.

(7) each subassembly pressure tested by other than the component Certificate Holder is listed on the Code Data Report Form;

(8) the pressure tested subassemblies of pumps or valves are subsequently assembled by mechanical methods only;

(9) welds examined during the subassembly pressure test need not be reexamined during the system pressure test.

WB-6114.3 Material Pressure Test.

The component or appurtenance pressure test may be used in lieu of any such test required by the material specification for a part or material used in the component or appurtenance, provided:

(a) nondestructive examinations, if required by the material specification, can be performed subsequent to the component or appurtenance pressure test;

(b) the material can be repaired by welding in accordance with the rules of WB-4130, if required, as a result of the pressure test;

(c) postweld heat treatment, when required after repairs, can be performed in accordance with WB-4620.

WB-6115 Machining After Pressure Test

An additional amount of material, not to exceed 10% of the wall thickness or $\frac{3}{8}$ in. (10 mm), whichever is less, is permitted on the completed component during pressure testing where machining to critical dimensions and tolerances is required.

WB-6120 PREPARATION FOR TESTING

WB-6121 Exposure of Joints

All joints, including welded joints, shall be left uninsulated and exposed for examination during the test.

WB-6122 Addition of Temporary Supports

Components designed to contain vapor or gas may be provided with additional temporary supports, if necessary, to support the weight of the test liquid.

WB-6123 Restraint or Isolation of Expansion Joints

Expansion joints shall be provided with temporary restraints, if required, for the additional pressure load under test.

WB-6124 Isolation of Equipment Not Subjected to Pressure Test

Equipment that is not to be subjected to the pressure test shall be either disconnected from the component or system or isolated during the test by a blind flange or similar means. Valves may be used if the valves with their closures are suitable for the proposed test pressure.

WB-6125 Treatment of Flanged Joints Containing Blanks

Flanged joints at which blanks are inserted to isolate other equipment during the test need not be retested.

WB-6126 Precautions Against Test Medium Expansion

If a pressure test is to be maintained for a period of time and the test medium in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure.

Page 197

WB-6127 Check of Test Equipment Before Applying Pressure

The test equipment shall be examined before pressure is applied to ensure that it is tight and that all low pressure filling lines and other items that should not be subjected to the test have been disconnected or isolated.

WB-6200 HYDROSTATIC TESTS

WB-6210 HYDROSTATIC TEST PROCEDURE

WB-6211 Venting During Fill Operation

The component or system in which the test is to be conducted shall be vented during the filling operation to minimize air pocketing.

WB-6212 Test Medium and Test Temperature

(a) Water or an alternative liquid, as permitted by the Design Specification, shall be used for the hydrostatic test.

(b) It is recommended that the test be made at a temperature that will minimize the possibility of brittle fracture (Appendix G). The test pressure shall not be applied until the component, appurtenance, or system and the pressurizing fluid are at approximately the same temperature.

WB-6220 HYDROSTATIC TEST PRESSURE REQUIREMENTS

[98]

WB-6221 Minimum Hydrostatic Test Pressure

(a) The installed system shall be hydrostatically tested at not less than either 1.5 times MNOP or 1.25 times MNIP of any component within the boundary protected by the overpressure protection devices which satisfy the requirements of WB-7000.

(b) Valves shall be hydrostatically tested in accordance with the rules of WB-3500.

(c) Components shall be hydrostatically tested at not less than either 1.5 times MNOP or 1.25 times MNIP.

[98]

WB-6222 Maximum Permissible Test Pressure

The stress limits specified in WB-3226 shall be used in determining the maximum permissible test pressure. In multichamber components, pressure may be simultaneously applied to the appropriate adjacent chamber to satisfy these stress limits.

WB-6223 Hydrostatic Test Pressure Holding Time

The hydrostatic test pressure shall be maintained a minimum of 10 min prior to initiation of the examination for leakage required by WB-6224.

WB-6224 Examination for Leakage After Application of Pressure

Following the application of the hydrostatic test pressure for the required time (WB-6223), all joints, connections, and regions of high stress, such as regions around openings and thickness transition sections, shall be examined for leakage. Except in the case of valves which shall be examined while at test pressure, this examination shall be made at a pressure equal to the greater of the MNOP or three-fourths of the test pressure and it shall be witnessed by the Inspector. Leakage of temporary gaskets and seals, installed for the purpose of conducting the hydrostatic test and which will be replaced later, may be permitted unless the leakage exceeds the capacity to maintain system test pressure for the required amount of time. Other leaks, such as those from permanent seals, seats, and gasketed joints in components, may be permitted when specifically allowed by the Design Specification. Leakage from temporary seals or leakage permitted by the Design Specification shall be directed away from the surface of the component to avoid masking leaks from other joints.

WB-6300 PNEUMATIC TESTS

WB-6310 PNEUMATIC TESTING PROCEDURES

WB-6311

WB-6311 General Requirements

When a pneumatic test is performed, it shall be conducted in accordance with the requirements of WB-6100 and this Subarticle.

WB-6312 Test Medium and Test Temperature

(a) The gas used as the test medium shall be nonflammable.

(b) Testing temperature shall be in accordance with WB-6212(b).

Page 198

WB-6313 Procedure for Applying Pressure

The pressure in the system shall gradually be increased to not more than one-half of the test pressure, after which the pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached.

WB-6320 PNEUMATIC TEST PRESSURE REQUIREMENTS

[98]

WB-6321 Minimum Required Pneumatic Test Pressure

(a) The installed system shall be pneumatically tested at not less than either 1.5 times MNOP or 1.25 times MNIP of any component within the boundary protected by the overpressure protection devices which satisfy the requirements of WB-7000.

(b) Valves shall be pneumatically tested in accordance with the rules of WB-3500.

(c) Components shall be pneumatically tested at not less than either 1.5 times MNOP or 1.25 times MNIP.

[98]

WB-6322 Maximum Permissible Test Pressure

The maximum test pressure shall be limited as defined in WB-6222.

WB-6323 Test Pressure Holding Time

The test pressure of WB-6321 shall be maintained for a minimum total time of 10 min.

WB-6324 Examination for Leakage After Application of Pressure

Following the application of pressure for the time specified in WB-6323, the test pressure shall be reduced to a value equal to the greater of the MNOP or three-fourths of the test pressure and held for a sufficient time to permit examination as defined in accordance with WB-6224.

WB-6400 PRESSURE TEST GAGES

WB-6411 Types of Gages to Be Used and Their Location

Pressure test gages used in pressure testing shall be indicating pressure gages and shall be connected directly to the component. If the indicating gage is not readily visible to the operator controlling the pressure applied, an additional indicating gage shall be provided where it will be visible to the operator for the duration of the test. For systems with a large volumetric content, it is recommended that a recording gage be used in addition to the indicating gages.

WB-6412 Range of Indicating Pressure Gages

(a) Analog type indicating pressure gages used in testing shall be graduated over a range not less than $1\frac{1}{2}$ times nor more

than 4 times the test pressure.

(b) Digital type pressure gages may be used without range restriction provided the combined error due to calibration and readability does not exceed 1% of the test pressure.

WB-6413 Calibration of Pressure Test Gages

All test gages shall be calibrated against a standard dead weight tester or a calibrated master gage. The test gages shall be calibrated before each test or series of tests. A series of tests is that group of tests using the same pressure test gage or gages which is conducted at the same site within a period not exceeding 2 weeks.

WB-6600 SPECIAL TEST PRESSURE SITUATIONS

WB-6610 COMPONENTS DESIGNED FOR EXTERNAL PRESSURE

Components designed for external pressure only shall be subjected to an internal test pressure at 1.25 times the design external pressure. The pressure shall be under proper control so that the required test pressure is never exceeded by more than 6%.

WB-6620 PRESSURE TESTING OF COMBINATION UNITS

WB-6621 Pressure Chambers Designed to Operate Independently

Pressure chambers of combination units that have been designed to operate independently shall be hydrostatically tested as separate vessels; that is, each chamber shall be tested without pressure in the adjacent chamber.

Page 199

WB-6622 Common Elements Designed for a Maximum Differential Pressure

(a) When pressure chambers of combination units have their common elements designed for the maximum differential pressure that can occur during startup, operation, and shutdown, and the differential pressure is less than the higher of the MNOP of the adjacent chambers, the common elements shall be subjected to a hydrostatic test pressure of at least $1\frac{1}{4}$ times the maximum differential pressure.

(b) Following the test of the common elements, as required by (a) above and their inspection, the adjacent chambers shall be hydrostatically tested (WB-6221). Care must be taken to limit the differential pressure between the chambers to the pressure used when testing the common elements.

July 1, 1998

American Society Of Mechanical Engineers

SEC III D3 REF MTL

REFERENCE MATERIAL

Page 201

July 1, 1998

American Society Of Mechanical Engineers

SEC III D3 CODES

CODES, STANDARDS, AND SPECIFICATIONS REFERENCED
IN TEXT

Page 203

ORGANIZATIONS

American Institute of Steel Construction

American Petroleum Institute

American Public Health Association

American Society of Mechanical Engineers

American Society for Nondestructive Testing

American Society for Testing and Materials

AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Specification for the Design, Fabrication and Erection of Structural Steel for Buildings, 1978

Specification for Structural Steel Buildings - Allowable Stress Design and Plastic Design, June 1, 1989

AMERICAN PETROLEUM INSTITUTE

API 605-1988 Large Diameter Carbon Steel Flanges

AMERICAN PUBLIC HEALTH ASSOCIATION

APHA-427C 16th Edition Test for Determination of Water Soluble Sulfides (Methylene Blue Method) - Standard Methods for the Examination of Water and Wastewater (1985)

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

ASME N626.3-1979 Qualifications and Duties of Specialized Professional Engineers, Including Addenda N626.3a-1989

ASME N626-1984-W87 Qualifications and Duties for Authorized Inspection Agencies and Personnel

ASME N626.3-1979 Qualifications and Duties of Personnel Engaged in ASME Boiler and Pressure Vessel Code, Section III, Division 1 and 2, Certifying Activities

Page 204

ASME NQA-1-1994 Quality Assurance Requirements for Nuclear Facilities

ASME QAI-1-1995 Qualifications for Authorized Inspection

AMERICAN SOCIETY FOR NONDESTRUCTIVE TESTING

SNT-TC-1A & Supplements Recommended Practice - Guidelines for the Qualification and Certification of Nondestructive Testing Personnel & Supplements

AMERICAN SOCIETY FOR TESTING AND MATERIALS

A 108-89a Standard Specification for Steel Bars, Carbon, Cold-Finished, Standard Quality

A 416-88b Standard Specification for Steel Strand, Uncoated Seven-Wire Stress-Relieved for Prestressed Concrete

A 421-80 (1985) Standard Specification for Uncoated Stress-Relieved Wire for Prestressed Concrete

A 490-90 Standard Specification for Heat-Treated Steel Structural Bolts, 150 ksi Minimum Tensile Strength

A 513-90 Standard Specification for Electric-Resistance-Welded Carbon and Alloy Steel Mechanical Tubing

July 1, 1998

American Society Of Mechanical Engineers
SEC III SI UNITS

The 1998 Edition of the Boiler and Pressure Vessel Code is based on U.S. Customary (ft-lb) units of measurement which are to be regarded as the standard. This supplement is provided as a convenience to the Code user and contains SI conversion factors for units contained in the Code.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE [Note (1)]

Quantity	Unit	Symbol	Other Units or Limitations
Space and Time			
plane angle	radian	rad	degree (decimalized)
length	meter	m	
area	square meter	m ²	
volume	cubic meter	m ³	liter (L) for liquid only (use without prefix other than in milliliter, mL)
time	second	s	minute (min), hour (h), day (d), week, and year
Periodic and Related Phenomena			
frequency	hertz	Hz	revolutions per second (r/s)
rotational frequency	revolutions per second	s ⁻¹	revolutions per minute (r/m)
Mechanics			
mass	kilogram	kg	
density	kilogram per cubic meter	kg/m ³	
moment of inertia	kilogram · meter ²	kg · m ²	
force	newton	N	
moment of force (torque)	newton-meter	N · m	
pressure and stress	pascal	Pa	(pascal = newton per square meter)
energy, work	joule	J	kilowatt-hour (kW · h)
power	watt	W	
impact strength	joule	J	
section modulus	meter ³	m ³	
moment of section (second moment of area)	meter ⁴	m ⁴	
fracture toughness	Pa · $\sqrt{m}$		
Heat			
temperature — thermodynamic [Note (2)]	kelvin	K	degree Celsius (°C)
temperature — other than thermodynamic	degree Celsius	°C	kelvin (K)
linear expansion coefficient	meter per meter-kelvin	K ⁻¹	°C ⁻¹
quantity of heat	joule	J	
heat flow rate	watt	W	
thermal conductivity	watt per meter-kelvin	W/(m · K)	W/(m · °C)
thermal diffusivity	square meter per second	m ² /s	
specific heat capacity	joule per kilogram-kelvin	J/(kg · K)	J/(kg · °C)
Electricity and Magnetism			
electric current	ampere	A	
electric potential	volt	V	
current density	ampere per meter ²	A/m ²	
magnetic field strength	ampere per meter	A/m	

NOTES:

- (1) Conversion factors between SI units and U.S. customary are given in SI-1, "ASME Orientation and Guide for Use of SI (Metric) Units," and ASTM E 380.
- (2) Preferred use for temperature and temperature interval is degrees Celsius (°C), except for thermodynamic and cryogenic work where kelvins may be more suitable. For temperature interval, 1 K = 1°C exactly.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE [Note (1)]

COMMONLY USED CONVERSION FACTORS
(For Others See ASTM E 380) [See Note (1)]

Quantity	To Convert From	To	Multiply by [Note (2)]	
plane angle	degree	rad	1.745 329	E-02
length	in	m	2.54*	E-02
	ft	m	3.048*	E-01
	yd	m	9.144*	E-01
area	in ²	m ²	6.451 6*	E-04
	ft ²	m ²	9.290 304*	E-02
	yd ²	m ²	8.361 274	E-01
volume	in ³	m ³	1.638 706	E-05
	ft ³	m ³	2.831 685	E-02
	US gallon	m ³	3.785 412	E-03
	Imperial gallon	m ³	4.546 09	E-03
	liter	m ³	1.0*	E-03
mass	lbm	kg	4.535 924	E-01
	ton (metric) (mass)	kg	1.000 00*	E+03
	ton (short 2000 lbm)	kg	9.071 847	E+02
force	kgf	N	9.806 65*	E+00
	lbf	N	4.448 222	E+00
bending, torque	kgf · m	N · m	9.806 65*	E+00
	lbf · in	N · m	1.129 848	E-01
	lbf · ft	N · m	1.355 818	E+00
pressure, stress	kgf/m ²	Pa	9.806 65*	E+00
	lbf/ft ²	Pa	4.788 026	E+01
	lbf/in ² (psi)	Pa	6.894 757	E+03
	kips/in ²	Pa	6.894 757	E+06
	bar	Pa	1.0*	E+05
energy, work	Btu (IT) [Note (3)]	J	1.055 056	E+03
	ft · lbf	J	1.355 818	E+00
power	hp (550 ft · lbf/s)	W	7.456 999	E+02
fracture toughness	ksi $\sqrt{\text{in}}$	Pa · $\sqrt{\text{m}}$	1.098 843	E+06
temperature	°C	K	$t_K = t_C + 273.15$	
	°F	K	$t_K = (t_F + 459.67)/1.8$	
	°F	°C	$t_C = (t_F - 32)/1.8$	
temperature interval	°C	K	1.0*	E+00
	°F	K or °C	5.555 555	E-01

NOTES:

- (1) Care should be taken when converting formulas or equations that contain constant terms or factors. The value of these terms must be understood and may also require conversion.
- (2)(a) Relationships that are exact in terms of the base units are followed by a single asterisk.
 (b) The factors are written as a number greater than 1 and less than 10 with 6 or less decimal places. The number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example: 3.523 907 E-02 is $3.523\ 907 \times 10^{-2}$ or 0.035 239 07.
- (3) International Table.

COMMONLY USED CONVERSION FACTORS